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AN AUTOMATED SEARCH FOR VARIABILITY IN CHROMOSPHERICALLY ACTIVE STARS

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ABSTRACT

We have completed an automated photometric survey of 66 potential or known chromospherically active late-type stars with the 0.4 m Vanderbilt/Tennessee State robotic telescope. The precision of the observations from this telescope matches that predicted from photon and scintillation noise alone and represents a significant improvement in the precision of previous robotic telescope surveys of chromospherically active stars. Light variability has been detected and its period has been determined for 47 stars, 41 of which are newly discovered variables. The primary mechanism of variability is rotational modulation of a spotted surface. In addition we have detected eclipses in HD 62668 and HD 141690 and the ellipticity effect in HD 223971. The light variations of HD 181475 are the result of pulsation while the variability mechanism of HD 99267, a newly identified member of a small group of early-F stars, is so far unidentified. High-dispersion spectroscopic observations of all the variable stars also have been obtained and analyzed to determine spectral type, $v \sin i$, and velocity variability for each star. As a by-product of the spectral-type determinations, approximate abundances for a number of supposed metal-poor binaries have been determined by comparison with stars of known abundances. In most cases our abundances are much closer to the solar value than those previously measured. The minimum radius and Rossby number of each spotted star have been computed. We also have determined whether or not the spotted component of each binary system is synchronously rotating. Important questions remain about the evolutionary state or duplicity of some of our stars, including HD 17925, HD 22694, HD 29697, HD 51066, HD 72146, HD 98800, BD +13°13, BD +70°959. Candidates for Doppler imaging include HD 51066, HD 82286, HD 171488, and HD 208472. © *1995 American Astronomical Society.*

1. INTRODUCTION

Over the past several years, operations with robotic telescopes have become increasingly more efficient, more productive, and more economical (Henry 1995a). At the same time, the precision of photometric observations made with such telescopes has improved by an order of magnitude through the use of larger apertures, precision photometers, new observing tactics, and rigorous quality-control monitoring (Henry 1995b). Observations with millimagnitude precision are now routine on larger telescopes and ventures into the submillimagnitude regime are being initiated (Henry 1995b). Sophisticated new software tools are making the scheduling and management of robotic telescopes easier and scientifically more productive (Drummond *et al.* 1995). In this paper we present the results of a new survey of known and likely chromospherically active stars conducted with the Vanderbilt/Tennessee State 0.4 m automatic photoelectric telescope (APT), which takes advantage of many of these advances in automatic telescopes. As a result, many more low-amplitude variable stars are found in this survey than in previous robotic-telescope surveys of chromospherically active stars. Almost two-thirds of this sample of new variable stars have amplitudes ≤0.05 mag.

Following the work of Strassmeier & Hall (1988a, 1988b), Strassmeier *et al.* (1989), and Hooten & Hall (1990) we take, as our primary sources of candidates, stars with known Ca II H and K emission, late-type binaries, young single stars, and optical counterparts to x-ray and extreme ultraviolet sources. In this paper we report the results of our photometry as well as high-dispersion spectroscopy for each of the 47 variable stars. Preliminary results for some of our stars already have appeared in the main tables (Tables 1–6) or in the candidate list (Table 7) of the second edition of *A Catalog of Chromospherically Active Binary Stars* (*CCABS II*) by Strassmeier *et al.* (1993). The first edition of this catalog (Strassmeier *et al.* 1988) will be referenced as *CCABS I.* Our spectroscopic results for a few of the stars were briefly summarized by Fekel & Balachandran (1994) but are more extensively discussed and sometimes slightly revised in the present work. Results in this paper supersede those given in both *CCABS II* and Fekel & Balachandran (1994). In future editions of *CCABS* some of the candidates can be advanced

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TABLE 1. Star identifications.

HD(HDE)	BD(CD)	Other	HR	IRAS	HIC
7205	+40°248	SAO 37026	---	01102+4123	5684
17925	−13°544	EP Eri	857	02501−1258	13402
18632	+7°459	SAO 110894	---	---	13976
18645	−1°428	SAO 130230	---	---	13968
22694	+17°601	SAO 93538	---	---	17076
29697	+20°802	V834 Tau	---	04383+2048	21818
33363	+75°217	SAO 5481	---	05116+7553	24760
39743	+49°1423	SAO 40720	2054	05532+4901	28162
51066	+75°280	SAO 6053	---	06575+7529	34101
62668	+47°1484	NSV 3726	---	07436+4727	38003
70573	+2°1951	SAO 116694	---	---	---
72146	+29°1772	SAO 80232	---	08292+2929	41875
72429	+11°1865	SAO 97905	---	---	41951
80953	+64°733	SAO 14875	3722	09217+6409	46247
82286	+63°848	SAO 14919	---	09299+6302	46919
82443	+27°1775	SAO 80897	---	09298+2712	46843
85091	+11°2108	SAO 98794	---	---	48215
89546	+61°1183	SAO 15153	---	10183+6109	50752
98800	(−24°9706)	SAO 179815	---	11195−2430	---
99267	+30°2154	SAO 62550	---	---	55766
112859	+47°2007	SAO 44410	---	---	63368
113816	−4°3419	SAO 139157	---	---	63958
118234	+21°2548	SAO 82886	---	13327+2102	66286
118981	+2°2705	SAO 120060	---	---	66708
122767	+25°2723	SAO 83143	---	14009+2450	68660
131511	+19°2881	NSV 6847	5553	14511+1921	72848
141690	+25°2973	SAO 84018	---	---	---
144110	+51°2051	SAO 29761	---	---	78519
148127	+24°3003	SAO 84364	---	16230+2410	80435
148405	+24°3008	SAO 84381	---	---	---
160934	---	---	---	---	86346
171488	+18°3734	SAO 103862	---	---	91043
181475	−4°4781	SAO 143296	---	19181−0435	95099
202951	+10°4516	SAO 107020	8149	21164+1059	105224
203387	−17°6245	32 ι Cap	8167	21194−1702	105515
206301	−14°6102	42 Cap	8283	21388−1416	107095
208472	+43°4087	SAO 51437	---	21532+4410	108198
223971	+38°5091	SAO 73597	---	---	---
(337518)	+27°3245	SAO 86811	---	---	93817
---	−0°4234	NSV 13768	---	---	---
---	+13°13	SAO 91772	---	---	999
---	+30°2130	---	---	---	55135
---	+36°2193	---	---	---	56132
---	+48°3686	SAO 51891	---	---	---
---	+70°959	ET Dra	---	---	---
---	---	1E2349.8−0112	---	---	---
---	---	Wa Tau 1	---	---	---

to the main tables while a few should be deleted because they have proven to be single stars.

2. LITERATURE SEARCH

At times during our extensive literature search we found papers that used unfamiliar names, such as satellite-catalog designations, for relatively bright stars. In some papers the stars were poorly cross referenced or not cross referenced at all. As a result, despite the use of SIMBAD, we sometimes came upon important results by chance rather than by design. To alleviate such identification difficulties in the future, we have compiled a list of names for each of the 47 variables (Table 1). Although a few of the stars have variable star names, HR numbers, Flamsteed numbers, and/or Bayer designations, we use HD number followed by BD number as the primary identifier in the rest of this paper. Two stars are so faint that they have neither an HD nor BD number and so are identified by other designations. Column 1 is the HD or HDE number while column 2 lists the BD or CD number. In column 3 various other names including variable star name, Bayer designation, Flamsteed number, suspected variable star number or SAO number are listed. Two stars without any of the above identifications are listed by other designations. Seven stars are bright enough to have HR numbers, which are listed in column 4. Identifications from two other catalogs may be particularly useful for future work on the stars, so in columns 5 and 6 we have listed the *IRAS* designation and *The Hipparcos Input Catalogue* number (Turon *et al.* 1992), respectively.

Table 2 lists independent determinations of V, $B-V$, and $U-B$ that we could find in the literature. Catalog entries that represent means or composites of other published values are not included. Values not certain to be on the UBV system are omitted as well. Most were determined by the technique of all-sky photometry but a few, appropriately identified, are means of multiple measures determined by the technique of differential photometry. In five cases where no photometry on the UBV system has been published, we have listed V magnitudes determined from our own differential photometry and the known V magnitudes of the comparison and/or check stars. In a sixth case, BD +48°3686, we found no literature values for it, its comparison, or its check star. Instead, there are only three very disparate values of the apparent visual magnitude, given in the BD Catalog, the SAO Catalog, and SIMBAD, which show a range of 0.8 mag! The $U-B$ and $B-V$ indices prove helpful, in some cases, in verifying the spectral class and/or luminosity class. The range of V magnitudes, as we will show, is marginally useful in corroborating the variability that we establish in this paper.

