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PHOTOMETRY OF 50 SUSPECTED VARIABLE STARS

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ABSTRACT

Fifty stars have been chosen as suspected variable stars and analyzed for variability. A large portion of this sample are stars that are either proved active chromosphere stars or are candidates for such activity. The photometric data base consists of differential V measurements of the Vanderbilt 16 inch (41 cm) automatic photoelectric telescope and 25 observers at 26 observatories worldwide. Published photometric data have also been utilized, with proper adjustments made to ensure that all magnitudes are differential. Searches for photometric period, amplitudes, and times of minimum light showed 68% of the sample to be photometrically variable with periods found for 34. Two stars were deemed nonvariable for the period of observation. Conclusive statements could not be made concerning the photometric variability of the 14 remaining stars.

Subject headings: stars: emission-line — stars: variables

I. INTRODUCTION

The purpose of this study was to determine which of the 50 suspected variable stars listed in Table 1 were in fact photometrically variable. Of these, 40 appeared in a list of 40 suspected variable stars published by Fekel and Hall (1985). Ten other stars were added to the original list of 40, making a total of 50 stars being investigated. All but two of these 50 were either known or suspected to be chromospherically active (CA). The variability of the two exceptions, HR 6902 and HD 120727, was believed to be caused by eclipses. Three stars on the list (AD Cap, V1379 Aql, and BL CVn) already were designated as variable stars. AD Cap was included because significantly different photometric periods have been reported (Antonopoulou 1987). For the other two, assignment of their variable star names occurred after this study began.

Stars placed on the list were considered CA if their spectra contained the Ca II H and K core emission features. Other stars were considered candidates for chromospheric activity (CA) if they were known to have convective envelopes and/or to rotate rapidly, since the combination of those two factors is known to be closely associated with CA (Hall 1987).

Convective envelopes are present in stars of middle F and later spectral type, making this an easily determinable CA indicator because of already existing spectral classifications.

Information concerning rotation rates is not as easily available. A star's period of rotation can be inferred from spectroscopic measurements of line broadening; if the inclination of the axis of rotation and the stellar radius can be estimated, then $v \sin i$ can yield an estimate of P_{rot}. Relatively few of the stars in Table 1, however, have been studied in such spectroscopic detail. Short-period binaries usually are synchronized, resulting in rapid rotation. For this reason, several binary systems with short orbital periods are included in this study.

II. OBSERVATIONS

New photometric data for this project have been gathered by the Vanderbilt 16 inch (41 cm) automatic photoelectric telescope (APT) atop Mount Hopkins near Tucson, Arizona (Hall 1989), and 26 observatories worldwide. Observers contributing data are listed in Table 2 along with telescope size and observatory location. The left-hand column of Table 2 contains an assigned observer number. This number is used in Table 3 to identify which observers contributed data to which program stars. Observations were made differentially, corrected for atmospheric extinction, and transformed to match the V bandpass of the Johnson UBV system. All differential magnitudes are in the sense of variable minus comparison, where the variable and comparison stars are identified in Table 1. This new photometry, in the form of mean differential magnitudes, has been sent to the IAU Commission 27 Archive of Unpublished Variable Stars (Breger 1988), where it is available as File No. 219.

In addition, previously published data were included in the analyses. These sources include Lloyd Evans and Koen (1987); Spurr and Hoff (1987); Fekel, Moffett, and Henry (1986); Percy *et al.* (1986); Henry, Murray, and Hall (1982); Collier Cameron (1987); Lines *et al.* (1985); and Bopp (1988). The published measurements of Hall and Pazzi (1987) were also made available.

It was not easy to assess the accuracy of the photometric material because it came from several very different sources and was not homogeneous. For many of the previously published data discussed in the above paragraph, one can consult the original reference for a discussion of accuracy. Each differential magnitude from the APT is a mean of three separate intercomparisons between a variable and its comparison star. Hall, Kirkpatrick, and Seufert (1986) and Strassmeier and Hall (1988) thoroughly discussed the accuracy achieved with a smaller (10 inch [25 cm]) but otherwise similar APT. A typical mean had an internal error of ± 0.005

TABLE 1

THE 50 SUSPECTED VARIABLE STARS

Variable Name	Comparison Name	JD Range (2,440,000+)	Number of Nights	Number of Observations	Comparison Star Magnitude	Notes
V1379 Aql.......	HD 185567	3381–7433	153	263	8.330	1
BL CVn	HD 115941	5797–7328	80	142	...	
AD Cap	...	...	...	...	...	
ι Cap	HD 202890	6286–7434	91	131	...	
27 Cyg...........	η Cyg	6275–6744	72	79	...	
10 LMi	...	...	...	...	...	
HR 6902	HR 6857	7003–7022	9	9	...	
HR 7578	HD 188276	5853–7434	84	101	...	
HD 1405	HD 1406	6349–7434	66	91	...	
HD 6286	HD 6009	6309–7434	72	96	...	
HD 9313	HD 8910	6306–7121	42	42	...	
HD 10909	HD 10701	3859–7435	86	118	9.373	1
HD 12545	HD 12478	6654–6882	16	16	...	
HD 17144	HD 17320	3785–6381	54	63	7.376	1
HD 19485	HD 19607	6321–7435	68	73	...	
HD 19754	HD 19421	3785–7142	76	91	7.774	1
HD 19942	HD 19769	6320–7440	70	79	...	
HD 30957	HD 31097	7423–7616	86	98	...	
HD 31993	HD 32073	3856–7434	87	96	6.695	1
HD 33798	HD 34248	6320–7434	118	197	...	
HD 34198	HD 33667	3589–7434	64	74	6.432	1
HD 43930	HD 44497	6452–6910	39	39	...	
HD 65195	HD 65369	7277–7434	17	18	...	
HD 71028	HD 71008	6410–7268	84	94	...	
HD 71071	HD 70788	3578–6936	69	78	8.604	1
HD 90385	HD 90042	6452–6947	60	61	...	
HD 96511	HD 96589	6525–6564	4	4	...	
HD 105341	HD 105424	6474–6962	78	88	...	
HD 106495	HD 106024	6523–6549	4	4	...	
HD 120727	HD 121303	5440–6563	39	45	...	
HD 122767	HD 122693	6238–6993	72	77	...	
HD 127386	HD 126991	6236–6986	70	71	...	
HD 128220	HD 128254	7275–7328	47	88	...	
HD 141690	HD 141732	6237–7089	53	53	...	
HD 144515a	HD 144064	6270–7428	84	134	...	
HD 148405	HD 148127	6490–6947	63	68	...	
HD 152178	HD 152501	6593–7329	57	85	...	
HD 155989	SAO 84947	6282–7096	51	52	...	
HD 158393	...	...	...	...	...	
HD 160952	HD 160834	6320–7096	57	57	...	
HD 163621	HD 164280	6236–7434	186	212	...	
HD 181809	50 Sgr	3382–7434	168	211	5.58	2
HD 181943	HD 181219	3382–7434	94	126	7.657	1
HD 191262	HD 191011	6238–7434	109	142	...	
HD 193891	HD 193517	6957–7434	64	88	...	
HD 195040	...	...	...	...	...	
HD 202134	...	...	...	...	...	
HD 203251	...	...	...	...	...	
HD 204934	HD 204642	6320–7121	37	38	...	
HD 209943	HD 209885	6270–6678	13	13	...	

NOTES.—(1) Aligned by method described in text; (2) visual magnitude from Hoffleit 1964.

mag in V and an external error of ± 0.012 mag. According to Hall, Henry, and Sowell (1990), errors with the 16 inch APT are smaller. Data from the worldwide observers also were usually the average of three intercomparisons. The median internal standard error of these means was ± 0.007 mag. Any mean with an internal standard error greater than 0.03 mag was scrutinized. In most cases it was possible to find the cause of the large error and correct it; if no cause could be identified, however, the mean was not rejected. It is expected that a few systematic errors (such as that produced by an inaccurate value adopted for an observer's transformation coefficient, or an assumed value of $\Delta(B-V)=0$ when the color difference between a variable and its comparison was not known, or a large air mass) will cause the external error of a mean to be larger, from about ± 0.01 mag in the most favorable cases to around ± 0.03 mag in the very few unfavorable cases. Later, when data from all sources were plotted as a light curve for a given suspected variable, a few gross

TABLE 2

SUMMARY OF PHOTOELECTRIC OBSERVERS

Observer Number	Observer Name	Observatory Name	Telescope (cm)	Observatory Location
2	H. J. Landis	Landis	20	Locust Grove, Georgia
6	W. S. Barksdale	Barksdale	36	Winter Park, Florida
15	R. E. Fried	Braeside	41	Flagstaff, Arizona
18	U. of N. Iowa	Hillside	41	Cedar Falls, Iowa
21	R. D. Lines	Lines	51	Phoenix, Arizona
25	C. W. Rogers	Southwestern Oklahoma State University	36	Weatherford, Oklahoma
27	D. M. Slauson	Summitt	20	Swisher, Iowa
28	H. J. Stelzer	Stelzer	36	River Forest, Illinois
32	N. F. Wasson	Sunset Hills	20	Hacienda Heights, California
33	E. J. Burke	Lowell	70	Flagstaff, Arizona
34	R. C. Reisenweber	Rolling Ridge	20	Erie, Pennsylvania
38	L. Pazzi	Nigel Astronomical	30	Nigel, South Africa
45	S. I. Ingvarsson	Tjorn Island	36	Skarhamn, Sweden
47	H. D. Powell	East Tennessee State University	20	Johnson City, Tennessee
49	J. E. Pearsall	Beech Hill	20	McMinnville, Tennessee
52	W. Bisard	Brooks	36	Mount Pleasant, Michigan
54	G. L. Fortier	Fortier	32	Baie d'Urfe, Quebec, Canada
61	G. W. Henry	Kitt Peak	41	Tucson, Arizona
62	G. W. Henry	Cloudcroft	122	Cloudcroft, New Mexico
66	J. C. Soder	Einstein Astrophysical	20	Sidney, Ohio
71	A. Sadun	Wallace	61	Decatur, Georgia
73	A. W. Parker	Houston Astronomical	36	Houston, Texas
76	R. E. Milton	Klamath	20	Somes Bar, California
77	R. Campbell	Thomsen	20	Keene, Texas
79	T. Duncan	Duncan	9	Bettendorf, Iowa
80	P. Heckert	Mount Laguna	61	San Diego, California

TABLE 3

DATA GROUPS ANALYZED

Star	Data Group	JD Range (2,440,000+)	Number of Observations	Observers	Published Observations
V1379 Aql.......	1	3381–3788	5	33, 38, 62, APT	a, b, c, d
	2	4071–4180	25		
	3	4363–4461	36		
	4	4680–4914	63		
	5	5115–5227	38		
	6	6647–6711	9		
	7	6959–6985	11		
	8	7276–7433	76		
BL CVn	1	5797–5889	49	6, 28, APT	e
	2	7271–7328	93		
AD Cap	1	...	...		f
ι Cap	1	6286–6409	43	2, 18, 25, 27, 38	
	2	6675–6794	26		
	3	7020–7096	7		
	4	7295–7329	30		
	5	7415–7434	25		
27 Cyg	1	6275–6744	79	2, 6, 18, 32, 34, 47, 52, 79	
10 LMi	1	...	...		g
HR 6902	1	7003–7022	9	18	

TABLE 3—*Continued*

Star	Data Group	JD Range (2,440,000+)	Number of Observations	Observers	Published Observations
HR 7578	1	5853–6023	17	6, 38, 66, APT	
	2	6211–6211	2		
	3	6609–6758	13		
	4	6999–7059	9		
	5	7276–7328	47		
	6	7418–7434	13		
HD 1405	1	6349–6422	14	6, 18, 54, 80, APT	
	2	6673–6838	54		
	3	6959–7122	4		
	4	7415–7434	23		
HD 6286	1	6309–6446	25	6, 25, 33, 45, 47, 54, APT	
	2	6654–6826	27		
	3	6958–7121	31		
	4	7415–7434	13		
HD 9313	1	6306–6472	24	6, 25, 45, 47, 49, 54	
	2	6654–6819	15		
	3	7095–7121	3		
HD 10909	1	3859–3880	9	38, APT	c
	2	4071–4254	27		
	3	4550–4650	14		
	4	4750–4975	20		
	5	7410–7435	17		
HD 12545	1	6654–6882	16	45, 76	
HD 17144	1	3785–6381	63	38	a, c
HD 19485	1	6321–6495	53	6, 21, 45, 47, APT	
	2	6739–6839	8		
	3	7097–7097	1		
	4	7418–7435	11		
HD 19754	1	3785–4974	85	6, 25	c
	2	6466–7142	6		
HD 19942	1	6320–6530	38	6, 25, 45, 47, 54, APT	
	2	6654–6880	21		
	3	7000–7200	2		
	4	7410–7440	20		
HD 30957	1	7423–7616	98	APT	
HD 31993	1	3856–3873	9	6, 18, APT	c
	2	4133–4277	19		
	3	4590–4967	17		
	4	6390–6869	39		
	5	7417–7434	11		
HD 33798	1	6320–7434	197	6, 45, 47, 54, APT	h
HD 34198	1	3589–3875	12	6, 38, 73, APT	c
	2	4133–4279	21		
	3	4590–4638	8		
	4	4919–4967	11		
	5	6825–7196	7		
	6	7417–7434	15		
HD 43930	1	6452–6550	19	6, 47, 54	
	2	6774–6910	20		
HD 65195	1	7277–7434	18	APT	
HD 71028	1	6410–6579	51	6, 25, 47, 49, 54, 73	
	2	6764–6926	36		
	3	7208–7268	7		
HD 71071	1	3579–3873	7	6, 73, APT	c
	2	4179–4281	15		
	3	4591–4748	11		
	4	4904–4973	18		
	5	6551–6569	3		
	6	6825–6936	24		