3. PHOTOMETRIC OBSERVATIONS AND ANALYSES

Photometric observations of the stars in our sample were obtained with the Vanderbilt/Tennessee State 0.4 m automatic photoelectric telescope on Mt. Hopkins, Arizona. Each program star was observed differentially with respect to a comparison star in both B and V filters. A check star was also included in the standard group observing sequence K,S,C,V,C,V,C,V,C,S,K, where K is the check star, C is the comparison, V is the program star, and S is a sky observation. In our reductions we used nightly extinction coefficients determined from standard-star observations whenever possible and three-night running averages otherwise. Group mean differential magnitudes in the sense $V-C$ and $K-C$ were transformed to the Johnson UBV system with long-term mean transformation coefficients. The external precision of our observations, defined as the standard deviation of a single nightly group observation from the seasonal mean magnitude, was determined to be around 0.003 mag from observations of selected pairs of especially stable stars. This matches the precision predicted from photon and scintillation noise alone for this telescope and represents a threefold or fourfold improvement in the precision of robotic telescope photometry (Henry 1995b). Details about the telescope, precision photometer, reduction methods, and further improvements in the precision of automatic-telescope observations also can be found in Henry (1995b).

The results of our photometric observations, summarized in Table 3, were determined from the V band observations of each star unless otherwise specified. The first three columns list the variable star, comparison star, and check star, respectively. Although most of the stars have been monitored for two to five seasons with the APT, we have generally presented the analysis of only one subset of the observations, chosen to demonstrate the variability most convincingly. This subset is specified for each star in columns 4 and 5. When interesting comparisons could be made with other subsets or the entire data set, we have presented the additional results in our discussion of the individual stars. The results of periodogram analysis for each star, derived from the data in the Julian-date range listed, are given in column 6. Column 7 gives the amplitude of light variability, usually determined from inspection of the light curve. The vast majority of the stars in our sample are chromospherically active, so their brightness variations are the result of rotational modulation of starspots. The remaining stars vary by other mechanisms. Several stars exhibit additional light variations due to eclipses but the eclipse variations are not included in column 7. If the amplitude is variable within the Julian-date range given in column 4, column 7 cites the largest amplitude within that range. The final column of Table 3 gives the standard deviation of the nightly check-star minus comparison-star observations from their respective seasonal means. This serves as a measurement of the precision of the observations as well as a check on the constancy of the comparison and check stars.

This paper includes only stars from our survey for which we can demonstrate convincing variability. Our criteria were as follows: (1) The variability must be periodic and the amplitude at that period must be statistically significant. (2) The same periodicity must manifest itself in both the V and the B data sets. (3) The same periodicity must be present in more than one observing season or, if the variability was seen in only one observing season, the period should be plausible. Plausibility in this context means that the photometric period is very close to the synchronous or pseudosynchronous period expected in cases of a close binary system containing one spotted star or the observed photometric period, combined with the star's $v \sin i$, gives a minimum radius consistent with the star's spectral type.

Of the 66 stars in our survey, 42 (64%) are reported variable in this paper and a couple more, not included here, are suspected variables that did not meet our criteria for convincing variability. For six of the 42 stars, prior announcements of variability have occurred in the recent literature. In addition to the 42 variable program stars, five (4%) of our comparison and check stars have proven to be variable as well and are included in this paper. A sixth, HD 113449, did not meet our criteria for inclusion as a definite new variable. Our criteria for potential new variables obviously result in much better odds for detection of variability than the more-or-less random selection of comparison and check stars from the

TABLE 2. Published *UBV* magnitudes.

Star	V (mag)	B−V (mag)	U−B (mag)	Reference
HD 7205	7.27	0.77	0.31	Sandage & Kowal (1986)
	7.254	---	---	Olsen (1993)
HD 17925	6.05	0.87	0.56	Johnson & Knuckles (1957)
	6.04	0.87	---	Nikonov *et al.* (1957)
	6.01	0.88	---	Cousins & Stoy (1963)
	---	0.87	0.55	Sandage & Smith (1963)
	6.04	0.86	---	Lake (1964)
	6.05	0.87	0.56	Johnson *et al.* (1966, Table 2)
	6.04	0.87	---	Johnson *et al.* (1966, Table 10)
	6.08	0.86	0.54	Feinstein (1966)
	6.05	0.86	---	Cousins *et al.* (1966)
	6.04	0.85	0.58	Johnson *et al.* (1968)
	6.05	---	---	Rufener (1971)
	6.057	---	---	Golay (1973)
	6.062	---	---	Rufener (1976)
	6.04	0.87	0.55	Eggen (1978)
	6.026	0.876	0.565	Blanco *et al.* (1979)
	6.071	---	---	Rufener (1981)
	6.023	---	---	Olsen (1983)
	6.075	---	---	Rufener (1988)
	6.00	---	---	Petit (1990)
	6.06	---	---	Petit (1990)
	6.01	0.87	---	Bessel (1990)
	6.06[a]	0.88[a]	0.60[a]	Cutispoto (1992)
	6.041	---	---	Olsen (1993)
HD 18632	7.961	---	---	Rufener (1988)
	7.954	---	---	Olsen (1993)
HD 18645	8.01	---	---	Scharlach & Craine (1980)
	7.932	---	---	Olsen (1983)
HD 22694	8.28	0.81	0.40	Oja (1987b)
	8.19	0.83	0.38	Latham *et al.* (1992)
	8.247	---	---	Olsen (1993)
HD 29697	8.01	1.08	0.93	Sandage (1969)
	7.98	1.11	0.91	Epps (1972)
	8.00	1.09	0.94	Eggen (1974)
	8.01[a]	1.095[a]	0.945[a]	Chugainov (1981)
	8.25[a]	1.06[a]	0.985[a]	Chugainov (1981)
	8.01	1.08	0.92	Sandage & Kowal (1986)
	8.004	1.290	---	Upgren & Lu (1986)
	7.996	---	---	Rufener (1988)
HD 33363	7.549	---	---	Olsen (1993)
HD 39743	6.47	0.994	---	Haggkvist & Oja (1987)
HD 51066	6.956	---	---	Olsen (1993)
HD 62668	7.707	---	---	this paper[b,d]
	7.703	---	---	this paper[c,d]
HD 70573	8.739	---	---	Olsen (1993)
	8.692	---	---	Olsen (1994)
HD 72146	7.280	---	---	Olsen (1993)
HD 72429	7.946	---	---	Olsen (1983)
	7.939	---	---	Olsen (1994)
HD 80953	6.28	1.46	---	Elvius & Haggkvist (1966)
	6.27	1.47	1.74	Rybka (1969)
	6.23	1.48	1.74	Rybka (1979)
HD 82286	8.351	---	---	Olsen (1993)

TABLE 2. (continued)

Star	V (mag)	B−V (mag)	U−B (mag)	Reference
HD 82443	7.01	0.77	0.33	Argue (1963)
	7.01	0.77	0.33	Eggen (1964)
	6.98	0.776	0.347	Sturch & Helfer (1972)
	7.032	---	---	Rufener (1976)
	7.030	---	---	Rufener (1981)
	7.020	---	---	Rufener (1988)
HD 85091	7.61	---	---	McMillan *et al.* (1976)
	7.597	---	---	Rufener (1981)
	7.613	---	---	Olsen (1983)
	7.64	0.60	0.01	Sandage & Kowal (1986)
	7.610	0.610	0.05	Carney & Latham (1987)
	7.589	---	---	Rufener (1988)
HD 89546	7.452	---	---	this paper[c,d]
HD 98800	9.08	1.26	1.07	Eggen (1974)
	8.89	1.25	1.12	Gregorio-Hetem *et al.* (1992)
	9.13	---	---	Zuckerman & Becklin (1993)
	8.945[a]	---	---	Henry & Hall (1994)
HD 99267	6.880	---	---	Olsen (1983)
	6.87	0.31	0.02	Oja (1985)
HD 112859	7.98	0.93	0.54	Schild (1973)
HD 113816	8.27	1.15	---	Buckley *et al.* (1987)
HD 118234	7.57	1.08	0.93	Haggkvist & Oja (1973)
HD 118981	8.21	0.57	0.01	Sandage & Kowal (1986)
	8.21	0.57	0.05	Carney & Latham (1987)
	8.200	---	---	Olsen (1993)
	8.228	---	---	Olsen (1994)
HD 122767	7.96	1.33	1.43	Haggkvist & Oja (1973)
HD 131511	6.01	0.83	---	Nikonov *et al.* (1957)
	6.00	0.84	0.49	Argue (1963)
	6.017	---	---	Golay (1973)
	6.019	---	---	Rufener (1976)
	6.00	0.84	0.49	Eggen (1978)
	6.02	0.83	0.52	Cowley *et al.* (1967)
	6.019	---	---	Rufener (1981)
	5.97	0.84	0.57	Kamper & Lyons (1981)
	5.994	---	---	Olsen (1983)
	6.016	---	---	Rufener (1988)
	6.01	---	---	Petit (1990)
	6.04	---	---	Jasevicius *et al.* (1990)
	6.001	---	---	Olsen (1993)
HD 141690	8.66	0.65	0.19	Eggen (1963)
	8.69	0.62	0.14	Guetter (1980)
	8.666	---	---	Olsen (1993)
HD 144110	8.626	---	---	Olsen (1993)
HD 148127	7.79	1.60	1.95	Oja (1987a)
HD 148405	8.96	0.91	0.52	Oja (1984)
HD 160934	10.28	1.23	0.95	Weis (1993)
HD 171488	7.389	---	---	Olsen (1983)
	7.456	---	---	Olsen (1994)
HD 181475	6.91	---	---	Pel (1976)
	6.96	2.07	2.14	Fernie (1983)
HD 202951	6.006	---	---	Rufener (1981)
	5.96	1.648	---	Haggkvist & Oja (1987)
	5.977	---	---	Rufener (1988)
HD 203387	4.28	0.90	0.57	Cousins & Stoy (1963)
	4.290	0.902	0.577	Gutierrez-Moreno *et al.* (1966)
	4.27	0.91	0.56	Johnson *et al.* (1966, Table 2)
	4.269	0.897	0.565	Johnson *et al.* (1966, Table 4)
	4.267	0.916	0.551	Johnson *et al.* (1966, Table 4)
	4.29	0.90	0.57	Johnson *et al.* (1966, Table 10)
	4.28	0.87	0.59	van den Bergh (1967)
	4.296	0.890	0.630	Celis (1975)
	4.274	---	---	Rufener (1981)
	4.29	0.903	0.58	Haggkvist & Oja (1987)
	4.274	---	---	Rufener (1988)

TABLE 2. (continued)

Star	V (mag)	B−V (mag)	U−B (mag)	Reference
HD 206301	5.18	0.65	0.20	Eggen (1965)
	5.15	0.67	---	Corbin (1971)
	5.164	0.674	0.181	Jennens & Helfer (1975)
	5.133	---	---	Rufener (1976)
	5.15	0.665	0.15	Eggen (1978)
	5.136	---	---	Rufener (1981)
	5.17	---	---	Reglero *et al.* (1987)
	5.13	---	---	Keenan & Yorka (1988)
	5.147	---	---	Rufener (1988)
	5.18	---	---	Jasevicius *et al.* (1990)
	5.152	---	---	Olsen (1993)
	5.167	---	---	Olsen (1994)
HD 208472	7.455	---	---	this paper[c,e]
HD 223971	6.63	0.67	0.31	Walker (1971)
	6.631	---	---	Olsen (1983)
HDE 337518	8.92	---	---	this paper[c,e]
BD −0°4234	9.89	0.96	0.48	Eggen & Greenstein (1965)
	9.89	0.96	0.48	Eggen (1968)
	9.90	0.97	0.49	Sandage (1969)
	9.89	0.94	---	Wanner (1972)
	9.89	0.98	0.48	Peterson *et al.* (1980)
	9.870	---	---	Spite *et al.* (1984)
	9.90	0.97	0.50	Sandage & Kowal (1986)
	9.820	---	---	Rufener (1988)
	9.81	---	---	Lazauskaite & Tautvaisiene (1990)
	9.78	0.94	0.50	Upgren *et al.* (1992)
BD +13°13	8.59	0.81	0.27	Sandage (1981)
	8.59	0.81	0.27	Sandage & Kowal (1986)
	8.50	0.81	0.26	Bergoffen *et al.* (1988)
	8.44[a]	0.78[a]	0.28[a]	Rodono *et al.* (1994)
BD +30°2130	9.29	0.62	0.15	Carney & Latham (1987)
BD +36°2193	9.89	0.67	0.12	Carney & Latham (1987)
	9.887	0.669	0.112	Figueras *et al.* (1990)
BD +48°3686	---	---	---	---
BD +70°959	9.70[a]	1.08[a]	0.90[a]	Jetsu *et al.* (1992)
1E 2349.8−0112	10.66	---	---	this paper[c,e]
Wa Tau 1	10.37	0.96	0.58	Walter (1986)
	10.34	0.94	0.49	Martin *et al.* (1994)

Notes to Table 2

[a]mean of range from differential photometry
[b]mean of var − comp differential magnitude
[c]mean of var − check differential magnitude
[d] *V* magnitude from Rufener (1988)
[e] *V* magnitude from Nicolet (1978)

field. A similar success rate of 68% was enjoyed by Hooten & Hall (1990) in their survey of suspected chromospherically active stars.

It is instructive to compare the range of V values appearing in Table 2 with the amplitude of variability discovered by differential photometry. We do this in Fig. 1. On the abscissa are amplitudes from differential photometry, where circles are ΔV (differential) amplitudes from our paper (Table 3 or text) and squares are ΔV (differential) amplitudes from previously published sources (for HD 17925, HD 29697, HD 98800, BD −0°4234, and BD +13°13). On the ordinate are the ranges of the values of V in Table 2. For HD 223971, the value of ΔV (differential) plotted represents the amplitude of the combined ellipticity effect plus starspot variability but not the much larger eclipse amplitude. The straight line indicates perfect correlation, and we see there is a positive correlation, though not a tight one. Frankly, we expected the majority of the Table 2 ranges to be smaller (lie below the line) because a typical single entry in Table 2 is a mean of several individual measures at different epochs. In fact, the majority are larger (above the line). We understand this by-

TABLE 3. Photometric results.

Variable Star	Comp HD	Check HD	JD Range 2440000 +	N_{obs}	Period (days)	V Amplitude (mag)	σ ck–comp (mag)
HD 7205	7590	8007	9284-9383	50	21.3 ± 0.4	0.03	0.007
HD 17925	18690	18511	9235-9407	81	6.85 ± 0.03	0.03	0.008
HD 18632	18258	18262	9235-9424	91	10.22 ± 0.05	0.02	0.005
HD 18645	18145	16765	9638-9705	29	21.6 ± 0.6	0.02	0.007
HD 22694	22072	23052	9236-9427	84	7.17 ± 0.02	0.04	0.005
HD 29697	284676	29169	9638-9805	48	3.936 ± 0.003	0.17	0.006
HD 33363	32231	33355	9256-9445	87	41.5 ± 0.2	0.12	0.008
HD 39743	40084	38104	8899-9097	82	73.1 ± 0.6	0.17	0.004
HD 51066	48840	45947	9407-9474	32	16.2 ± 0.3	0.05	0.006
HD 62668	61363	60652	8905-9118	92	69.7 ± 0.5	0.23	0.004
HD 70573	71136	70458	9262-9492	141	3.296[a] ± 0.002	0.05	0.006
HD 72146	71008	71093	9252-9493	142	28.5 ± 0.1	0.16	0.007
HD 72429	72075	72505	9262-9496	99	9.37 ± 0.04	0.015	0.005
HD 80953[b]	- - -	- - -	9638-9805	87	97[c] ± 3	0.03[c]	- - -
HD 82286	80953[d]	84179	9638-9805	82	3.270 ± 0.005	0.09	0.008[d]
HD 82443	83098	83821	9638-9717	39	5.43 ± 0.03	0.06	0.004
HD 85091	84722	85259	9646-9805	90	3.416 ± 0.009	0.03	0.004
HD 89546	90400	91480	9356-9519	125	21.5 ± 0.3	0.10	0.005
HD 98800	98828	98346	9697-9805	38	14.8 ± 0.2	0.03	0.008
HD 99267[e]	- - -	- - -	9285-9529	75	0.575[a] ± 0.001	0.03	- - -
HD 112859	112570	111421	9103-9164	56	18.5 ± 0.4	0.08	0.005
HD 113816	113449[d]	111998	9415-9528	68	23.5 ± 0.2	0.04	0.008[d]
HD 118234	117816	119126	8944-9166	128	64 ± 1	0.20	0.008
HD 118981	118865	117266	9703-9805	47	5.94 ± 0.04	0.01	0.005
HD 122767	122693	123999	9319-9548	112	96[c] ± 1	0.03[c]	0.004
HD 131511	132296	129972	9081-9165	94	10.39 ± 0.03	0.04	0.006
HD 141690	141732	141714[f]	9008-9167	107	4.64 ± 0.02	0.01	0.008[f]
HD 144110	143595	144204	9481-9548	38	1.651[a] ± 0.003	0.05	0.006
HD 148127[g]	- - -	- - -	9347-9547	100	13.80 ± 0.06	0.05	- - -
HD 148405	148127[d]	148554	9352-9547	98	56.9 ±0.8	0.04	0.015[d]
HD 160934	161014	160361	9481-9547	30	1.842[a] ± 0.005	0.02	0.005
HD 171488	171286	170829	9481-9545	35	1.338[a] ± 0.002	0.10	0.004
HD 181475[h]	180086	181391[i]	8382-8439	39	31 ± 1	0.06	0.008
HD 202951[j]	203842	202908[i]	9096-9155	35	21.6 ± 0.5	0.03	0.007
HD 203387	202890	202671	8757-9689	175	68.0 ± 0.3	0.03	0.007
HD 206301	205829	206561	9234-9340	39	12.1 ± 0.2	0.01[k]	0.008
HD 208472	208916	208513	9235-9362	64	22.54 ± 0.05	0.36	0.005
HD 223971	223636	224721	9235-9389	71	53 ± 1	0.01[k]	0.004
HDE337518	337653	179422	9486-9545	33	2.693[a] ± 0.005	0.06	0.004
BD −0°4234	205784	204121	9245-9352	20	4.03 ± 0.02	0.05	0.005
BD +13°13	1168	1419	9236-9384	67	1.852[a] ± 0.003	0.05	0.006
BD +30°2130	96778	99267[l]	9285-9529	83	6.80 ± 0.02	0.03	0.020[l]
BD +36°2193	100066	99373	9365-9516	56	8.31 ± 0.04	0.015	0.005
BD +48°3686	212072	212712	9638-9736	41	2.42[a] ± 0.01	0.08	0.006
BD +70°959	161937	164613	9374-9545	53	14.24 ± 0.02	0.23	0.007
1E2349.8−0112	224037	223825	8898-9009	19	1.145[a] ± 0.002	0.12	0.008
Wa Tau 1	29246	29169	9245-9443	42	1.487[a] ± 0.002	0.04	0.005