TABLE 3—*Continued*

Star	Data Group	JD Range (2,440,000+)	Number of Observations	Observers	Published Observations
HD 90385	1	6452–6579	35	6, 25, 45, 47, 54, 73	
	2	6834–6947	26		
HD 96511	1	6525–6564	4	54	
HD 105341	1	6474–6610	56	6, 18, 47, 54	
	2	6825–6962	32		
HD 106495	1	6523–6549	4	47, 54	
HD 120727	1	5440–6563	45	15, 38	
HD 122767	1	6238–6993	77	6, 25, 33, 45, 47, 54	
HD 127386	1	6236–6275	11	6, 33, 45, 47, 54, 71	
	2	6525–6610	27		
	3	6874–6986	33		
HD 128220	1	7275–7328	88	APT	
HD 141690	1	6237–7089	53	6, 25, 33, 45, 47, 54	
HD 144515a	1	6270–7428	134	6, 25, 33, 47, 71, 77, APT	
HD 148405	1	6490–6947	68	6, 21, 45, 47	
HD 152178	1	6593–7329	85	33, APT	
HD 155989	1	6282–6408	13	6, 25, 45, 54, 80	
	2	6525–6678	18		
	3	6890–7096	21		
HD 158393	1	...	...		i
HD 160952	1	6320–7096	57	6, 25, 45, 47, 54, 80	
HD 163621	1	6236–6419	57	6, 18, 25, 33, 34, 45, 47, 54, 77, 80, APT	
	2	6525–6742	40		
	3	6890–7107	49		
	4	7276–7329	55		
	5	7418–7434	11		
HD 181809	1	3382–4459	28	6, 38, 61, APT	a, c
	2	4682–5166	45		
	3	6623–6746	37		
	4	6968–7098	25		
	5	7276–7434	78		
HD 181943	1	3382–7434	126	38, APT	a, c, j
HD 191262	1	6235–7434	125	6, 18, 33, 47, 54, 71, 77, 80, APT	
HD 193891	1	6957–7434	88	33, APT	
HD 195040	1	...	...		c
HD 202134	1	...	...		k
HD 203251	1	...	...		c
HD 204934	1	6320–7121	38	6, 45, 47, 54, 80	
HD 209943	1	6270–6309	9	54, 71, 80	
	2	6675–6678	4		

References to published observations.—(a) Fekel, Moffett, and Henry 1986; (b) Henry, Murray, and Hall 1982; (c) Lloyd Evans and Koen 1987; (d) Collier Cameron 1987; (e) Lines *et al.* 1985; (f) Antonopoulou 1987; (g) Skiff and Lockwood 1986; (h) Spurr and Hoff 1987; (i) Lloyd Evans, Balona, and Fekel 1987; (j) Bopp 1988; (k) Bopp, Africano, and Quigley 1986.

errors became apparent. Any point much farther than 3 standard deviations from the mean (or smooth light curve) was not included in subsequent analysis.

For the sake of consistency, when the published results were given in magnitudes rather than differentials, they were converted to differential magnitudes. In the cases where magnitudes were known for the comparison star, this conversion process was accomplished by simply subtracting the magnitude of the comparison star from that of the program star.

When comparison star magnitudes were not known, a value was subtracted from the published magnitudes so as to align the averages of the differential and nondifferential data sets. Table 1 contains the values subtracted from the published observations and the sources of those values. The absence of an entry in the last two columns of Table 1 means either that no published data were available for that particular star or that the published results were differential themselves and used the same comparison star as this work. If the "Comparison Name" column in Table 1 contains no entry, no new data were obtained by the APT or worldwide observers for this study.

III. ANALYSIS PROCEDURES

As mentioned, the intent of this project was to determine which of the 50 stars listed in Table 1 were variable. For the purposes of this study, a star was deemed variable if a convincing photometric period could be found. Stars for which no convincing photometric period could be found were deemed possibly variable if the magnitude range displayed was significantly larger than expected from errors in the photometry. The process by which variability was ascertained included five parts: (*a*) visual inspection of the light curve, (*b*) division of the data into groups, (*c*) execution of a period search, (*d*) construction of a phase plot, and (*e*) calculation of the rms deviation.

a) *Visual Inspection of the Light Curve*

Plots of the differential magnitudes versus the heliocentric Julian Dates of the observations were examined. Such visual inspections allowed for the qualitative weighting of the various observers. Weights of one or zero were assigned to each observer on a star-by-star basis, depending upon whether the observer's points contained a significant amount of scatter relative to the other observers. In only a few cases was it necessary to assign an observer a weight of zero.

b) *Division of the Data into Groups*

A first attempt was made to use the entire data set for analysis. When this attempt failed to produce meaningful results, obvious gaps in the data coverage were used as dividing lines. A group was defined as any set of data covering a relatively continuous interval of time, but not necessarily a complete observing season. Analysis was then performed on each group separately. The data groups analyzed are identified in Table 3.

c) *Execution of a Period Search*

A search for periodicity was accomplished by fitting a sine curve of the form

$$l = A + B\cos\theta + C\sin\theta \qquad (1)$$

to the data by the method of least squares. In the above equation, l is differential magnitude converted to light units, θ is photometric phase computed with an assumed period, and A, B, and C are constants to be determined. By sequentially searching over a wide range of periods and calculating the sum of the squares of the residuals $[\Sigma(O-C)^2]$ from each least-squares fit, it was possible to determine a "best" period. The "best" period ($P_{\rm best}$) was considered that which produced the minimum value of $\Sigma(O-C)^2$ [symbolized by $\Sigma(O-C)^2_{\rm best}$].

The uncertainty of $P_{\rm best}$ can be estimated from the two values of P, one shorter and one longer, which give a value of $\Sigma(O-C)^2$ larger than $\Sigma(O-C)^2_{\rm best}$ by the amount Δ, where

$$\Delta = \frac{\sum(O-C)^2_{\rm best}}{N-3}. \qquad (2)$$

Here N is the number of points in the data group.

d) *Construction of a Phase Plot*

Plots of differential magnitude versus photometric phase were made with the adopted period. These are shown in Figures 1–26, where only one representative data group is illustrated. From the phase plot for each group a determination of the calculated (full) amplitude of the light variation and the time of minimum light, $T_{\rm min}$, was made.

If the light variation is not strictly sinusoidal or if the amplitude has changed during the interval of time covered by the data group, the calculated amplitude and $T_{\rm min}$ will not be quite as accurate. Any significant deviation from a sinusoidal shape will, however, be apparent by examination of the phase plot.

e) *Calculation of the Root Mean Square Deviation*

The standard deviation of points from the best sinusoidal fit is given by

$$\sigma_1 = \left[\frac{\sum(O-C)^2_{\rm best}}{N-3}\right]^{1/2}. \qquad (3)$$

This should be a measure of the external error of the observed magnitudes, although it will be larger than the intrinsic observational error if the light variation was not strictly sinusoidal or if the amplitude was not constant.

IV. GENERAL RESULTS

The results of this study are summarized in Tables 4 and 5. A star was considered variable if a photometric period could be found with a good degree of confidence. Entries of "Yes," "Maybe," and "No" in the second column of Table 5

TABLE 4

RESULTS OF ANALYSIS

Star (1)	ΔV (mag) (2)	Data Group (3)	P_{phot} (days) (4)	V-Amplitude (mag) (5)	T_{min} (JD 2,440,000+) (6)	σ_1 (mag) (7)
V1379 Aql........	0.056±0.005	1	...	...	...	...
		2	13.2±0.3	0.081±0.011	4079.2±0.3	0.017
		3	21.6±0.2	0.245±0.005	4377.01±0.08	0.005
		4	13.2±0.2	0.115±0.010	4695.9±0.2	0.025
		5	26.8±0.4	0.206±0.011	5137.0±0.3	0.023
		6	25.2±0.4	0.299±0.031	6666.7±0.3	0.017
		7	25.7±0.9	0.126±0.011	6964.2±.8	0.008
		8	25.7±0.1	0.231±0.007	7290.37±0.12	0.019
BL CVn...........	−1.058±0.004	1	(9.346)	0.147±0.005	5808.43±0.06	0.013
		2	(9.346)	0.126±0.007	7275.65±0.09	0.024
AD Cap...........	...	1	2.96	0.015	1975.65	...
ι Cap	−2.634±0.002	1	...	...	...	...
		2	2.20±0.19	0.057±0.019	6677.18±0.10	0.028
		3	5.0±0.2	0.064±0.009	7020.83±0.11	0.005
		4	4.9±0.3	0.016±0.007	7296.6±0.3	0.012
		5	4.4±0.2	0.022±0.007	7415.3±0.3	0.012
27 Cyg	1.479±0.003	1	50–60	~0.05	...	...
10 LMi	...	1	40.4	0.012	6053.0	...
HR 6902	...	1	385	~0.21	~7018.7	...
HR 7578	−1.756±0.004	1	...	...	...	...
		2	...	...	...	...
		3	6.5±0.05	0.064±0.014	6613.8±.2	0.013
		4	18.7±0.4	0.030±0.003	7013.7±0.3	0.015
		5	16.5±0.5	0.030±0.003	7288.5±0.3	0.007
		6	12±2	0.095±0.038	7425.4±0.6	0.032
HD 1405	2.081±0.004	1	1.64±0.01	0.066±0.019	6360.58±0.19	0.019
		2	29±1	0.041±0.012	6677.8±0.4	0.024
		3	...	...	...	...
		4	1.745±0.005	0.087±0.004	7415.354±0.014	0.006
HD 6286	1.225±0.012	1	(35.3)	0.149±0.019	6311.5±0.7	0.025
		2	(35.3)	0.296±0.032	6662.5±0.5	0.039
		3	(35.3)	0.384±0.020	6983.3±0.3	0.030
		4	6.21±0.15	0.223±0.040	7416.92±0.16	0.042
HD 9313	−0.206±0.002	1	13.91±0.24	0.018±0.006	6303.8±0.7	0.019
		2	14.0±0.2	0.028±0.008	6991.2±0.6	0.009
		3	...	...	...	...
HD 10909	−1.5334±0.004	1	...	...	...	...
		2	32.03±0.19	0.074±0.003	4058.7±0.3	0.006
		3	...	...	...	...
		4	31.1±0.4	0.074±0.018	4814.2±1.2	0.027
		5	33±5	0.119±0.007	7431.9±0.4	0.009
HD 12545	0.660±0.016	1	25.1±0.2	0.160±0.028	6672.1±0.6	0.027
HD 17144	0.855±0.001	1	15.93±0.02	0.011±0.002	3794.8±0.5	0.005
HD 19485	−0.458±0.002	1	6.45±0.03	0.029±0.005	6319.9±0.2	0.013
		2	5.79±0.03	0.031±0.005	6753.52±0.15	0.004
		3	...	...	...	...
		4	6.3±0.4	0.022±0.012	7424.1±0.4	0.008
HD 19754	0.321±0.007	1	47.87±0.06	0.176±0.013	3807.5±0.5	0.035
		2	47.08±0.12	0.144±0.008	6503.2±0.5	0.004

TABLE 4—*Continued*

Star (1)	ΔV (mag) (2)	Data Group (3)	P_{phot} (days) (4)	V-Amplitude (mag) (5)	T_{min} (JD 2,440,000+) (6)	σ_1 (mag) (7)
HD 19942	−0.350±0.005	1	22.3±0.2	0.019±0.012	6325±2	0.022
		2	22.0±0.2	0.095±0.013	6653.4±0.5	0.019
		3	...	...	...	...
		4	23±2	0.217±0.194	7413±3	0.005
HD 30957	0.614±0.003	1	...	...	...	0.030
HD 31993	0.849±0.002	1	...	...	...	...
		2	6.88±0.04	0.025±0.005	4136.9±0.2	0.007
		3	...	...	...	...
		4	28.7±0.1	0.056±0.008	6396.1±0.7	0.016
		5	4.8±0.2	0.014±0.005	7421.5±0.3	0.005
HD 33798	−0.775±0.002	1	9.825±0.015	0.380±0.005	6326.3±0.19	0.021
HD 34198	0.522±0.002	1	30.25±0.15	0.044±0.004	3880.1±0.4	0.003
		2	27.5±0.4	0.042±0.008	4135.0±0.6	0.008
		3	31±3	0.071±0.014	4616.6±0.9	0.008
		4	25.5±0.7	0.063±0.016	4930.9±0.4	0.004
		5	...	...	...	...
		6	15±2	0.016±0.006	7426.0±0.9	0.006
HD 43930	0.438±0.004	1	3.40±0.04	0.062±0.017	6452.5±0.2	0.013
		2	3.42±0.01	0.062±0.017	6781.46±0.012	0.020
HD 65195	1.547±0.002	1	...	...	...	0.017
HD 71028	0.449±0.002	1	8.35±0.1	0.020±0.007	6410.6±0.5	0.015
		2	18.2±0.8	0.020±0.006	6769.7±0.9	0.011
		3	...	...	...	...
HD 71071	−1.248±0.002	1	...	...	...	...
		2	34.3±0.7	0.037±0.005	4186.9±0.8	0.005
		3	65±3	0.032±0.005	4611.9±1.4	0.004
		4	38.5±0.9	0.043±0.004	4935.5±0.5	0.004
		5	...	...	...	...
		6	9.46±0.03	0.51±0.012	6827.6±0.4	0.017
HD 90385	−0.081±0.002	1	12.5±0.2	0.022±0.006	6461.6±0.5	0.005
		2	13.5±0.3	0.030±0.012	6839.5±0.8	0.008
HD 96511	−0.586±0.005	1	...	...	...	0.009
HD 105341	0.829±0.002	1	14.3±0.3	0.022±0.004	6477.9±0.4	0.009
		2	5.55±0.08	0.029±0.009	6827.7±0.3	0.015
HD 106495	−0.058±0.012	1	...	...	...	0.024
HD 120727	1.574±0.006	1	...	...	...	0.043
HD 122767	−0.119±0.005	1	...	...	...	0.045
HD 127386	0.704±0.002	1	8.7±0.4	0.020±0.005	6243.1±0.4	0.005
		2	70±19	0.020±0.008	6586±4	0.011
		3	13.8±0.2	0.025±0.007	6880.0±0.5	0.011
HD 128220	0.006±0.001	1	...	...	...	0.006
HD 141690	−0.295±0.002	1	...	...	...	0.017
HD 144515a	1.280±0.002	1	4.999±0.002	0.036±0.005	6272.64±0.11	0.018
HD 148405	1.216±0.003	1	...	...	...	0.021
HD 152178	−0.707±0.004	1	22.35±0.05	0.075±0.009	6605.5±0.4	0.027
HD 155989	−0.220±0.003	1	39±2	0.024±0.006	6319.8±1.5	0.005
		2	37±3	0.037±0.012	6548±2	0.014
		3	30.0±0.5	0.049±0.013	6895.9±1.3	0.014

TABLE 4—*Continued*

Star (1)	ΔV (mag) (2)	Data Group (3)	P_{phot} (days) (4)	V-Amplitude (mag) (5)	T_{min} (JD 2,440,000+) (6)	σ_1 (mag) (7)
HD 158393	...	1	30.9597	~0.06	...	...
HD 160952	−0.562±0.002	1	41.0±0.5	0.022±0.006	6342.1±1.6	0.014
HD 163621	1.932±0.004	1	4.95±0.05	0.043±0.005	6338.7±0.2	0.031
		2	4.6±0.2	0.045±0.013	6528.73±0.17	0.023
		3	...	...	...	...
		4	3.35±0.02	0.053±0.009	7278.70±0.08	0.018
		5	...	...	...	...
HD 181809	1.084±0.006	1	58.7±0.2	0.190±0.018	3382.2±0.9	0.024
		2	59.4±0.5	0.209±0.023	4699.5±0.8	0.038
		3	61.1±0.4	0.310±0.009	6664.6±0.2	0.015
		4	59.1±1.7	0.200±0.015	6974±8	0.026
		5	57.8±0.5	0.123±0.006	7331.5±0.5	0.016
HD 181943	1.851±0.004	1	385.3±0.6	0.145±0.006	3537±2	0.019
HD 191262	−0.051±0.004	1	...	...	...	0.048
HD 193891	0.295±0.005	1	40.65±0.05	0.142±0.006	6995.3±0.2	0.016
HD 195040	...	1	23.2	0.15−0.23	...	...
HD 202134	...	1	61.0	~0.13	...	...
HD 203251	...	1	44.3	0.02	...	...
HD 204934	1.466±0.002	1	...	...	...	0.012
HD 209943	−1.331±0.005	1	1.166±0.003	0.060±0.015	6270.11±0.04	0.010
		2	(1.166)	0.014±0.011	6675.27±0.15	0.002

TABLE 5

CONCLUSIONS

Star	Variable?	Source of Discovery
V1379 Aql.......	Yes	Lloyd Evans and Koen 1987
BL CVn	Yes	Lines *et al.* 1985
AD Cap	Yes	Antonopoulou 1987
ι Cap	Maybe	
27 Cyg...........	Yes	Percy *et al.* 1986
10 LMi	Yes	Skiff and Lockwood 1986
HR 6902	Yes	This work
HR 7578	Yes	This work
HD 1405	Yes	This work
HD 6286	Yes	This work
HD 9313	Yes	This work
HD 10909	Yes	Lloyd Evans and Koen 1987
HD 12545	Yes	This work
HD 17144	Yes	Lloyd Evans and Koen 1987
HD 19485	Yes	This work
HD 19754	Yes	Lloyd Evans and Koen 1987
HD 19942	Yes	This work
HD 30957	Maybe	
HD 31993	Maybe	
HD 33798	Yes	Spurr and Hoff 1987
HD 34198	Yes	Lloyd Evans and Koen 1987
HD 43930	Yes	This work
HD 65195	No	
HD 71028	Maybe	
HD 71071	Yes	Lloyd Evans and Koen 1987
HD 90385	Yes	This work
HD 96511	Maybe	
HD 105341	Maybe	
HD 106495	Maybe	
HD 120727	Maybe	
HD 122767	Maybe	
HD 127386	Maybe	
HD 128220	No	
HD 141690	Maybe	
HD 144515a	Yes	This work
HD 148405	Maybe	
HD 152178	Yes	This work
HD 155989	Yes	This work
HD 158393	Yes	Lloyd Evans, Balona, and Fekel 1987
HD 160952	Yes	This work
HD 163621	Yes	This work
HD 181809	Yes	Hall and Pazzi 1987
HD 181943	Yes	This work
HD 191262	Maybe	
HD 193891	Yes	This work
HD 195040	Yes	Lloyd Evans and Koen 1987
HD 202134	Yes	Bopp, Africano, and Quigley 1986
HD 203251	Yes	Lloyd Evans and Koen 1987
HD 204934	Maybe	
HD 209943	Yes	This work

show whether photometric variability was apparent. When a star's variability had been discovered prior to this study, the source of the discovery is given in the last column of Table 5. In every case column (2) of Table 4 gives the mean of the available differential magnitudes. When a "best" photometric period could be found, columns (4), (5), (6), and (7) of Table 4 contain the period, calculated full amplitude, time of minimum light (the first occurrence of the event in a particular Julian Date interval, specified in Table 3), and σ_1 for each data group. In the cases where the observations in the Julian Date light curves covered a magnitude range significantly larger than that expected for the observational scatter of a constant star, but no convincing photometric period could be found, the entry "Maybe" is placed in the second column of Table 5, and column (7) of Table 4 contains the standard deviation of a single point from the mean.

In work like this, the danger exists that an alias period has been found rather than the "real" period. In fact, an alias and the real period can give similar $O-C$ residuals when a least-squares fit is used. One protection against this danger is the occurrence of the same period, or nearly the same, in more than one season of photometry. This is because data from different seasons in general differ in spacing, total number, and baseline. Such was the case in almost half of the stars we concluded were variable. Another protection is to examine check star photometry. For data groups in which coincident check star photometry was available, we carried out three types of analysis: (1) We searched for significant periodicities in the check-minus-comparison differential magnitudes, using the method described in § III*c*. (2) We searched for a correlation between Δm(variable minus comparison) and Δm(check minus comparison). (3) For the check star photometry we computed phases using the variable star's adopted period, appearing in Table 4, and evaluated an amplitude. None of these analyses indicated that the adopted variable star's period appears in the check star data. A final protection will be the inclusion of additional, more recent photometry. Any future period studies should combine newer photometry with all available older photometry. That is why we have made our data accessible in the IAU Archive.

About two-thirds of the program stars are shown to be variable. Of the 50 candidate variable stars, 34 have had periods successfully determined either in this study or in published sources. Only two stars, HD 65195 and HD 128220, have been classified as nonvariable for the duration of available data. No conclusive period was found for the remaining 14 candidate variables. Thus, they could not be classified with confidence as either variable or nonvariable. Section V discusses the individual stars in greater detail.

V. INDIVIDUAL STARS

a) V1379 Aql = HD 185510

Bidelman and MacConnell (1973) reported a spectral type of K0 III/IV and emission lines of Ca II H and K. The emission features were confirmed as being very strong by Fekel and Simon (1985), who also report very weak Hα absorption and a $v \sin i$ value of 15 ± 3 km s^{-1} for the K

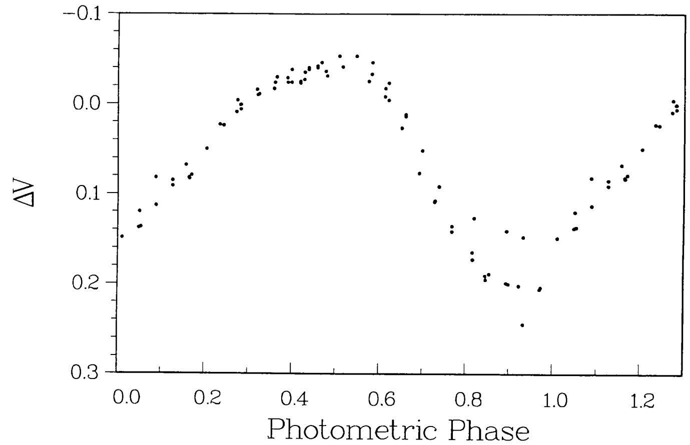

FIG. 1.—Phase plot for V1379 Aql minus HD 185567; $P_{phot} = 25.7$ days. The data shown were obtained during the interval JD 2,447,276–2,447,433.

star. Fekel and Simon found a hot continuum at ultraviolet wavelengths and classified this companion as a B subdwarf. The orbital period found spectroscopically by Balona (1987) was 20.659 ± 0.002 days with an eccentricity of 0.09 ± 0.07. Eclipses of the hot companion (Balona *et al.* 1987) have a depth of approximately 0.15 mag in the $(U-B)$ color index and much smaller, only 0.02 or 0.03 mag, in the $(B-V)$ color index. The eclipses are masked in the visual by other sources of larger photometric variability, as shown by Henry, Murray, and Hall (1982) and by Lloyd Evans and Koen (1987).

Period analysis of eight different data groups yielded meaningful periods for the last seven. Five of the seven periods were close to 26 days, and the other two were close to 13 days. This might suggest that the active component of V1379 Aql has a rotation period around 26 days but at times (data groups 2 and 4) had two main spot groups on opposite hemispheres. The full amplitude averaged 0.2 mag when one spot was present but only 0.1 mag when two spots were present. If the 26 day photometric period is also assumed to be the rotation period, then the system is in asynchronous rotation and the minimum radius of the K star is approximately 7.7 $R_\odot$, consistent with the III/IV classification. Figure 1 refers to data group 8.

b) BL CVn = HD 115781

Fekel, Moffett, and Henry (1986) report that the spectral type of this double-lined spectroscopic binary is K III+F, with $v \sin i$ values of 35 and 7 km s^{-1}, respectively. Moderate Hα absorption is also found by Fekel, Moffett, and Henry. Strassmeier *et al.* (1990*a*) found Ca II H and K emission. Griffin and Fekel (1988) report an orbital ephemeris of

$$\mathrm{JD(hel.)} = \underset{\pm 0.03}{2{,}445{,}280.30} + \underset{\pm 0.0012}{18.6917}n,$$

where the initial epoch is a time of maximum positive radial velocity.

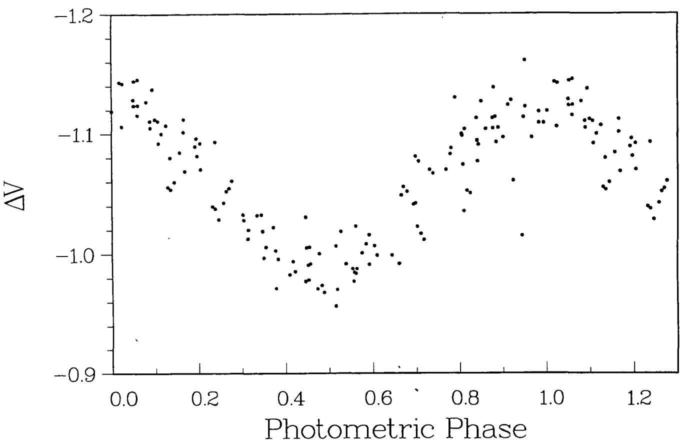

FIG. 2.—Phase plot for BL CVn minus HD 115941; $P_{phot} = 9.346$ days. The data shown were obtained during the interval JD 2,445,797–2,447,328.

Lines *et al.* (1985) found this system to have a photometric period of 9.31 ± 0.06 days and an amplitude of 0.16 mag. They attributed the light variability to the ellipticity effect because the orbital period was twice the photometric period and times of maximum brightness occurred at times of maximum positive radial velocity. These observations also imply that the orbital eccentricity cannot be far from zero.