Notes to TABLE 3

[a]More than one possible period, see discussion
[b]Comp star for HD 82286, see discussion
[c]Results from B data analysis
[d]Comp star variable, see discussion
[e]Check star for BD+30°2130, see discussion
[f]Check star is the low amplitude variable δ CrB (Fernie, J. D. 1991, PASP, 103, 1091)
[g]Comp star for HD 148405, see discussion
[h]Originally comp star for HD 181391, see discussion
[i]Originally the suspected variable
[j]Originally comp star for HD 202908, see discussion
[k]Amplitude determined from Fourier fit
[l]Check star is variable, see discussion

noting that virtually all of our 47 variables are starspot variables, well known to have amplitudes dramatically variable over time. Consequently, one might expect the range displayed over several years to be larger than amplitudes determined from just one season of photometry.

4. SPECTROSCOPIC OBSERVATIONS AND ANALYSES

We obtained at least one high-dispersion spectroscopic observation of all 47 variables. The stars were observed at Kitt Peak National Observatory (KPNO) with the coudé feed

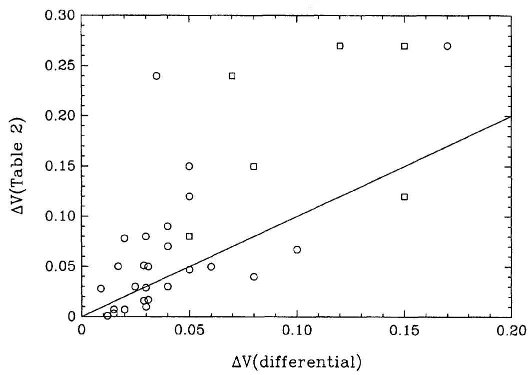

FIG. 1. Comparison of the range of V values appearing in Table 2 (y axis) versus the amplitude of variability discovered by differential photometric monitoring (x axis, circles=our paper, squares=previously published). The straight line indicates perfect correlation.

telescope, coudé spectrograph, and a Texas Instruments CCD detector. The observations were obtained at red wavelengths with the vast majority centered at 6430 Å. One or two observations of Hα at 6563 Å and the lithium line at 6708 Å also were obtained for many of the stars. The spectra have a wavelength range of 80 Å, a resolution of 0.21 Å, and a signal-to-noise (S/N) ratio of 100 or more except for those obtained of the faintest stars. For one star an observation of the Ca II H and K lines was obtained. That spectrum has a wavelength range of 56 Å and a resolution of 0.2 Å.

Radial velocities for the program stars were measured with the KPNO IRAF cross-correlation program, FXCOR (Fitzpatrick 1993). Several IAU velocity standards (Pearce 1957) were observed and their velocities were assumed from the work of Scarfe *et al.* (1990). Since additional observations will be obtained for nearly all of the stars, we have not listed the individual velocities, which will be published at a later time. Instead, for the constant-velocity stars we simply quote an average velocity plus its standard error and for the binaries, preliminary values of only the orbital period and eccentricity, the two elements of particular interest in discussions of synchronous rotation. In virtually all of the cases the final published values of those elements will be only slightly different because of a longer baseline and improved phase coverage.

We have determined the projected rotational velocities of our stars with the procedure of Fekel *et al.* (1986). In our red-wavelength-region spectra we measured the full width at half maximum of three to seven relatively unblended features and averaged those values. For those stars with narrow lines, weak to modest strength unsaturated lines were used while for spectra with broad lines, any relatively unblended lines were used. Instrumental broadening was taken into account and then the remaining line width was converted into a velocity and multiplied by an empirical constant of 0.591. To obtain the final $v \sin i$ value, a macroturbulence appropriate for the spectral type was assumed from the work of Gray (1982, 1989), Soderblom (1982), or Marcy & Basri (1989). The estimated uncertainty depends to some extent on the value of $v \sin i$ as well as an intercomparison of the results from measurements of multiple spectra.

For most stars with $v \sin i \leq 8$ km s^{-1} the spectral types were determined by visual comparison. We used the method of Strassmeier & Fekel (1990), who identified several luminosity-sensitive and temperature-sensitive line ratios in the 6430–6465 Å region along with the general appearance of the spectrum as spectral-type criteria. In addition, for K dwarfs the strength of the wings of the saturated lines in this wavelength region is a very useful criterion. For the comparisons a variety of standards were used whose spectra were obtained with the same telescope-spectrograph-detector setup and had typical S/N ratios of 200 or greater. Many of the standards are listed by Strassmeier & Fekel (1990), although additional stars were observed, primarily from the list of Keenen & McNeil (1989). In our discussions the spectral types of the standards are from Keenan & McNeil (1989) unless otherwise noted. The vast majority of those standards have near solar iron abundances with most of the [Fe/H] values ranging from -0.2 to 0.2. Although we do not have a grid of metal-poor or metal-rich stars, observations of a few such stars have been obtained, necessitated particularly by our observation of some metal-poor binaries. When appropriate in our discussions, the metal abundances of our standards are noted. They have come from the extensive and extremely useful work of Taylor (1991, 1994), who has placed the abundances from numerous papers, most of which are also referenced in the compilation of Cayrel de Strobel *et al.* (1992), on a consistent scale and has computed mean abundance values and their associated errors.

In cases where the projected rotational velocity of a single star is greater than about 8 km s^{-1}, as well as for double-lined spectroscopic binaries, a visual comparison becomes difficult. Thus, the comparison spectra were created by a computer program developed by Huenemoerder & Barden (1984) and Barden (1985). For a single star the program simply rotationally broadens the lines of the chosen standard spectrum. For a binary the chosen standard spectra are appropriately summed and shifted while the lines are rotationally broadened. We note that, as the line broadening increases, classification becomes more difficult since modest line-strength changes are smeared out. In some of the most rapidly rotating stars the line profiles are modified by a reduced flux from cooler starspots. The spectrum of at least one star shows significant line asymmetries while in another the lines appear to have flat bottoms and are not as deep as in the appropriate standard.

For the vast majority of stars we estimate the uncertainty of our spectral classifications as one or sometimes two subclasses while our luminosity classes are uncertain by half a class. Discussed in Sec. 6 and flagged in Table 4 are a few cases where the uncertainties are greater. In several instances our spectral classes and/or luminosity classes are very different from those determined by Fleming *et al.* (1989) for their x-ray sources. We conclude that their types should be viewed with caution. Likewise, when compared with our standards, some of the metal-poor binaries appear to have metal abundances that are much closer to the solar value than the values found by Laird *et al.* (1988), which were repeated in Latham *et al.* (1988). Latham *et al.* (1988) noted some difficulties with their technique in determining the metallicities of

TABLE 4. Summary of properties.