The photometric period of 9.346 ± 0.001 days found for the total data base was consistent with that found by Lines *et al.* (1985). If the initial epoch of the orbital ephemeris is brought forward and a half-cycle is allowed to account for the change from minimum to maximum light, it can easily be seen that the times of maximum light output coincide with the times of maximum positive or negative radial velocity, within the allowed uncertainties. This confirms the results of Lines *et al.* and supports their argument that ellipticity causes the photometric variability. Analysis repeated with two data groups, with the 9.346 day period, gave amplitudes and T_{min} values which were consistent. Figure 2 shows the phase plot for the entire data set.

c) AD Cap = HD 206046

This is a 9.8 mag SB2 system classified by Hall (1976) as an RS CVn binary. Ca II H and K emission has been observed in both components by Popper (1976). This system also shows Hα emission (Strassmeier *et al.* 1988). Popper (1976) reported the orbital period to be roughly 3 days, instead of 6.11825 days as previously found by Tsesevich (1954). Popper, in private communication with Antonopoulou (1987), finds the photometric period to be 2.96 days, while Antonopoulou (1987), using IR photometry, finds it to be 2.985 days. Popper's spectroscopic observations yield a lower mass limit of 0.5 $M_\odot$ for the G5 primary component and 1.1 $M_\odot$ for the secondary. Hall (1980) says the secondary is also of spectral type G5. No new photometric observations were available.

d) 32 ι Cap = HR 8167 = HD 203387

Wilson (1976) pointed out that this bright ($V = 4.28$ mag) G8 giant star has Ca II H and K emission of moderate intensity. When Young, Mielbrecht, and Abt (1987) searched for radial velocity variations that might indicate duplicity, they classified ι Cap as a constant radial velocity star. Hoffleit and Jaschek (1982) list the projected rotational velocity as less than 17 km s^{-1}.

The entire data set was divided into five data groups, four of which yielded meaningful periodicities. Three of those four were nearly the same, between 4.5 and 5.0 days. The other was very different, and its periodogram did not show a significant dip between 4.5 and 5.0 days. If the 4.5 day photometric period is taken to be the rotation period, then the implied minimum radius is approximately 1.5 $R_\odot$. If the giant classification is accurate, then ι Cap must be rotating nearly pole-on. For these reasons, ι Cap is marked in Table 5 as questionably variable.

e) 27 Cyg = HR 7689 = HD 191026

This star is a bright ($V = 5.36$ mag) K0 subgiant with Ca II H and K emission (Wilson 1976). Blanco *et al.* (1970) were the first to report photometric variations in 27 Cyg, but they did not pursue any analysis. Percy *et al.* (1986) reported an amplitude of ∼0.05 mag in V on a time scale of 50–60 days. The values of the period range and approximate amplitude entered in Table 4 are those of Percy *et al.* (1986).

f) 10 LMi = HR 3800 = HD 82635

No new unpublished photometric observations were made of this bright ($V = 4.55$ mag) chromospherically active G8 giant (Wilson 1976). The differential Strömgren observations of Skiff and Lockwood (1986) showed an amplitude variation of 0.0116 mag in the y bandpass with a period of 40.4 ± 0.2 days. The results of Skiff and Lockwood are entered in Table 4.

g) HR 6902 = HD 169689

This bright ($V = 5.65$ mag) star shows a composite spectrum consisting of spectral types G9 II and B8 V according to Griffin (1988*a*). This system was classified as a ζ Aurigae–type binary by Griffin, in part because it exhibits spectroscopic atmospheric eclipses with a period of 385 days. This period is entered in Table 4. No mention of photometric eclipses could be found in the literature.

New observations consist of nine points gathered on nine nights near a time of predicted primary eclipse, which was JD(hel.) = 2,447,018.7 (Griffin and Griffin 1987). They appear to define an eclipse, with three points [JD(hel.) = 2,447,017.6073, 2,447,018.6963, and 2,447,019.6034] at minimum, and one point [JD(hel.) = 2,447,012.6211] on the downward slope between first and second contact. The differential magnitude changes from an average of 0.22 mag to 0.43 mag during the eclipse; thus, an amplitude of 0.21 mag is entered in Table 4. The duration, depth, and time of minimum light are consistent with the orbital parameters given by Griffin (1988*a*).

h) HR 7578 = HD 188088

Fekel and Beavers (1983) found HR 7578 ($V = 6.18$ mag, spectral types K2–3 V + K2–3 V) to be a double-lined spec-

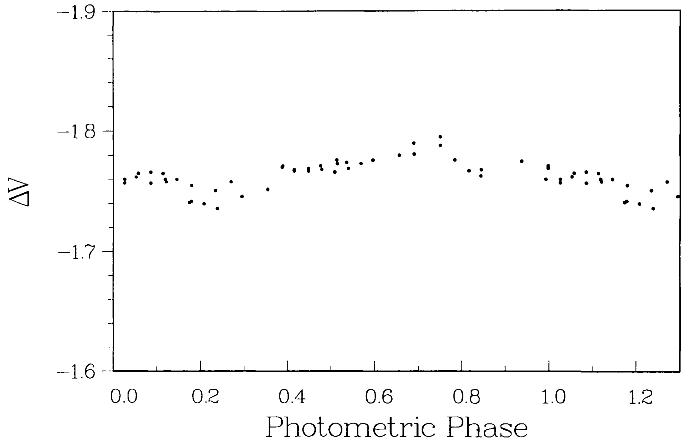

FIG. 3.—Phase plot for HR 7578 minus HD 188276; $P_{phot} = 16.5$ days. The data shown were obtained during the interval JD 2,447,276–2,447,328.

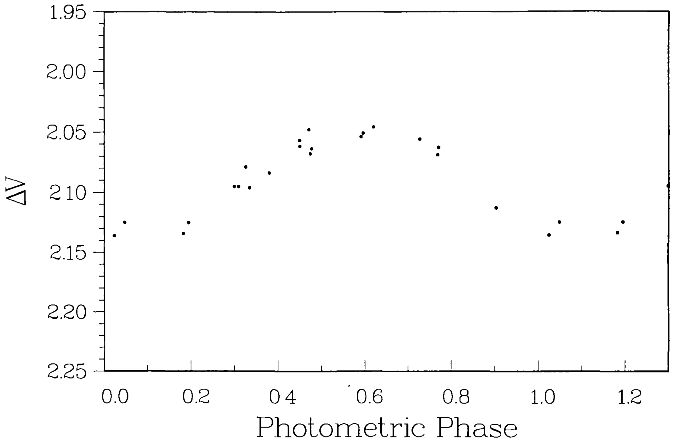

FIG. 4.—Phase plot for HD 1405 minus HD 1406; $P_{phot} = 1.745$ days. The data shown were obtained during the interval JD 2,447,415–2,447,434.

troscopic binary with an orbital period of 46.8 days and $e = 0.692$. This system is *super-metal-rich* (Taylor 1970) and shows moderate to strong Ca II H and K emission. Fekel and Beavers give the projected rotational velocity as $v \sin i = 5$–8 km s^{-1}, from which they derive a rotation period of 5–8 days by assuming that the two stars have radii of 0.8 $R_{\odot}$.

Of the six data groups, group 5 showed the least scatter and produced the most reliable photometric period, namely, 16.5 days. This is significantly different from the rotation period derived by Fekel and Beavers (1983), but the discrepancy can be explained if, as Fekel and Beavers hinted, their value of $v \sin i$ is an upper limit. Hall (1986) showed that the Fekel-Beaver rotation period of 5–8 days implied that HR 7578 was rotating pseudosynchronously. If the longer 16.5 day period is correct, it will be rotating more slowly than synchronously. Figure 3 refers to group 5.

i) *HD 1405*

HD 1405 was classified in the *Henry Draper Catalogue* as G5; Fehrenbach and Burnage (1982) reported K3. No luminosity classification could be found in the literature, although the short-period photometric variations suggest a dwarf class. Moderate Ca II H and K emission has been reported by Bidelman (1985*a*), prompting Strassmeier *et al.* (1988) to list this star as a chromospherically active binary star candidate.

All photometric observations of this star are new. Of the four groups, the last one contained the least internal scatter and yielded 1.745 days as the most reliable photometric period. Internal scatter in the other groups limited analysis and produced periods that were inconsistent. Because the last data group was fitted with such a small rms deviation, the variability of HD 1405 seems certain. Figure 4 refers to the last group.

j) *HD 6286*

In a spectroscopic survey of late-type stars, Heard (1956) observed HD 6286 and determined it to have a variable radial velocity. His spectroscopy showed the system to be an

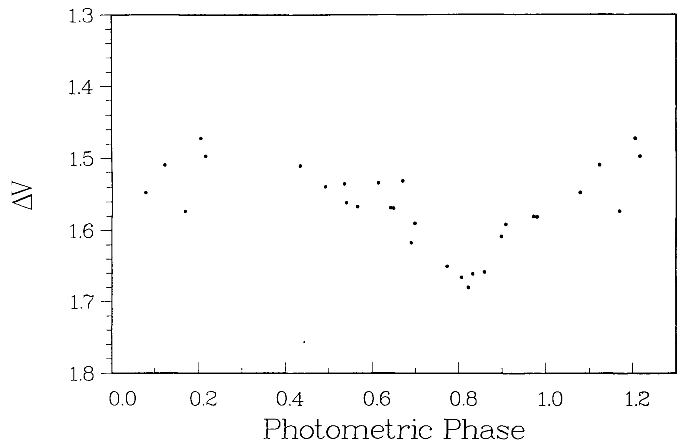

FIG. 5.—Phase plot for HD 6286 minus HD 6009; $P_{phot} = 35.3$ days. The data shown were obtained during the interval JD 2,446,309–2,446,446.

SB1 with a G2 V primary. Bidelman (1983) reported moderate Ca II H and K emission.

The best period found for group 4 was 6.21 days, while the combined groups 1–3 showed a strong periodicity at 35.3 ± 0.1 days. These three groups produced rms deviations that were on the same order. When the 35.3 day period was forced on each of the first three groups individually, the amplitudes were seen to differ from group to group but increase monotonically. It would be nice if the 6.2 day period found in group 4 is for some reason spurious. Group 4 consisted of only 13 data points obtained over a 17 day interval, less than half of the 35.3 day cycle. However, when the 35.3 day period was forced on group 4, the fit was very poor, and the data did not phase well with groups 1–3. Additional photometry of this large-amplitude variable would be very interesting. Figure 5 refers to data group 1.

k) *HD 9313*

HD 9313 is a 7.81 mag SB1 system classified as spectral type G5 in the *Henry Draper Catalogue*. However, Griffin and

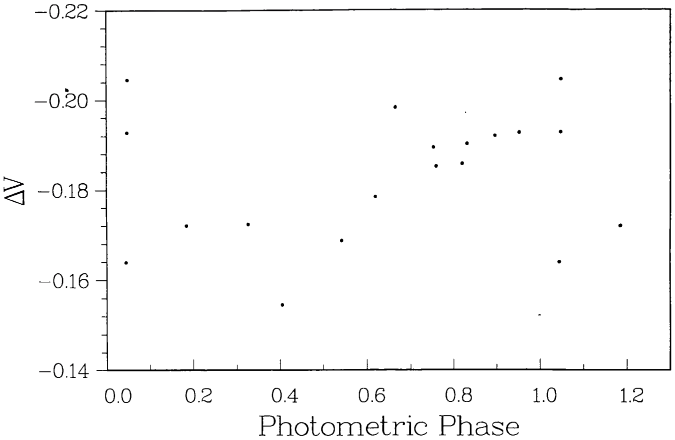

FIG. 6.—Phase plot for HD 9313 minus HD 8910; $P_{phot} = 14.0$ days. The data shown were obtained during the interval JD 2,446,654–2,446,819.

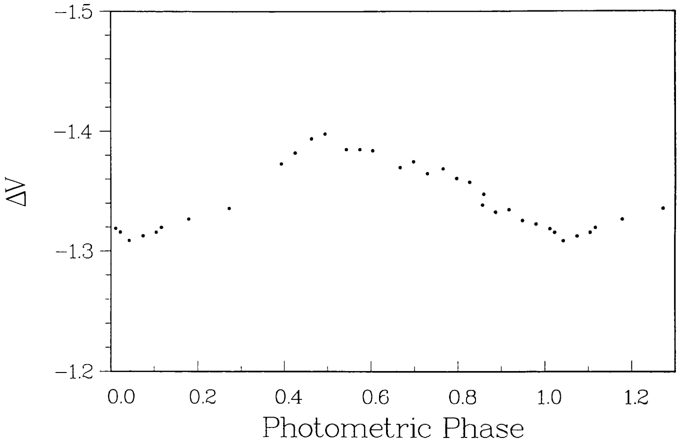

FIG. 7.—Phase plot for HD 10909 minus HD 10701; $P_{phot} = 32.025$ days. The data shown were obtained during the interval JD 2,444,071–2,444,254.

Emerson (1975) state that their photoelectric radial velocity measures indicate K0 as a more realistic value. No mention of luminosity class or Ca II H and K emission could be found in the available literature. Orbital elements determined by Griffin and Emerson place the orbital period at 53.504 ± 0.004 days with an eccentricity of 0.394 ± 0.006.

The photometric periods found for the first two groups are quite consistent with each other, around 14 days, and their calculated amplitudes are comparable, around 0.02 mag. Because of the paucity of data, no analysis was performed on the last group. A period search was performed on the entire data set to see whether the measurements would phase together and produce useful results. The period determined in this manner was 13.86 ± 0.05 days, producing an amplitude of 0.019 ± 0.005 mag and a time of minimum light of JD $2,446,303.9 \pm 0.5$. The phase plot for the middle group is shown in Figure 6. Because of the small amplitude, the phase plot seems to show a great deal of scatter, but the rms deviation from the best sinusoidal fit is only 0.009 mag.

l) *HD 10909*

Bidelman and MacConnell (1973) classify this SB1 system as K0 IV and note the presence of Ca II H and K emission. Fekel, Moffett, and Henry (1986) confirm both the subgiant classification and the Ca II emission features, as well as observe Hα absorption and a $v \sin i$ of 6 km s^{-1}. The orbital period and eccentricity have been found by Balona (1987) to be 15.05 days and 0.39, respectively.

Lloyd Evans and Koen (1987) report a photometric period of 32 days. Their data, combined with the new observations, create a data set spanning 10 years. Periods could be found within three of the five observing groups. Period searches within groups 1 and 3 resulted in no convergence. The three values found are reasonably consistent within their uncertainties. The "best" period when all five groups are phased together was 31.54 ± 0.02 days, with a full amplitude of 0.067 ± 0.008 mag and T_{min} = JD $2,443,867.3 \pm 0.6$. This mean amplitude should not be taken literally, because the amplitude clearly has not remained constant. If the 31.54 day photometric period is also taken to be the rotation period, then the system is rotating much more slowly than synchronously and the implied minimum radius is approximately 3.7 $R_\odot$, consistent with the IV classification. Figure 7 refers to the first data group.

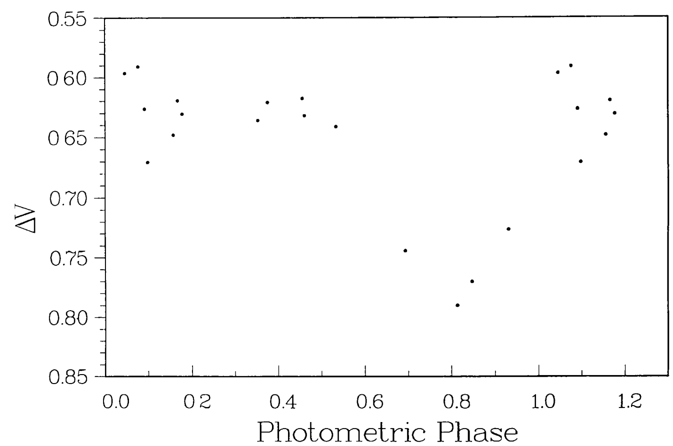

FIG. 8.—Phase plot for HD 12545 minus HD 12478; $P_{phot} = 25.1$ days. The data shown were obtained during the interval JD 2,446,654–2,446,882.

m) *HD 12545*

Bidelman (1985*b*) reports that this system has strong Ca II H and K core emission. Strassmeier *et al.* (1990*a*) report this G5 IV system to be an SB1 with an orbital period of 23.9 days and find a $v \sin i$ of 17 km s^{-1}.

The entire data set of only 16 points was used to derive the photometric period of 25.1 days. The light curve in Figure 8 shows that the full amplitude is quite large but the rms deviation for this fit was also large, and the data showed poor phase coverage. A sinusoidal fit of the light curve with phases computed using the 23.9 day orbital period was even worse, with an rms deviation of 0.040 mag. If the 25.1 day photometric period is also taken to be the rotation period, then the implied minimum radius is 8.43 $R_\odot$. This suggests a giant classification, in conflict with the IV classification.

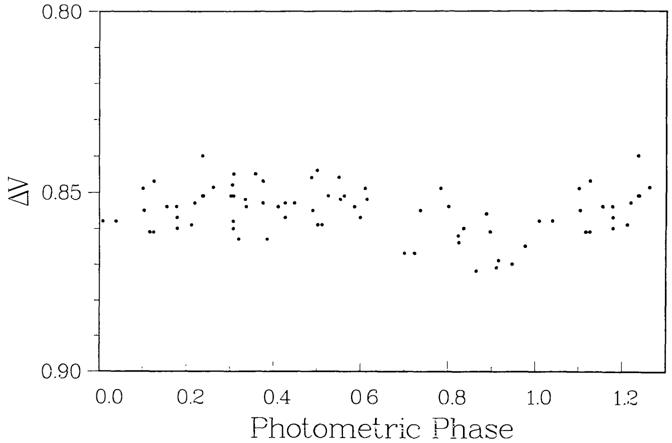

FIG. 9.—Phase plot for HD 17144 minus HD 17320; $P_{phot} = 15.93$ days. The data shown were obtained during the interval JD 2,443,785–2,446,381.

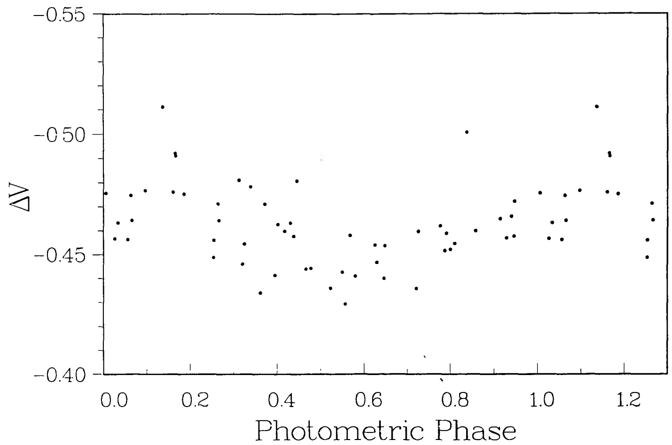

FIG. 10.—Phase plot for HD 19485 minus HD 19607; $P_{phot} = 6.45$ days. The data shown were obtained during the interval JD 2,446,321–2,446,495.

n) HD 17144

Fekel, Moffett, and Henry (1986) list this star as G 8 III/IV with weak emission in the Ca II H and K lines and $v \sin i = 15$ km s^{-1}. Spectroscopic observations of Balona (1987) show the radial velocity to be constant, suggesting that this star is single.

Lloyd Evans and Koen (1987) found this star to vary by approximately 0.02 mag with a period of 16.2 days. Only three new magnitudes were added to the already published data base for this star. A period search performed on the entire data set yielded a "best" photometric period close to that found by Lloyd Evans and Koen and a small but statistically significant amplitude. With that 15.93 day period, the unpublished data phased in well with the published data; with the older 16.2 day period, scatter was larger, with an rms deviation of 0.006 mag, and the light curve was not as well defined. If the 15.93 day photometric period is also taken to be the rotation period, then the implied minimum radius is approximately 4.7 $R_\odot$, consistent with the III/IV classification. With so few new photometric observations gathered, little more can be said about this new variable. Figure 9 refers to the entire data set.

o) HD 19485

Heard (1956) observed HD 19485 as part of a survey of late-type stars and classified it as a G5 dwarf. The orbital period of this SB2 (spectral type G4 V+G6 V) system is listed by Strassmeier *et al.* (1990*a*) as 6.15 days with $v \sin i$ values of 10 and 6 km s^{-1} for the respective spectral types. Strassmeier *et al.* also find this system to have Ca II H and K emission.

Of the four data groups, group 3 contained only one point. Analysis performed on groups 1, 2, and 4 each yielded periods around 6 days, although only the first and last groups show periods which agree within their formal errors. The full amplitudes of all three groups were equal within their errors. Figure 10 refers to the first group, with $P_{best} = 6.45$ days. If the 6.45 day photometric period can also be taken as the rotation period for the G4 and G6 stars, then the system is rotating more slowly than synchronously and the implied minimum radii are 1.3 and 0.8 $R_\odot$, respectively.

p) HD 19754

Bidelman and MacConnell (1973) and Fekel, Moffett, and Henry (1986) report that this eighth magnitude G8 IV–III system is chromospherically active as evidenced by the Ca II H and K emission features. The projected rotational velocity is $v \sin i = 8$ km s^{-1}. Balona (1987) found this SB1 system to have an orbital period and eccentricity of 48.3 ± 0.3 days and 0.10 ± 0.05, respectively. The photometric period found by Lloyd Evans and Koen (1987) is 48.2 days, in close agreement with the orbital period.

The first data group consisted of the same photometric measurements discussed by Lloyd Evans and Koen (1987). The second data group consisted of six new measurements. The new data were consistent with the period and amplitude found by Lloyd Evans and Koen. When all measurements, new and published, were combined, the resulting photometric period was 48.01 ± 0.04 days, the calculated full amplitude was 0.164 ± 0.013 mag, and T_{min} was JD $2,443,805.6 \pm 0.6$. Figure 11 refers to the entire data set. The phase diagram of these data versus the 48.01 day period suggests that the amplitude has not remained constant. If the 48.01 day photometric period is taken to be the rotation period, then the system is in synchronous rotation and the implied minimum radius is approximately 7.6 $R_\odot$, consistent with the IV–III classification.

q) HD 19942

Bidelman (1985*a*) detected moderate Ca II H and K emission from this bright ($V = 7.30$ mag) G5 subgiant (Hirshfeld and Sinnott 1982). A visual inspection of observations by Fekel (1989) shows this system to be a single-lined spectroscopic binary with a small $v \sin i$ and an orbital period on the order of 20 days.

Of the four groups, only group 3 contained too few data points to yield a photometric period. The three determinations of the period, between 22 and 23 days, are all consis-

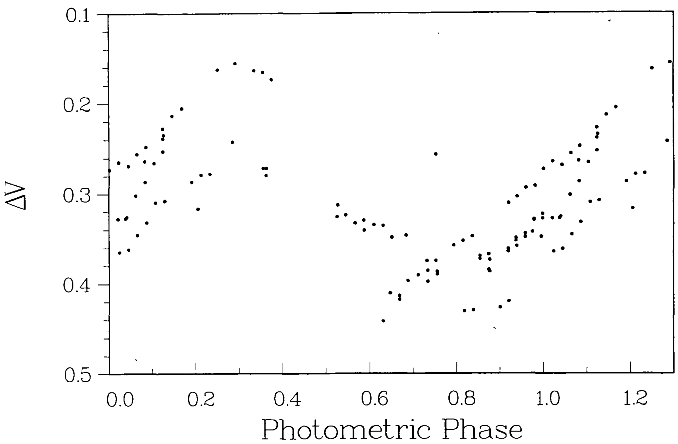

FIG. 11.—Phase plot for HD 19754 minus HD 19421; $P_{phot} = 48.01$ days. The data shown were obtained during the interval JD 2,443,785–2,447,142.

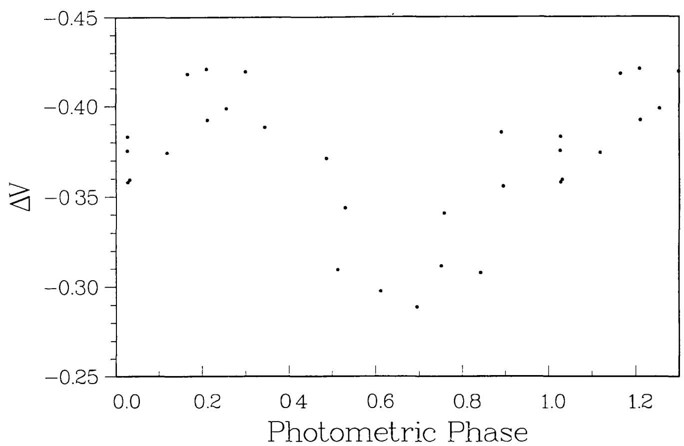

FIG. 12.—Phase plot for HD 19942 minus HD 19769; $P_{phot} = 22.0$ days. The data shown were obtained during the interval JD 2,446,654–2,447,122.

tent with one another, but the amplitude has increased dramatically from 0.02 to 0.22 mag. If a radius of 3 $R_\odot$ is assumed and the 22 day photometric period is taken to be the rotation period, then the implied $v \sin i$ is less than or equal to 7 km s^{-1}. Figure 12 shows the result of analysis for the data contained in group 2.

r) HD 30957

Young (1974) observed the Ca II H and K emission features in this star and considered it a probable spectroscopic binary. More recent spectroscopic observations by Fekel (1989) confirm that HD 30957 is indeed a double-lined spectroscopic binary consisting of spectral types K2 V+K3 V. Although Fekel (1989) has not computed a formal orbit from his radial velocity measurements, he estimates the orbital period to be longer than 10 days or shorter than 1 day. Strassmeier *et al.* (1990*a*) find both stars in the system to have $v \sin i$ values of 6 km s^{-1}.

Differential photometric observations were obtained and organized into two data sets, one for the program star minus the comparison star (set A) and the other for the check star (HD 28780) minus the comparison star (set B). The data of set A show a disturbance near JD 2,447,510 which is also apparent in the data of set B, implying that a momentary (~ days) brightening of the comparison star was responsible. Any variations outside of this disturbance, for both sets A and B, are either very small or nonexistent. A period search of set A from a fraction of a day to 100 days showed no significant dips in the periodogram.

s) HD 31993

Bidelman and MacConnell (1973) report Ca II H and K emission lines and a spectral type of K2 III+F. While reporting more recent spectroscopic observations, Fekel, Moffett, and Henry (1986) state that $v \sin i$ is 31 km s^{-1} but that the F secondary component could not be seen. These observations prompted Strassmeier *et al.* (1988) to place this star on a list of candidate CA binary stars. Balona (1987), however, reports no significant radial velocity variations and considers HD 31993 a single star.

Lloyd Evans and Koen (1987) found a period of 6.78 days in a subset of their photometric observations which we call group 2. A phase plot given by Lloyd Evans and Koen in their Figure 1 for that interval showed a small-amplitude variation. Analysis of group 2 yielded a weak photometric period at 6.88 days, close to the 6.78 day period found by Lloyd Evans and Koen. A similar photometric period could not be found in the other four data groups. Instead, longer periods of 28.7 and 26.8 days appeared strongest in group 4 and are not excluded in group 5 because of the small number of measurements it contained. The wide range in magnitude suggests variability, but the periodicity must be considered uncertain. Rotation periods of 6.8 and 28 days would imply minimum radii of 4.2 and 16.5 $R_\odot$, respectively, both consistent with the III classification.

t) HD 33798

Moderate emission of Ca II H and K is apparent in this star (Bidelman 1985*a*). A spectral classification of G5 is given by the *Henry Draper Catalogue* and is the only one found in the available literature. Recent spectroscopic observations by Fekel (1989) found this system to be a K0 III single star with a $v \sin i$ of 29 km s^{-1}.