Star	Spectral Type	P_{orb} (days)	Eccen.	v sin i (km s^{-1})	P_{phot} (days)	R_{min} ($R_\odot$)	Sync. Rotation	Rossby Number	Var. Mech.[a]
HD 7205	G8 V	SB	- - -	≤3	21.3	- - -	- - -	0.74	S
HD 17925	K2 V	SB:	- - -	≤3	6.85	- - -	- - -	0.18	S
HD 18632	K2 V	const	- - -	≤3	10.22	- - -	- - -	0.27	S
HD 18645	G2 III-IV	const	- - -	8	21.6	3.4	- - -	0.27	S
HD 22694A	K1 IV-V	8.65[b]	0.39[b]	7	7.17	1.0	no	0.13	S
B	K1 IV-V			7	- - -	- - -	- - -	- - -	-
HD 29697	K4 V	const:	- - -	7	3.936	0.5	- - -	0.09	S
HD 33363	K0 III	20.9	0.06	9	41.5	7.4	no	0.26	S
HD 39743	G8 III	83.1	0.18	8	73.1	11.6	pseudo	0.48	S
HD 51066	K0 III[b]	const	- - -	40[b]	16.2	12.8	- - -	0.10	S
HD 62668	K0 III	69.3	0.0	14	69.7	19.3	yes	0.43	S,Ec
HD 70573	G2 V:	const	- - -	11	3.296[c]	0.7	- - -	0.14	S
HD 72146	G8 III[b]	const	- - -	14	28.5	7.9	- - -	0.19	S
HD 72429	G2 IV:	const	- - -	16	9.37	3.0	- - -	0.18	S
HD 80953	K4 III	const:[b]	- - -	4	97	7.7	- - -	0.27	S
HD 82286A	K0: IV	SB	- - -	35:	3.270	2.3	likely	0.04	S
B	K0: IV			35:	- - -	- - -	- - -	- - -	-
HD 82443	K0 V	const	- - -	5	5.43	0.5	- - -	0.15	S
HD 85091A	F9 V	3.39[b]	0.0[b]	7	3.416	0.5	yes	0.53	S
B	K0: V			6:	- - -	- - -	- - -	- - -	-
HD 89546	G8 IV:	21.3	0.0	15	21.5	6.4	yes	0.30	S
HD 98800Aa	K5: V[b]	262[b]	0.48[b]	<11[b]	14.8	- - -	no	0.31	S
Ba	K5: V[b]	315[b]	0.78[b]	<11[b]	- - -	- - -	- - -	- - -	-
HD 99267	F1 V	const:	- - -	93	0.575[c]	1.1:	- - -	- - -	U
HD 112859A	K0 III	18.7	~0.0	17	18.5	6.2	yes	0.11	S
B	late F			≤6	- - -	- - -	- - -	- - -	-
HD 113816	K0 III	23.7	~0.0	5	23.5	2.3	yes	0.14	S
HD 118234	K1 III	59.1[b]	0.59[b]	5.5	64	7.0	no	0.36	S
HD 118981A	F9 V	14.5[b]	0.48[b]	7	5.94	0.7	pseudo	0.92	S
B	K0: V			7:	- - -	- - -	- - -	- - -	-
HD 122767	K3 III	1189[b]	0.87[b]	8	96	15.2	no	0.35	S
HD 131511	K1 V	125.4[b]	0.49[b]	4[b]	10.39	0.8	no	0.29	S
HD 141690Aa	G2 IV-V	4.67[b]	0.05[b]	17	4.64	1.5	pseudo	0.13	S,Ec
Ac	G5-8 V	SB[b]	- - -	≤6	- - -	- - -	- - -	- - -	-
HD 144110A	G8 V	1.67[b]	~0.0[b]	26	1.651[c]	0.85	yes	0.06	S
B	K1 V			22	- - -	- - -	- - -	- - -	-
HD 148127	K4 III	const:	- - -	4	13.8	1.1	- - -	0.04	S:
HD 148405	G6 III	52.5[b]	~0.0[b]	7	56.9	7.9	yes	0.39	S
HD 160934	K7 V	const:	- - -	13	1.842[c]	0.5	- - -	0.02	S
HD 171488	G2: V:	const	- - -	33	1.338[c]	0.9	- - -	0.06	S
HD 181475	K7 IIa[b]	const:	- - -	4:	31	- - -	- - -	- - -	P
HD 202951	K5 III	const:	- - -	4	21.6	1.7	- - -	0.06	S:
HD 203387	G6 III	const	- - -	6	68.0	8.1	- - -	0.47	S
HD 206301A	G2 IV	13.17	0.17	5	12.1	1.2	no	0.23	S
B	G2-5: V			4	- - -	- - -	- - -	- - -	-
HD 208472	G8 III	22.6	~0.0	21	22.54	9.4	yes	0.15	S
HD 223971A	G6 III	50.1[b]	0.0[b]	6	53	6.3	yes	0.37	S,Ec,El
B	late A			50:	- - -	- - -	- - -	- - -	-
HDE337518A	K0 V	2.73[b]	~0.0[b]	11	2.693[c]	0.6	yes	0.08	S
B	K3 V			11	- - -	- - -	- - -	- - -	-
BD −0°4234A	K2: V	3.76[b]	0.0[b]	7	4.03	0.6	yes	0.10	S
B	K5: V			6	- - -	- - -	- - -	- - -	-
BD +13°13A	G8 V	1.84[b]	0.0[b]	19	1.852[c]	0.7	yes	0.06	S
B	K5: V			14:	- - -	- - -	- - -	- - -	-
BD +30°2130	G1 IV-V	6.57[b]	0.0[b]	7	6.80	0.9	yes	0.21	S
BD +36°2193	G6 V	7.15[b]	0.0[b]	4	8.31	0.7	no	0.30	S
BD +48°3686	K1 V	const	- - -	16	2.42[c]	0.8	- - -	0.07	S
BD +70°959	K0 III[b]	const	- - -	19[b]	14.24	5.3	- - -	0.09	S
1E2349.8−0112	G5: V	const	- - -	41	1.145[c]	0.9	- - -	0.04	S
Wa Tau 1A	K0 V	SB	- - -	16	1.487[c]	0.5	likely	0.04	S
B	K3 V			16	- - -	- - -	- - -	- - -	-

Notes to TABLE 4

[a]Ec = eclipse, El = ellipticity, P = pulsation, S = spots, U = unknown

[b]Value from literature, see individual-star discussion

[c]More than one possible period, see individual-star discussion

: = A more uncertain quantity, see individual-star discussion

SB = spectroscopic binary of unknown period

const = constant velocity

double-lined binaries with similar components. Those problems, however, are not the source of the discrepancies, since we have analyzed only one such binary.

5. SUMMARY OF STELLAR PROPERTIES

Table 4 summarizes for each star the results of our spectroscopic analyses as well as properties derived from our photometry and spectroscopy. Although the vast majority of information in this table comes from our present work, in some cases values from the literature are given and referenced. Quantities somewhat more uncertain than the rest are identified by a colon; the reader should refer in such cases to the discussion of the individual star. Column 1 lists the system names with individual binary components identified if more than one component has been detected spectroscopically. Spectral types for the stars are given in column 2. Column 3 lists the known orbital period of each system or identifies a star as having a constant velocity, indicating that the star is single. In some cases our conclusion about velocity constancy is a combination of our results and those from the literature. If no orbital period is known but the star has a definitely variable velocity or double lines have been detected in its spectrum, it is listed as SB. If it is known, the orbital eccentricity is given in column 4. For several of our systems the eccentricity is listed as approximately zero when the formal value is quite small, generally ≤ 0.03, but complete phase coverage of the orbits has not yet been obtained. Results of our $v \sin i$ measurements are listed in column 5, in a few cases as upper limits. Photometric periods from Table 3 are given again in column 6. All but two, those for HD 99267 and HD 181475, are starspot periods and hence are assumed to be rotation periods. The minimum radius computed, when appropriate, from the values of the previous two columns is given in column 7. In column 8 we have compared the orbital and rotation periods of the binaries and determined which stars are rotating synchronously, pseudosynchronously, or nonsynchronously. In column 9 we compute the Rossby number, as discussed below, for each spotted star while the mechanisms of variability are summarized in column 10.

Because we conclude that most of the stars vary as a result of rotational modulation of a late-type, hence convective, star whose photospheric surface is mottled by dark patches called starspots, the Rossby number, the ratio of rotation period to convective turnover time, has been computed for those stars. Hall (1991, 1994) has shown that a Rossby number $\lesssim 0.65$ is required for a star to have large spots and hence be significantly variable (greater than about 0.01 mag) by rotational modulation. The $B-V$ color index appropriate for the observed spectral type in column 2 is used to get the convective turnover time for a main-sequence star of that color (Gilliland 1985), which is then scaled up by a factor depending on the observed luminosity class (Hall 1991, 1994). The rotation period comes from column 6. In cases of composite spectra and dissimilar components, the spectrum of the primary star is used. No Rossby number is given for two stars almost certain not to be starspot variables (HD 99267 and HD 181475) but is given for two single late-K giants (HD 148127 and HD 202951) that might be. The photometric variability we find is in virtually perfect accord with the $R_0 \lesssim 0.65$ threshold. For HD 118981, $R_0 = 0.92$ but its photometric amplitude of 0.009 mag is right at the level of significance. For HD 7205, $R_0 = 0.74$, on the wrong side of the threshold by only a hair, but its amplitude of 0.03 mag is relatively small.

The mechanism for variability in two stars requires some discussion. HD 148127 and HD 202951 are single K-type giants with surprisingly short photometric periods. Post-main-sequence evolution should result in dramatic slowing of rotation due to the combined effect of angular momentum conservation and magnetic braking (Gray 1989). If the variability is attributed to spot modulation and the photometric period is identified as the rotation period, the rotation period is easily short enough that the star's Rossby number should make large spots a virtual certainty. The short rotation period itself, however, remains a problem to understand. The only other mechanism for variability in single K-type giants that we can think to consider is pulsation, but Percy (1993) and Hall (1995) recently reviewed this question and concluded that there is no significant evidence that the pulsation mechanism seen in single M-type giants extends to the K-type giants. For these two stars, therefore, we have presumed the photometric period to be the rotation period, computed the Rossby number, entered "*S*" (for spots) as the mechanism, but added a colon to indicate our dilemma.