Differential photometric observations reported by Spurr and Hoff (1987) show that this star varies with an amplitude of about 0.07 mag with a period somewhere between 9.6 and 9.9 days. The observations of Spurr and Hoff were combined with the new unpublished observations. When various observing groups were analyzed separately, a consistent period of 9.8 days was apparent. The combined data set produced a "best" photometric period of 9.825 days and other parameters shown in Table 4. Figure 13 refers to the entire data set. If the 9.8 day photometric period can also be taken as the rotation period, then the implied minimum radius is 5.6 $R_\odot$, consistent with the III classification.

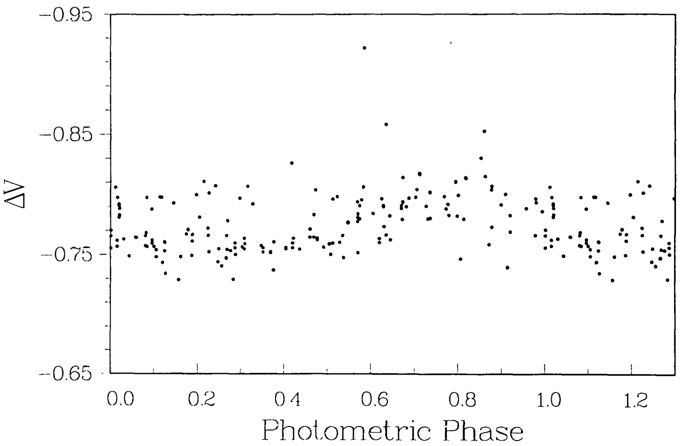

FIG. 13.—Phase plot for HD 33798 minus HD 34248; $P_{phot} = 9.8$ days. The data shown were obtained during the interval JD 2,446,320–2,447,434.

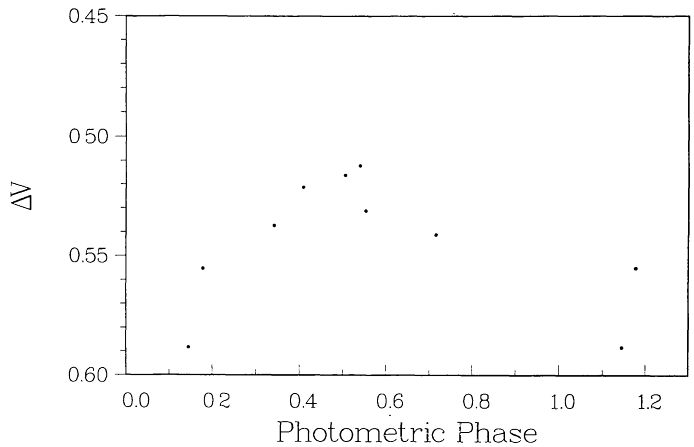

FIG. 14.—Phase plot for HD 34198 minus HD 33667; $P_{phot} = 30.5$ days. The data shown were obtained during the interval JD 2,444,590–2,444,638.

u) *HD 34198*

Bidelman and MacConnell (1973) and Fekel, Moffett, and Henry (1986) report the presence of Ca II H and K emission features in this star. The spectral classification according to Bidelman and MacConnell is K0 III+F, but Fekel, Moffett, and Henry did not detect the presence of the F secondary. Radial velocity observations by Balona (1987) showed this star to have a constant radial velocity and led him to believe it to be single. A measure of $v \sin i$ by Fekel, Moffett, and Henry gives 15 km s^{-1}.

This star was found variable by Lloyd Evans and Koen (1987), with a photometric period of 28.4 days but with variable amplitude. The published observations were combined with the new observations and divided into six groups, of which five yielded meaningful periods. Four of those five values of the period are very similar, around 29 days, although not all are equal within their formal errors. The last one is near half the average of the other four. It is reasonable to suppose that HD 34198 has a rotation period around 30 days and that the 15 day periodicity in group 6 was produced by two spots on opposite hemispheres. Analysis of the combined data set did not yield useful results. Figure 14 shows a phase plot for the data in group 3. If the 29 day photometric period is taken to be the rotation period, then the implied minimum radius is approximately 8.6 $R_{\odot}$, consistent with the III classification.

v) *HD 43930*

The *Henry Draper Catalogue* classifies this system as spectral type G5, but Fehrenbach (1961) reports K1 V. From photoelectric radial velocity measurements Radford and Griffin (1976*a*) find that this system is an SB1 with an orbital period of 111.69 ± 0.05 days and an eccentricity of 0.120 ± 0.024.

Periodograms for the two groups showed several dips of nearly equal depth distributed throughout the range searched. However, the only prominent dip that occurred in both groups at the same period was the one around 3.4 days. More observations with smaller internal scatter would help to confirm these results. Figure 15 refers to the second group.

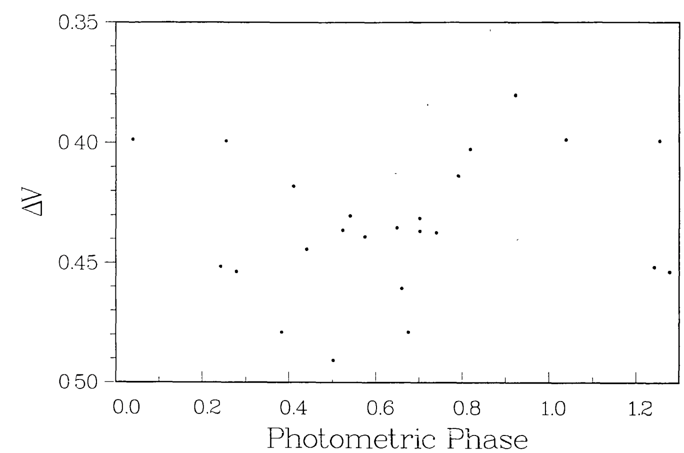

FIG. 15.—Phase plot for HD 43930 minus HD 44497; $P_{phot} = 3.42$ days. The data shown were obtained during the interval JD 2,446,774–2,446,910.

w) *HD 65195*

According to Griffin (1985), this system is an SB1, with a spectral type of G5 III, an orbital period of 37.8999 ± 0.0016 days, and an eccentricity which is zero within narrow limits. Strassmeier *et al.* (1990*a*) find this system to have a $v \sin i$ of 12 km s^{-1}. The 18 observations gathered for this study were obtained on 17 nights during the Julian Date interval JD 2,447,277–2,447,434.

An effort to look for periods in the range from a fraction of a day to 100 days yielded nothing meaningful. The mean differential magnitude for the entire data set is 1.544 ± 0.004 mag. The data set contains one spurious point which is more than 3 standard deviations from the mean. When this point is removed from the data set, the new mean differential magnitude and its error take on those values given in Table 4. Thus, if that one point is excluded, the data show that this star did not vary over a range greater than about 0.015 mag.

x) *HD 71028*

In a spectroscopic study of late-type stars conducted at David Dunlap Observatory, Heard (1956) noted that the K0 III star HD 71028 had a variable radial velocity with a range of ~ 69 km s^{-1} over the period of observation.

The significant range in magnitude covered by the photometric observations, $\Delta V = 0.113$ mag, suggests that the star might be variable, but period analysis of each of the three data groups did not reveal any significant periodicity.

y) *HD 71071*

Bidelman and MacConnell (1973) noted Ca II H and K emission lines and report K1 IV as the spectral class of this star. Fekel, Moffett, and Henry (1986) confirm both the spectral classification and the H and K emission. They also show this system to have strong Hα absorption and $v \sin i = 8$ km s^{-1}. Orbital elements found by Balona (1987) include an orbital period of 16.537 ± 0.006 days and an eccentricity of 0.13 ± 0.06.

Published photometric observations by Lloyd Evans and Koen (1987) have been added to new differential observations and searched for periodicity. The photometric period determined by Lloyd Evans and Koen was 32.92 days. Strassmeier *et al.* (1988) report that a second possible period could be 20.83 days. Period analysis performed on six data groups yielded the four periods shown in Table 4. Only two of those values, for groups 2 and 4, are even similar, but they are somewhat close to the 32.92 day period found earlier by Lloyd Evans and Koen. Two other periods which were consistent with each other were 21.0 ± 0.2 days associated with a weaker dip in the periodogram of data group 3 and 20.7 ± 0.2 days also associated with a weaker dip in the periodogram of group 4. Note that this 21 day period is consistent with the second possible period mentioned by Strassmeier *et al.* (1988). If the 21 day photometric period is taken to be the rotation period, then the system is an asynchronous rotator and the implied minimum radius is 3.3 $R_\odot$, consistent with the IV classification. Figure 16 shows a variation which is not strictly sinusoidal. The nonsinusoidal nature of the light variations may contribute to the apparent failure of the period-searching routine to detect a consistent period.

z) *HD 90385*

The *Henry Draper Catalogue* gives a spectral type of G0. More recent work by Radford and Griffin (1976*c*) points out that late G III is a more realistic classification. They found the orbital period of this SB1 system to be 99.85 ± 0.06 days. The eccentricity was found to be negligible and fixed at zero in their orbital solution.

The entire data set showed a range in magnitude of 0.133 mag from maximum to minimum (about 0.09 mag if one spurious point is excluded) and a relatively large scatter, both of which suggest variability. The two data groups yielded periods which were very similar and marginally consistent within their respective uncertainties, namely, 13 days. The amplitudes were small but statistically significant and also equal within their uncertainties. No periodicity was apparent in the vicinity of the approximately 100 day orbital period.

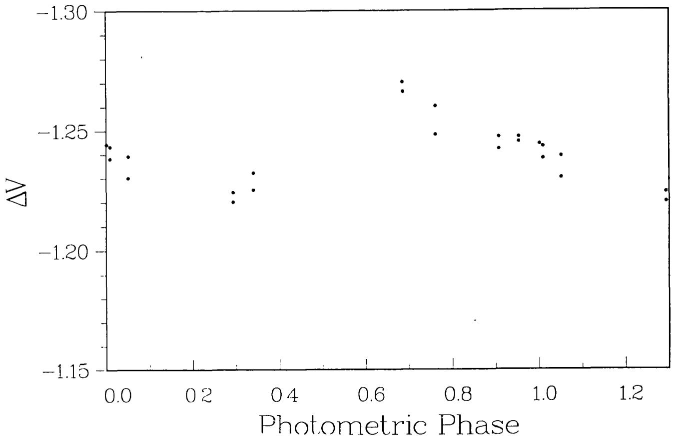

FIG. 16.—Phase plot for HD 71071 minus HD 70788; $P_{phot} = 20.7$ days. The data shown were obtained during the interval JD 2,444,904–2,444,973.

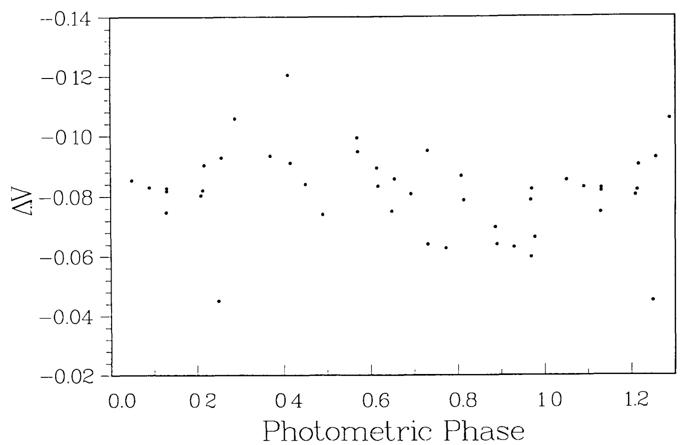

FIG. 17.—Phase plot for HD 90385 minus HD 90042; $P_{phot} = 12.5$ days. The data shown were obtained during the interval JD 2,446,452–2,446,579.

Figure 17 refers to group 1. If the 13 day photometric period can be assumed to represent the rotation period and the assumption that $e = 0$ is real, then the G0 star is rotating much faster than synchronously.

aa) *HD 96511*

This G0 IV star was among a sample of 68 late-type spectroscopic binaries observed for Ca II H and K emission by Young and Koniges (1977). No such emission was seen. For this SB1 system Sanford (1924) determined an orbital period of 18.8922 ± 0.0061 days and an eccentricity of 0.282 ± 0.017.

Only four photometric observations were obtained on four different nights during a 40 night interval. The total magnitude range was only 0.021 mag. Any statement concerning variability based on such a small sample of data would be inconclusive.

bb) *HD 105341*

The spectral type of this system according to the *Henry Draper Catalogue* is K5. A more modern classification is given by Upgren (1962) as K3 III. No mention of Ca II H and K emission was found in the available literature. HD 105341 is a single-lined spectroscopic binary, and orbital elements have been found by Griffin (1982*a*) to be $P_{\rm orb} = 194.10 \pm 0.10$ days and $e = 0.027 \pm 0.012$.

Period analysis yielded photometric periods for the two groups that were very different, suggesting that they are spurious. Moreover, both of these periods appear in the periodogram with weak statistical significance. No dips appeared in the vicinity of the 194 day orbital period.

cc) *HD 106495*

The original spectral classification of the *Henry Draper Catalogue* was K0. A G8 III type was found by Yoss (1977). Griffin (1981) states that a type K2 V or G8 III is consistent with the observed color indices, and solves for the orbital elements. Griffin's SB1 orbit has a period of 118.128 ± 0.014 days and an eccentricity of 0.206 ± 0.007.

Only four photometric observations were made during a 26 day interval. The magnitudes cover a range of 0.049 mag but no conclusive statement can be made concerning variability based on such a small number of observations.

dd) *HD 120727*

HD 120727 was placed on the list of suspected variable stars as a suspected eclipsing binary. Schöffel (1977) used HD 120727 (spectral type A0) as a comparison star in his photometric study of the eclipsing binary DL Vir. In his light curve of DL Vir (Schöffel 1977, Figs. 3 and 4) there were several disturbances, anomalous momentary brightenings. Hale (1980) suggested that such features in a light curve might have been caused by a comparison star varying in magnitude. The apparent sharpness of the features suggested that the comparison star might be an eclipsing binary.

The normal method of period analysis discussed in § III, which is based on sinusoidal light curve fits, could not be used for a suspected eclipsing binary system such as HD 120727. A plot of differential V-magnitude versus Julian Date showed one possible eclipse point at JD 2,445,514.6909 and no others. Since only one such event was recorded, future observations will be needed to decide whether this was an eclipse or a photometric error.

ee) *HD 122767*

Heard (1956) reported a K3 III spectral type and pointed out the system's variable radial velocity. In the recent spectroscopic orbit of Griffin (1988*b*) the orbital period is 1189.18 ± 0.17 days and the eccentricity is 0.871 ± 0.003.

The photometric observations showed that the data cover a magnitude range of 0.25 mag, but the period analysis could not successfully find a photometric period. Because of the large magnitude range, variability in HD 122767 is quite likely but unfortunately is not confirmed by a consistent periodicity. Unfortunately our photometry covered less than two-thirds of Griffin's orbital period and was centered on a time of apastron, not the more interesting periastron.

ff) *HD 127386*

The *Henry Draper Catalogue* classifies this eighth magnitude star as G5. Heard (1956) did not confirm this classification but instead listed the star as having a peculiar spectral type and a variable radial velocity. No other relevant information, such as Ca II H and K emission or orbital elements, could be found in the available literature.

Period analysis performed on each of the three data groups did not produce periods that were the same for all three groups. The total magnitude range was 0.062 mag, but, because no one consistent period could be found, this star is listed in Table 5 as questionably variable.

gg) *HD 128220*

This interesting system is a double-lined spectroscopic binary consisting of an O9 subdwarf and a G0 giant. Orbital solutions have been made by Wallerstein and Wolff (1966) and by Howarth (1987) mostly from *IUE* observations. Combining all solutions, Howarth adopted an orbital period of 871.78 ± 83 days and an eccentricity of 0.212 ± 0.012.

Analysis could not successfully determine a photometric period. This is not surprising, because the entire range in magnitude covered by the data was only 0.017 mag. Although the 52 day interval covered is only a small fraction of the long orbital period, HD 128220 is marked in Table 5 as not variable.

hh) *HD 141690*

This star is a single-lined spectroscopic binary containing a G0 IV star as the primary component (Heard 1956). A solution for the orbital elements could not be found in the available literature, although Heard reports a variable radial velocity with a total range of 40 km s^{-1} from five observations.

The observations showed a total magnitude range of 0.082 mag, but, because period analysis could not successfully find a photometric period, this system is considered questionably variable.

ii) *HD 144515a*

HD 144515 is a multiple system consisting of two single-lined spectroscopic binaries designated a and b by Mayor and Mazeh (1987). The composite spectral type is G8 IV (Roman 1955). For HD 144515a Mayor and Mazeh give an orbital period of 4.28549 ± 0.00004 days and an eccentricity of 0.031 ± 0.005. Although this period agrees well with the earlier orbital solution of Lucy and Sweeney (1971), the eccentricity is significantly different, namely, 0.087. Emission lines of Ca II H and K have been seen by Rutten (1986), confirming chromospheric activity. The second SB1 system, HD 144515b, has an orbital period of ~ 11 days (Mayor and Mazeh 1987). From a comparison of line depths at red wavelengths, it is approximately 0.9 mag fainter than HD 144515a and does not seem to play an important role in the observed photometric variations.

Analysis performed on the entire data set yielded a well-determined photometric period of 4.999 ± 0.002 days. Separate analysis of the data of one observer (Lines) who used two different comparison stars (HD 148127 and HD 144329)

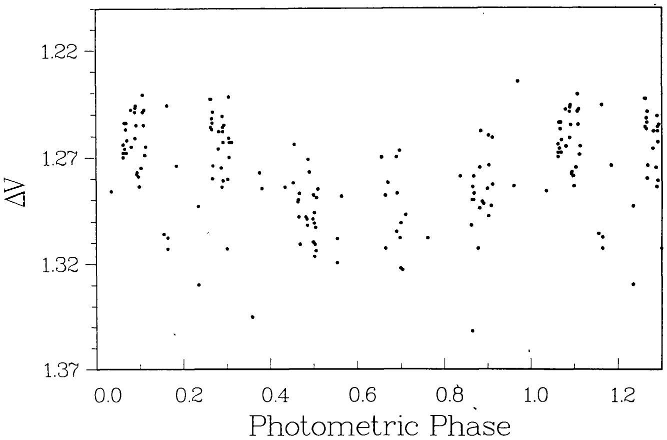

FIG. 18.—Phase plot for HD 144515 minus HD 144064; $P_{\text{phot}} = 4.999$ days. The data shown were obtained during the interval JD 2,446,270–2,447,428.

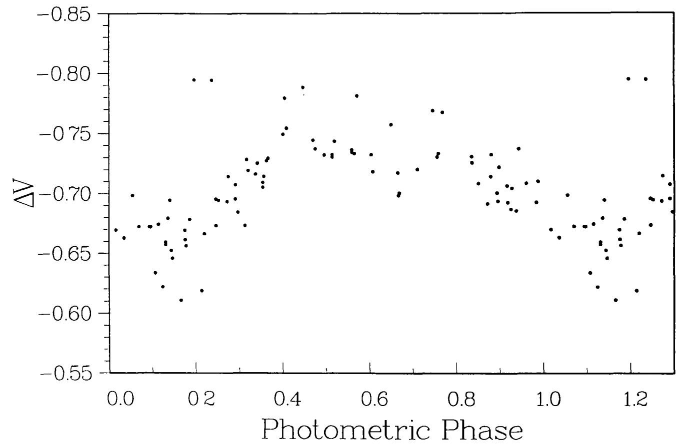

FIG. 19.—Phase plot for HD 152178 minus HD 152501; $P_{\text{phot}} = 22.35$ days. The data shown were obtained during the interval JD 2,446,593–2,447,329.

confirmed this period in both cases. No periodicity was found at the 4.3 day orbital period. Figure 18 refers to the entire data set. If the 5.0 day photometric period is also taken to be the rotation period, then the system is rotating somewhat faster than synchronously.

jj) *HD 148405*

The *Henry Draper Catalogue* lists the spectral type as K0. The system was found to be an SB1 by Griffin (1982*b*), who says that "dips" in his radial velocity traces suggest a luminosity class of III. A solution of the orbital elements by Griffin gave an orbital period of 52.453 ± 0.037 days with $e = 0.021 \pm 0.006$. No information concerning Ca II H and K emission could be found in the available literature, but Griffin points out that many giants found in systems with periods as short as 52 days are known to show RS CVn–type characteristics.

This is another star for which a photometric period could not be successfully determined. The full range of 0.107 mag observed in this star is perhaps larger than the expected scatter for a constant star, suggesting variability, but a photometric period could not be found.

kk) *HD 152178*

This is an SB1 system of spectral type G8/K0 Vp and showing Ca II H and K core emission (Houk 1982). Fekel (1989), in a computer comparison of the spectrum of HD 152178, found a good match with the K0 giant β Gem. Fekel also finds three possible orbital periods (28.6, 46.3, and 158 days) each with a convincingly noncircular orbit and a $v \sin i$ of 24 km s^{-1}.

Period analysis of the entire data set resulted in a well-determined photometric period of 22.35 days. A phase plot using this period produced a light curve, seen in Figure 19, which is not strictly sinusoidal. If the 22.35 day photometric period can also be assumed to be the rotation period, then the implied minimum radius is approximately 10 $R_{\odot}$. This suggests a giant classification, in conflict with the Houk V classification.

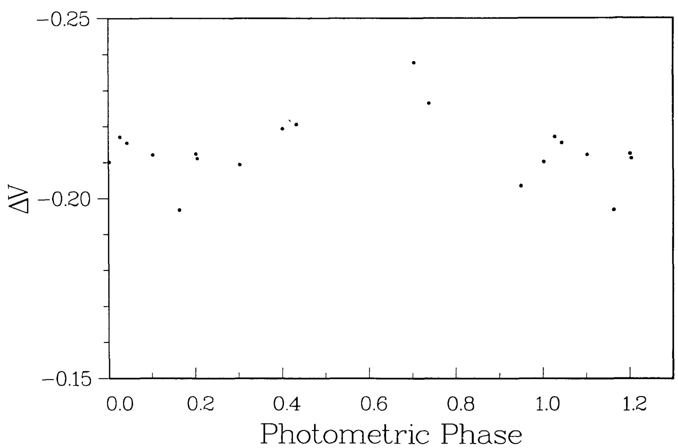

FIG. 20.—Phase plot for HD 155989 minus SAO 84947; $P_{\text{phot}} = 39$ days. The data shown were obtained during the interval JD 2,446,282–2,446,408.

ll) *HD 155989*

Heard (1956) noticed radial velocity variations and classified the spectrum of this star as G5 III. Later, Griffin (1978) solved the orbit and found the orbital period to be 122.56 days with an eccentricity of 0.318.

All of the "best" periods found for the three data groups are far from the 122.5 day orbital period. The periods found for groups 1 and 2 are consistent with each other, around 38 days, but that for group 3 is somewhat discordant, around 30 days. The disagreement in photometric periods may be due to the large internal scatter within each group. Figure 20 shows the phase plot for the first group.

mm) *HD 158393*

Lloyd Evans, Balona, and Fekel (1987) made HD 158393 the subject of a detailed study. This system is an SB2 (spectral types K1 III + F2 IV) with moderate Ca II H and K emission and Hα absorption features. An SB1 orbital solution was found by Balona (1987) and an SB2 solution by

Lloyd Evans, Balona, and Fekel (1987). The two published orbital solutions agree within their uncertainties. The second of the solutions gives an orbital period of 30.969±0.007 days with an assumed eccentricity of zero. Values of the $v \sin i$ parameters for the K and F spectral components are 22 and 9 km s^{-1}, respectively.

V-band observations on the *UBV* system made by Lloyd Evans, Balona, and Fekel (1987) showed a photometric period of 30.9597 days, very near the orbital period. The resulting phase plot, their Figure 5, produced an asymmetric light curve with an amplitude of approximately 0.06 mag. New photometric observations of HD 158393 were not available for this study. If the 31 day photometric period is assumed to represent the rotation period, then the system is in a state of synchronous rotation and the implied minimum radii of the K and F components are 13.5 and 5.5 $R_\odot$, respectively. These radii are consistent within the respective luminosity classifications of each star.

nn) *HD 160952*

Heard (1956) classified this star as a G8 giant and observed no radial velocity variations at that time. Later, however, Heard and Fehrenbach (1972) noticed velocity changes. An orbital solution published by Radford and Griffin (1976*b*) showed the orbital period to be 181.7±0.5 days and the eccentricity to be 0.38±0.06.

Analysis of the entire data set of photometric measurements made by six observers yielded a well-defined photometric period of 41.0 days and a small but statistically significant amplitude of 0.022 mag. No dip in the periodogram was seen around the 181.7 day orbital period. If the G8 star's true rotation period is *twice* 41 days, then it could be rotating pseudosynchronously. Figure 21 refers to the entire data set.

oo) *HD 163621*

Bidelman (1985*a*) noticed moderate Ca II H and K emission in the spectrum of this star. Strassmeier *et al.* (1988) list HD 163621 as a double-lined spectroscopic binary consisting of spectral types F+G5 IV with $v \sin i$ values of 8 and 8 km s^{-1}, respectively.

Analysis of five separate data groups produced useful results in three. The 3.35 day period found in group 4 had the smallest error, gave the smallest rms deviation, and produced the largest amplitude, but did not agree with the "best" periods found in groups 1 and 2. A period very near this 3.35 day value was also found by Burke (1989) in separate analysis of his photometry, which is included in data groups 1, 2, and 3. Figure 22 refers to group 4. If the 3.35 day photometric period is also taken to be the rotation period of the G5 star, then the implied minimum radius is 0.5 $R_\odot$. This is consistent with the IV classification but does not rule out a V classification.

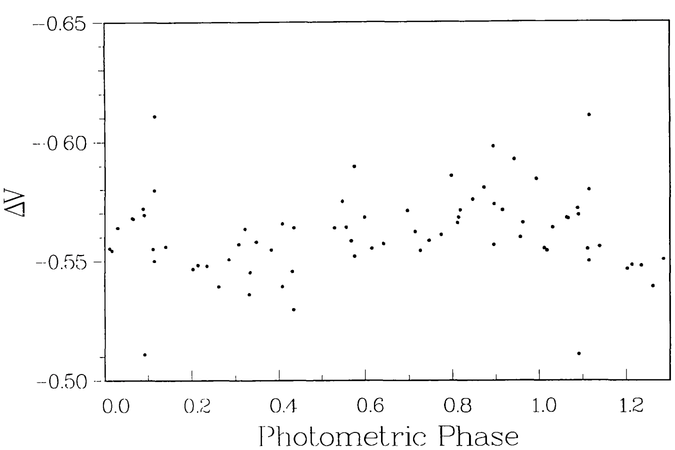

FIG. 21.—Phase plot for HD 160952 minus HD 160834; P_{phot} = 41.0 days. The data shown were obtained during the interval JD 2,446,320–2,447,096.