Of the 47 stars discussed in this paper, the following six have previously been discovered as variables: HD 17925=EP Eri, HD 29697=V834 Tau, HD 98800, HD 223971, BD +13°13, and BD +70°959=ET Dra. In two of those cases our new observations turn out to be extremely valuable. For HD 29697 we find that the previously announced photometric period is an alias of the true period while for HD 233971 we have discovered two additional mechanisms of variability. Of the 47 stars only V834 Tau, HD 62668, HD 131511, and BD −0°4234 have NSV numbers in the *New Catalogue of Suspected Variable Stars* (Kukarkin *et al.* 1982). Although the mechanism for variability in the vast majority of cases is rotational modulation of a spotted surface, other types of variability have also been found. In addition to starspots HD 62668, HD 141690, and HD 223971 have eclipses while HD 223971 also shows the ellipticity effect. We presume that HD 181475 is a late-type bright giant pulsating variable, while HD 99267 seems to be a newly found member of the puzzling group of F0 V variables (e.g., Krisciunas 1994; Hall 1995). As noted above, we presume that the mechanism of variability for HD 148127 and HD 202951 is a spotted rotating surface rather than pulsation.

Our previous papers discussing photometry of chromospherically active stars have emphasized binaries. However, of the 47 stars analyzed in the present work, a substantial number of spotted variables, 16 (34%), are single and this total includes 7 dwarfs and 9 giants (Table 4). Some of the single giants are newly identified members of a small group of stars whose rapid rotation is suggested to have come from the transfer of core angular momentum (see Fekel & Balachandran 1993). Fekel & Eitter (1989) and Hall & Henry

(1990) showed that the vast majority of chromospherically active binaries are synchronously rotating. We have discovered four systems, HD 22694, HD 33363, HD 206301, and BD +36°2193, with orbital periods less than 21 days whose rotation is neither synchronized nor pseudosynchronized, a rather unusual circumstance.

Fekel *et al.* (1994) updated Hall's (1986) initial list of chromospherically active stars that are in eccentric orbits and pseudosynchronously rotating (Hut 1981). In addition to HD 39743, which was included in Fekel *et al.* (1994), we have identified (Table 4) HD 118981 and HD 141490 as pseudosynchronous rotators, increasing the total of such systems to seven.

The discussions and results of this paper shed significant light on some of the candidate stars listed in *CCABS II.* HD 18645, HD 51066, and HD 72146 are single stars that do not qualify for inclusion in *CCABS* while HD 7205, HD 62668, HD 118234, HD 148405, and HDE 337518 should be promoted to full-fledged membership.

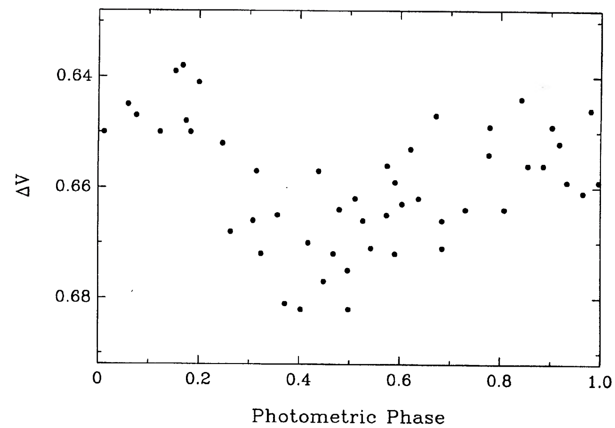

FIG. 2. Light curve of HD 7205 plotted against photometric phase calculated from the ephemeris HJD 2449200.0+21.3E. The amplitude in V is 0.03 mag.

6. DISCUSSION OF INDIVIDUAL STARS

6.1 HD 7205

One of Bidelman's (1985a) objective-prism discoveries was the weak Ca II emission in the spectrum of HD 7205. In addition he classified the spectrum Gp and noted that it was slightly weak lined. Halliwell (1979) had previously suggested that the star was in the local neighborhood. Sandage & Kowal (1986) obtained UBV photometry of it as part of a survey of high proper-motion stars while Olsen (1993) obtained $V=7.254$, $b-y=0.482$, and $c_1=0.339$ from Strömgren photometry. From a half-dozen Reticon spectra, Fouts (1987) identified HD 7205 as a single-lined spectroscopic binary but found no orbital period. Strassmeier *et al.* (1993) listed the star as a candidate in *CCABS II.*

We have one season of photometric data for HD 7205. Periodogram analysis was performed on a portion of the V data that had the most coherent light variation, roughly the middle two-thirds of the observing season. The resulting rotation period is $P=21.3\pm0.4$ days. An identical analysis of the B data gave the same period. The V data plotted against the 21.3 day period show an amplitude of 0.03 mag (Fig. 2). Though long, this period is not the longest known rotation period for a chromospherically active dwarf. From seven observations Dorren & Guinan (1982) claimed the K5 V star 61 Cyg A has modest photometric variations of a few hundredths of a magnitude on a time scale consistent with the 37 day period found by Vaughan *et al.* (1981) for its Ca II H and K flux variations.

Our three red-wavelength spectroscopic observations of this star have a velocity range of 25 km s^{-1}. From similar observations Stockton & Fekel (1992) detected the secondary of three of the binaries for which Fouts (1987) presented orbits; however, we detect no secondary features in our spectra of HD 7205. A visual comparison of its spectrum with those of our standards results in a classification of G8 V. The lines have little or no rotational broadening, with $v \sin i \leq 3$ km s^{-1}. Such a low $v \sin i$ is consistent with the rather long photometric period that we have determined for this dwarf. Additional spectroscopic observations are being obtained to determine its orbital elements.

6.2 HD 17925=HR 857=EP Eri

HD 17925 has been cited in more papers than any of the other 46 stars in our paper. It is of particular interest as a very nearby (8 pc away), very young (a few million years old) K-type dwarf with a high lithium abundance and Ca II H and K emission (Cayrel de Strobel & Cayrel 1989). Spectral types in the literature range from K0 V to K3 V. The Ca II H and K emission was first noted by Joy & Wilson (1949), with the best portrayal found in Pasquini *et al.* (1988), who characterize it as strong. This strong emission, indicative of chromospheric activity, was what persuaded us to place this star on our program. It is the suspected variable NSV 975 (Kukarkin *et al.* 1982), with Golay (1973) first listing it as a possible variable, though with no range indicated, and Petit (1990) later specifying a suspected range of 0.06 mag in V and a variability type of BY. Differential photometry by Blanco *et al.* (1979) did not indicate significant variability. At almost the same time that we began observing it, Cutispoto (1992) presented differential $UBVRI$ photometry that did show definite variability, with a range of 6.03–6.08 mag in V. From those data he suggested a tentative period of 6.5 days. His range is consistent with the 0.08 mag range seen in our Table 2 and his period is consistent with the rotation period deduced from modulation of Ca II K emission intensity, 6.9 days according to Vaughan *et al.* (1981) or 6.6±0.1 days according to Baliunas *et al.* (1983). The well-determined $v \sin i$ values reported in the literature are somewhat conflicting, ranging from 3.3 (Benz & Mayor 1984) to 8.1 km s^{-1} (Cayrel de Strobel & Cayrel 1989). The *Bright Star Catalogue* (Hoffleit 1982) lists its radial velocity as variable but the only evidence of velocity variability that we could find in the literature is one discrepant velocity from a low-dispersion spectrogram obtained by Popper (1942). The more recent and numerous velocities of Beavers & Eitter (1986) and Young *et al.* (1987) show no evidence of variability while from four CORAVEL-type velocities Tokovinin

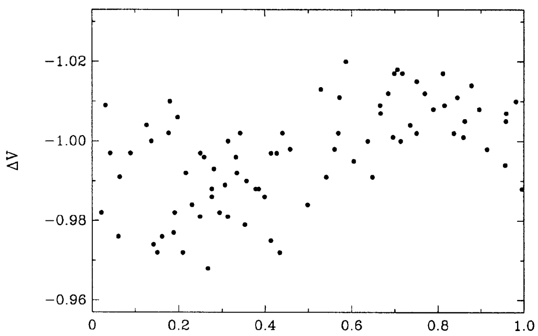

FIG. 3. Light curve of HD 17925 plotted against photometric phase calculated from the ephemeris HJD $2449200.0+6.85E$. The amplitude in V is 0.03 mag.

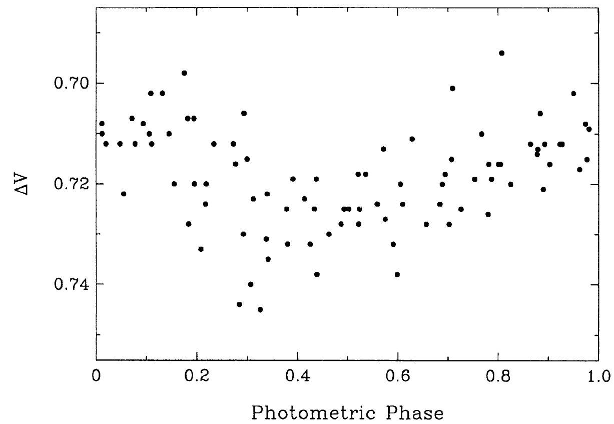

FIG. 4. Light curve of HD 18632 plotted against photometric phase calculated from the ephemeris HJD $2449200.0+10.22E$. The amplitude in V is only 0.02 mag.

(1992) judged it single. The weighted-mean trigonometric parallax from the new edition of the *Yale Parallax Catalogue* is 0.″100±0.″002 (*s.e.*) (van Altena 1995). The 72nd Name List of Variable Stars (Kazarovets & Samus 1995) has assigned it the designation EP Eri and variability type "RS."

We have two seasons of photometry for HD 17925. Periodogram analysis of the first season's data gives the rotation period $P=6.85\pm0.03$ days, confirming the tentative period found by Cutispoto (1992). Those data are plotted versus the rotation period in Fig. 3 and reveal an amplitude of approximately 0.03 mag. The light curve for the second season looks much like the first.

Consistent with the photometric activity we note that the Hα line of HD 17925 is partially filled by emission. Visual examination of our red-wavelength spectra results in a K2 V spectral type, which is identical to that determined by Wilson (1962). Our eight observations of HD 17925 result in a mean velocity of 18.1±0.02 km s^{-1}. Such an average velocity is in good agreement with that of Beavers & Eitter (1986), who obtained 18.8±0.3 km s^{-1} from 22 observations. We found $v \sin i=5.7\pm1$ km s^{-1} from four different spectra obtained in 1991 November but measured $v \sin i\leqslant3$ km s^{-1} from four additional spectra obtained in 1994 November. While our 1991 value might be considered consistent with the values of 8.1 km s^{-1} (Cayrel de Strobel & Cayrel 1989), 7.6 km s^{-1} (Tokovinin 1990), and 8 km s^{-1} (Basri & Marcy 1994) determined by other observers, our more recent value is distinctly different and similar to the value of 3.3 km s^{-1} found by Benz & Mayor (1984). The linewidth variations suggest that HD 17925 is an unresolved double-lined spectroscopic binary with nearly equal components, which may have an orbital period of months or years. Support for the binary hypothesis comes from the rotation period which, combined with a value of $v \sin i=8$ km s^{-1}, results in a *minimum* radius of 1.08 $R_\odot$, significantly too large for a K dwarf. If instead, a radius of 0.85 $R_\odot$ more appropriate for a K dwarf is assumed, the resulting rotational velocity is 6.3 km s^{-1}. If $v \sin i=3$ km s^{-1}, the rotational inclination is about 30°. The trigonometric parallax results in $M_v=6.0\pm0.04$ mag. A comparison with canonical values for a K2 dwarf, 6.3 mag (Corbally & Garrison 1984) or 6.5 mag (Gray 1992), indicates that our value from the parallax is somewhat larger. While it is in the direction predicted by our binary hypothesis, it is not conclusive. Thus, although the discordant $v \sin i$ measurements are strongly suggestive and the trigonometric parallax is supportive, speckle and/or new radial-velocity observations will be needed to confirm HD 17925 as a binary.

6.3 HD 18632

Fleming *et al.* (1989) identified HD 18632 with the x-ray source 1E0257.4+0733. They concluded that it is an apparently single G6 III with $v \sin i<10$ km s^{-1}. Earlier, G. P. Kuiper (Bidelman 1985b) had classified it K1. Favata *et al.* (1993) estimated an upper limit to its lithium abundance. Additional information was provided by Favata *et al.* (1995), who found $v \sin i=11$ km s^{-1} from the same spectrum and concluded that the known parallax of 0.″034 (van Altena 1995) clearly identifies the star as a dwarf. The combination of the spectral type and x-ray nature of this star led us to examine it further.

We have one season of photometry for HD 18632. Periodogram analysis of the V data finds the rotation period $P=10.22\pm0.05$ days. The data plotted in a phase curve with this period appear in Fig. 4, where the amplitude is seen to be only 0.02 mag. The identical period, within the uncertainties, was found in the B data. The relatively coherent phase curve, despite the small amplitude, suggests a fairly stable spot distribution on the star during the nearly 200 day observing season.

The velocities from our two spectra are almost identical and give an average of 28.3 km s^{-1}, supporting its classification as a constant-velocity star (Fleming *et al.* 1989). We find $v \sin i\leqslant3$ km s^{-1}, consistent with the upper limit of 10 km s^{-1} found by Fleming *et al.* (1989) but significantly less than that of Favata *et al.* (1995). From a visual examination of the red spectrum of HD 18632, it is obvious that the saturated lines have significant wings, making the star a dwarf. Its critical line ratios and the general appearance of its spectrum are very similar to that of HD 17925, the star in the preceeding discussion, and so we classify it as K2 V. The trigonometric parallax of 0.″034±0.″016 (*m.e.*) (van Altena

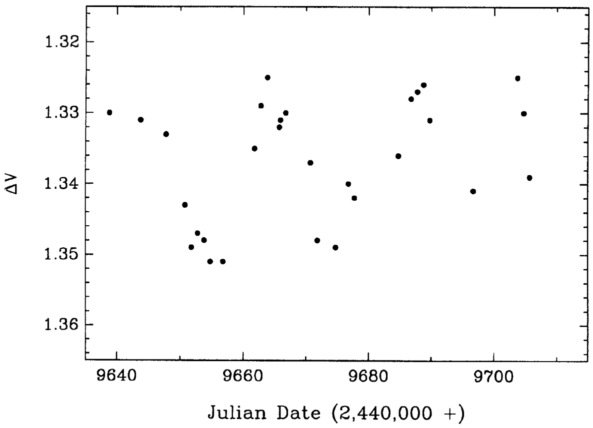

FIG. 5. Light curve of HD 18645 plotted against Julian date. The photometric period is 21.6 days, and the amplitude in V is only 0.02 mag.

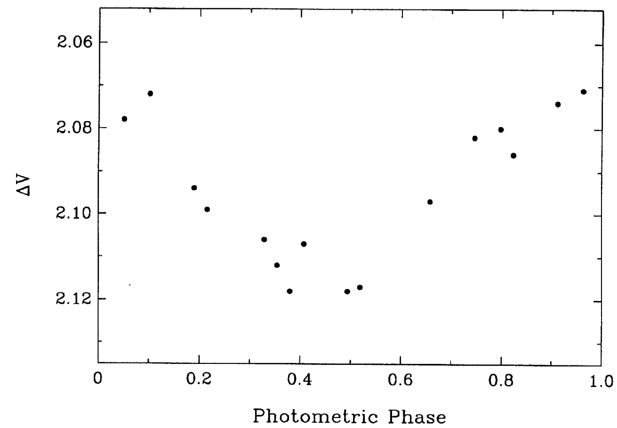

FIG. 6. Light curve of HD 22694 plotted against photometric phase calculated from the ephemeris HJD $2449200.0+7.17E$. The amplitude in V is 0.04 mag.

1995) and $V=7.95$ from Table 2 result in $M_v=5.6\pm1.0$ mag. As recently pointed out by Favata *et al.* (1995), such a value is consistent with a dwarf rather than the giant classification of Fleming *et al.* (1989).

6.4 *HD 18645*

From an examination of objective-prism plates Bidelman (1991) reported the detection of Ca II H and K emission features in the spectrum of HD 18645. Thus, it was added as a candidate in *CCABS II*. Duflot & Rebeirot (1966) classified it G2 III and found an average velocity of -9 km s^{-1} from four objective-prism spectra. Preliminary results for this star were given by Fekel & Balachandran (1994), who list it as a single G5 IV star with $v \sin i=9$ km s^{-1} and a log lithium abundance of less than 1.0.

Our photometric data from the last of three observing seasons are plotted in Fig. 5. Periodogram analysis of those data gives $P=21.6\pm0.6$ days for its period of rotation. The amplitude of variability is a very modest 0.02 mag. The first two observing seasons give similar results, except that some additional long-term variability is seen in the first season.

Here we give a more extensive account of our spectroscopic results than in Fekel & Balachandran (1994). From ten spectra we determine a constant velocity of 2.61±0.05 km s^{-1}. We slightly revise its $v \sin i$ to 8±1 km s^{-1}. In the 6430 Å region an appropriately broadened spectrum of 84 Her (G2 IV, Strassmeier & Fekel 1990) provides a better fit to the spectrum of HD 18645 than μ Her A (G5 IV). The weak Hα wings suggest an intermediate III–IV luminosity classification and so we classify it G2 III–IV. The core of the Hα line is partially filled by emission. With $v \sin i=8$ km s^{-1} and a rotational period of 21.6 days the minimum radius of the star is 3.4 $R_\odot$, quite consistent with a luminosity class of IV or III–IV.

6.5 *HD 22694*

In the course of a spectroscopic survey of high proper-motion stars, Latham *et al.* (1992) discovered that HD 22694 is a double-lined binary with a period of 8.65 days and a significant eccentricity of 0.39. Following the precepts of Carney *et al.* (1987), they also determined a metallicity [m/H]=-1.02 indicating that the system is rather metal poor. Pasquini & Lindgren (1994) found strong Ca II K line emission and a filled Hα line, identifying it as a chromospherically active binary. The relatively short orbital period, calcium emission, and 0.09 mag range in V (see Table 2) all indicate that this system should have photometric variability.