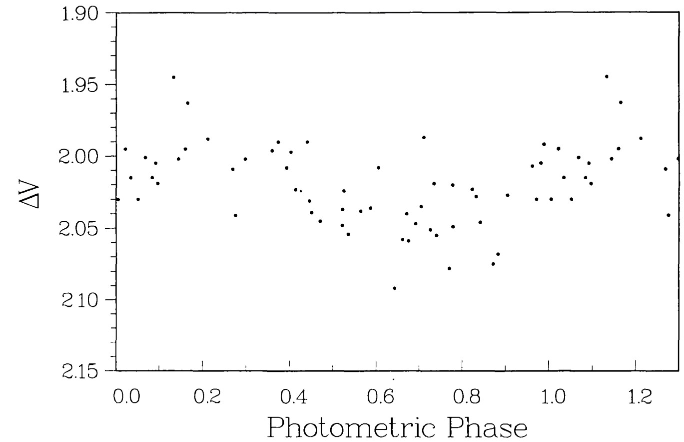

FIG. 22.—Phase plot for HD 163621 minus HD 164280; P_{phot} = 3.35 days. The data shown were obtained during the interval JD 2,447,276–2,447,329.

pp) *HD 181809*

Bidelman and MacConnell (1973) observed Ca II H and K emission in this bright (V = 6.67 mag) system and classified its spectral type as K1 III+F. Spectroscopic observations of Fekel, Moffett, and Henry (1986) confirm the Ca II emission, find no evidence of an F-type component, report moderate Hα absorption, and determined a $v \sin i$ value of 8 km s^{-1}. The orbital solution of Balona (1987) yields an orbital period of 13.048±0.002 days and an eccentricity of 0.05±0.05.

Photometry has been obtained by Hall and Pazzi (1987) and by Lloyd Evans and Koen (1987), both of which show that HD 181809 is a large-amplitude variable with a photometric period around 60 days. These observations as well as new ones combine to create a data base covering over 11 years which was subdivided into five groups. All five yielded unambiguous periods which are nearly the same. Figure 23 shows the phase plot for the third group. Analysis was also performed on the entire data set to yield a "best" photometric period of 60.23±0.04 days with an amplitude of 0.174±0.011 mag and T_{min} = 2,442,995.1±0.7. The mean amplitude for the entire data set is less meaningful than the values for the individual groups, because the amplitude is significantly variable. If the 60 day photometric period is also taken to be the rotation period, then the system is rotating much more

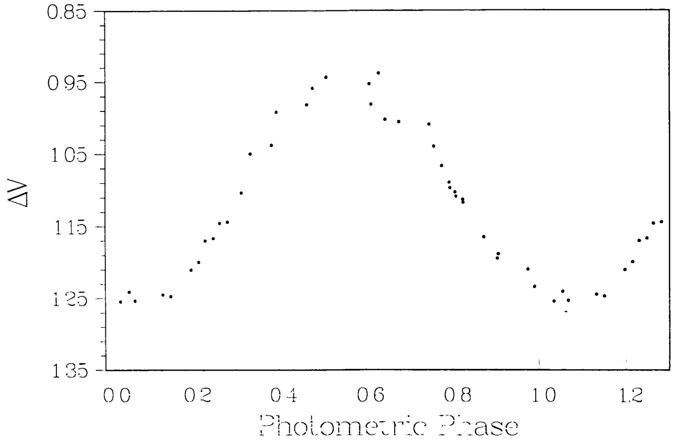

FIG. 23.—Phase plot for HD 181809 minus 50 Sgr; $P_{phot} = 61.1$ days. The data shown were obtained during the interval JD 2,446,623–2,446,746.

slowly than synchronously and has an implied minimum radius of 9.5 $R_{\odot}$, consistent with the III classification.

qq) *HD 181943*

According to Balona (1987), this is a single star of spectral class G8 IV. Ca II H and K emission lines have been found by Bidelman and MacConnell (1973), and the Hα feature is known to be filled in (Bopp and Hearnshaw 1983).

The photometric observations of Lloyd Evans and Koen (1987) and Bopp (1988) did not yield a reliable period but, when added to new measurements, were very useful. Published and unpublished photometric measurements were combined in a single group to create a data base covering over 11 years. The extremely long photometric period resulting from the search (385.3 days) is unusual for a chromospherically active single star. A phase plot for the entire data set is shown in Figure 24. HR 1362 is another chromospherically active single G8 IV star with a similarly long photometric period (Strassmeier *et al.* 1990*b*).

rr) *HD 191262*

The *Henry Draper Catalogue* lists a spectral type G5. Strassmeier *et al.* (1988) include this system in a list of candidate chromospherically active binary stars and report that the system is a double-lined spectroscopic binary with an orbital period of 5.42 days. Strassmeier *et al.* (1990*a*) found a spectral type of G5 V+G5 V along with $v \sin i$ values of 6 km s^{-1} for both components and Ca II H and K emission lines.

When the photometry is plotted against Julian Date, it shows a large range in magnitude. Analysis of the data yielded very different values for the best photometric period, none of them convincing. No periodicity was found near the orbital period.

ss) *HD 193891*

Weak emission lines of Ca II H and K were seen by Bidelman (1985*a*) prompting Strassmeier *et al.* (1988) to include this star in their list of candidate chromospherically active binaries. According to the *Henry Draper Catalogue*, the spectral class is K0.

The observations were used as a single data group without further subdivision. A single well-defined photometric period of 40.65 days was found, with a large amplitude of 0.14 mag. The resultant phase plot is depicted in Figure 25.

tt) *HD 195040*

HD 195040 is a single-lined spectroscopic binary classified by Bidelman and MacConnell (1973) as K2 III+F with emission lines of Ca II H and K. Collier *et al.* (1982) classified the system as K3 III/IV and identified it as a radio source with Hα emission. Orbital parameters have been found by Balona (1987) and include $P_{orb} = 23.206 \pm 0.018$ days and $e = 0.05 \pm 0.03$. A $v \sin i$ value of 24 km s^{-1} has been measured by Fekel, Moffett, and Henry (1986).

No new photometric measurements of HD 195040 were made, but the observations of Lloyd Evans and Koen (1987) show variability with a period of 23.2 days and amplitudes

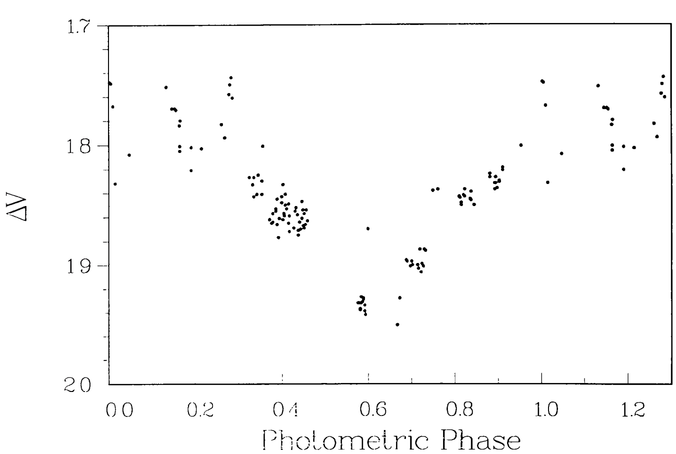

FIG. 24.—Phase plot for HD 181943 minus HD 181219; $P_{phot} = 385.3$ days. The data shown were obtained during the interval JD 2,443,382–2,447,434.

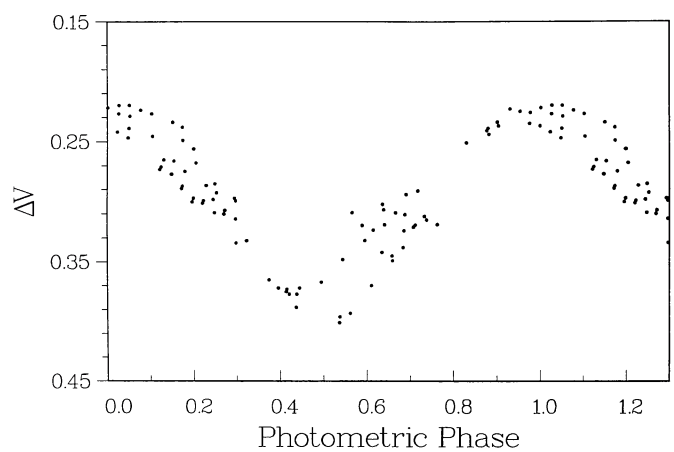

FIG. 25.—Phase plot for HD 193891 minus HD 193517; $P_{phot} = 40.65$ days. The data shown were obtained during the interval JD 2,446,957–2,447,434.

that range between 0.15 and 0.23 mag. If the 23.2 day photometric period is taken to be the rotation period, then the system is rotating nearly synchronously and has an implied minimum radius of approximately 11 $R_\odot$, more consistent with the III than with the III/IV classification.

uu) HD 202134

Bidelman and MacConnell (1973) reported Ca II H and K emission features and classified the spectrum as K1 III. Houk (1982) reports a spectral type of K1 IIIp. Spectroscopic observations by Balona (1987) show the system to be an SB1 with an orbital period of 63.090 ± 0.110 days, an eccentricity of 0.52 ± 0.07, and $v \sin i$ less than 10 km s^{-1}. Bopp and Hearnshaw (1983) report the star to have the Hα absorption filled in.

The only photometry of HD 202134 available is that of Bopp, Africano, and Quigley (1986) and that of Lloyd Evans and Koen (1987). The photometric period is approximately 61.0 days and is known to change. The amplitude of the light variation is found to be ~ 0.13 mag (Bopp, Africano, and Quigley 1986). If the 61 day photometric period can also be taken as the rotation period, then the star is rotating much more slowly than pseudosynchronously and has an implied minimum radius of 12 $R_\odot$, consistent with the III classification.

vv) HD 203251

Bidelman and MacConnell (1973) saw that the lines of Ca II H and K were in emission and classified the spectrum as K2 III+F. Ultraviolet observations by Fekel, Moffett, and Henry (1986) confirm the H and K emission but show no indications of the F companion; they also give the projected rotational velocity as $v \sin i = 40$ km s^{-1}. Bopp, Africano, and Quigley (1986) report that Hα appears as an absorption feature. Radial velocity measurements by Balona (1987) show no significant variations, implying that the star is single.

The photometric period determined by Lloyd Evans and Koen (1987) was 44.3 days, and the amplitude of the variation was found to be 0.02 mag. No new photometric measurements were available. If the 44.3 day photometric period can be taken as the rotation period, then the implied minimum radius is approximately 35 $R_\odot$, which would imply a star of luminosity class III/II or brighter.

ww) HD 204934

This is a K1 giant found by Heard and Fehrenbach (1972) to have a variable radial velocity. Orbital elements, revised from those of Radford and Griffin (1975), are given by Bassett (1978). In this solution the period was 144.41 ± 0.19 days and the eccentricity was 0.10 ± 0.03.

The available photometry scatters a bit more than expected for a constant star, with a total range of 0.072 mag, but no periodicity could be found. This star is listed as possibly variable in Table 5.

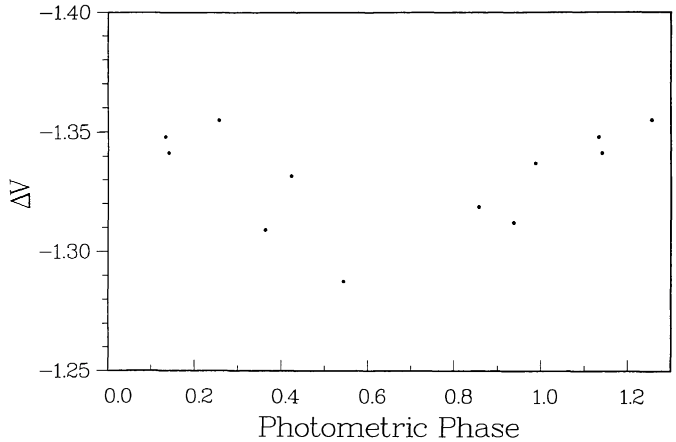

FIG. 26.—Phase plot for HD 209943 minus HD 209885; $P_{phot} = 1.166$ days. The data shown were obtained during the interval JD 2,446,270–2,446,309.

xx) HD 209943

This is a double-lined spectroscopic binary and is the B component of the visual binary ADS 15571. The spectral type of the dominant spectral component in the SB2 system is G4p (Sanford 1927). Sanford solved the spectroscopic orbit and, assuming a circular orbit, found the period to be 1.1522143 ± 0.0000003 days.

Data group 1, when searched for periodicity, showed a well-defined "best" period of 1.166 days, almost identical to the orbital period, and a moderate but significant amplitude from nine points. When that period was forced on data group 2, which contained only four points, the resulting amplitude was small and not statistically significant. Figure 26 depicts the phase light curve for data group 1. If the 1.166 day photometric period is also taken to be the rotation period, then the system is rotating nearly synchronously.

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