We have obtained two years of photometry for HD 22694. Periodogram analysis of the first year gives $P=7.17\pm0.02$ days. The second year gives the same result within the errors. Figure 6 shows the phase curve plotted with this period but with data restricted to the Julian-date range of 2449403–2449427, when the light curve showed the most coherent variation. The amplitude was then about 0.04 mag. The observed rotation period is quite different from the pseudosynchronous period (Hut 1981) of 4.30 days.

Our lone red-wavelength observation shows that the line strengths of the two components are similar and both sets of lines are relatively narrow. As a result, it was thought that the spectral classification would be straightforward. A visual comparison with our standards indicated approximate spectral types between K0 V and K2 V for both components. A more thorough analysis, however, resulted in contradictions. Surprisingly, spectrum addition with σ Dra (K0 V), which has [Fe/H]=-0.04 ± 0.08 (Taylor 1994), used for both components resulted in a reasonable fit to most line depths while the critical line ratios suggested a slightly later spectral class. A fit with ϵ Eri (K2 V), which is slightly metal poor with [Fe/H]=-0.20 ± 0.06 (Taylor 1994), produced line depths that are slightly too strong as well as line wings that are too strong. This suggests that the stars either are modestly evolved or, if they are really dwarfs, have slightly earlier spectral classes than ϵ Eri. Reasonable fits to the line strengths with the spectra of stars having such abundances appear to be in direct conflict with the very significant metal depletion of -1.02 found by Latham *et al.* (1992). The $v \sin i$ of 7±1 km s^{-1} for each component combined with our rotation period results in a minimum radius of 0.99 $R_\odot$, significantly too large for a K dwarf. Unfortunately, we have no significantly metal-poor subgiant or early-K dwarf stan-

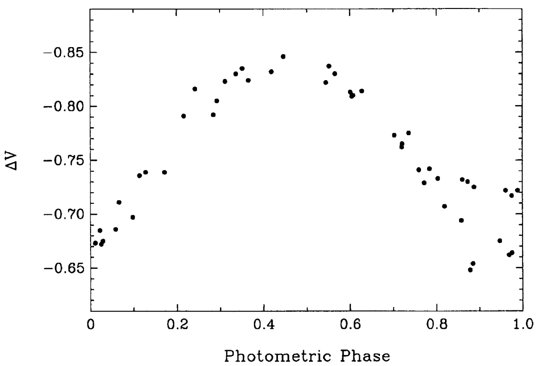

FIG. 7. Light curve of HD 29697 plotted against photometric phase calculated from the ephemeris HJD $2449600.0+3.936E$. The amplitude in V is 0.17 mag.

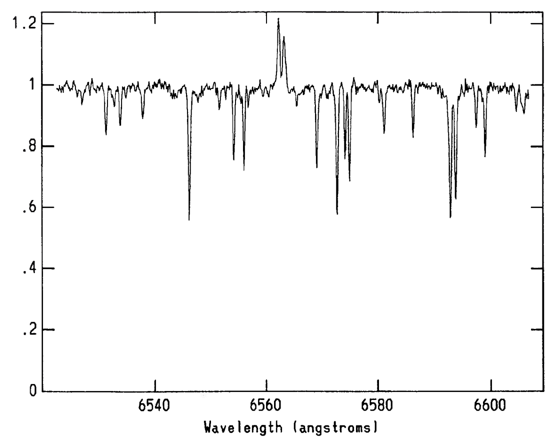

FIG. 8. A portion of the spectrum of HD 29697 in the Hα region with relative intensity plotted vs rest wavelength. While the core of Hα is in emission, the line wings have also been filled by emission.

dards for comparison. Thus, although approximately correct, our preliminary classification of the components, K1 IV–V for each, should be treated with some caution.

Besides our spectrum-addition results that suggest solar abundances, other properties indicate that HD 22694 is not an old system but rather the opposite. The U, V, W velocities computed by Latham *et al.* (1992) are each quite small and stand out when compared with the velocities of the other stars listed in their Table 1. Pasquini & Lindgren (1994) showed that the Ca II K emission of the system is strong, with its combined emission rising above the continuum. Despite an orbital period less than 10 days, the orbit is very eccentric. Also, our observed rotation period of 7.17 days is very different from the computed pseudosynchronous period of 4.30 days. All of the above properties are unexpected for a system presumed to be significantly older than the Sun. Instead, they are consistent with a much younger system. Additional observations will be needed to determine if this system is a ZAMS or perhaps even a pre-main-sequence binary.

6.6 HD 29697=V834 Tau

Young *et al.* (1989) had noted its exceptionally strong Ca II H and K emission and, from that, suggested that HD 29697 was probably an undiscovered binary with a short orbital period. This resulted in its inclusion as a candidate in *CCABS II*. However, Fouts & Sandage (1986) had already concluded that HD 29697 has a constant velocity. It turns out that Young *et al.* (1989), Strassmeier *et al.* (1993), and we ourselves had overlooked the fact that the variability had already been discovered by Chugainov (1981) and also that the designation V834 Tau as a variable of the BY Draconis type was already assigned, in The 67th Name List of Variable Stars (Kholopov *et al.* 1985). The variability observed by Chugainov (1981) had a range of 0.12 mag in V except for one night when its magnitude was about 0.25 mag fainter. From his data he found a possible photometric period of 1.3290 days. A value of 4.0 days for the rotation period can be found in Marilli *et al.* (1986), who cited a private communication from R. G. M. Rutten, and in Rutten (1986), who cited a private communication from A. M. van Genderen and four other individuals, but we have been unable to learn the real source of this determination. There seems to be agreement on the spectral type. The predominant classification found in the literature is K3 V. The star is a nearby neighbor having a trigonometric parallax of 0".074 (van Altena 1995). Given the range of variability observed by Chugainov (1981), it is perhaps a bit surprising that the values in our Table 2 show such a small range, only 0.03 mag in V. We note that the $B-V$ of Upgren & Lu (1986), listed in Table 2, is out of line with the others and may be an error.

For HD 29697, periodogram analysis of the second of our two seasons of photometry results in $P=3.936\pm0.003$ days. The phase curve for those data is plotted in Fig. 7. The amplitude of the light curve is approximately 0.17 mag and is rather large for a dwarf. The observed scatter between photometric phases 0.8 and 1.0 indicates some cycle-to-cycle variation over the course of the second observing season. Similar behavior having the same period was observed during the first observing season but with a somewhat smaller amplitude. The larger amplitude in the second season resulted from a further decrease in the brightness at minimum. In both seasons the suggested period of Chugainov (1981) is seen as an alias.

From three spectroscopic observations we obtain an average radial velocity of 1.1 ± 0.2 km s^{-1}. This average velocity is 6 km s^{-1} less than the value obtained by Fouts & Sandage (1986), who concluded from 20 observations that HD 29697 has a constant velocity. A comparison of the center-of-mass velocities of three binaries observed by both Fouts (1987) and Stockton & Fekel (1992) shows velocity differences of less than 2 km s^{-1} in each case. Thus, a velocity difference of 6 km s^{-1} for HD 29697 may reflect a real but perhaps long-term variation. A visual comparison of our HD 29697 spectrum with several K dwarf standards shows that many of its lines in the 6430 Å region have strong wings, so we have classified it K4 V, in good agreement with the K3 V classification of Wilson (1962). Similar to the results of Rutten *et al.* (1989) our spectrum of Hα shows that HD 29697 has modest emission above the continuum (Fig. 8). Our emission equivalent width above the continuum is 0.2 Å compared to

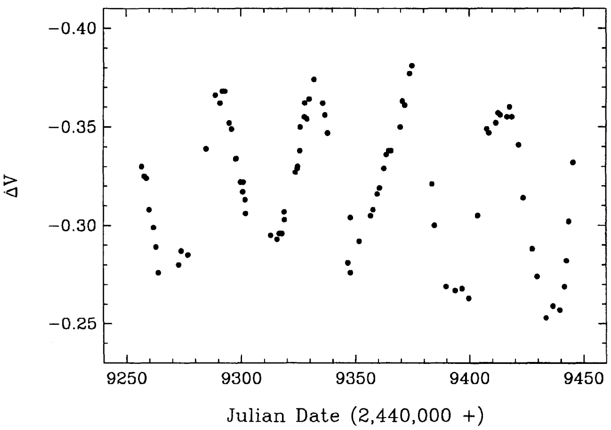

FIG. 9. Light curve of HD 33363 plotted against Julian date. The photometric period is 41.5 days, and the amplitude in V is 0.12 mag.

0.33 Å found by Rutten *et al.* (1989). From three spectra we determine $v \sin i = 7 \pm 1$ km s^{-1}. This rotational velocity combined with the rotation period results in a minimum radius of 0.54 $R_\odot$, which leads to a rotational inclination of about 50°.

As might be anticipated from the evidence of strong chromospheric activity, the lithium line is visible and has an equivalent width of 79 mÅ. The combination of strong chromospheric activity, significant rotation, and detection of the lithium line indicates that the star is quite close to the ZAMS. To compare this field star with the lithium abundances of similar cluster stars in the Pleiades (Soderblom *et al.* 1993a), we assume an effective temperature of 4450 K, which from their Table 2 results in a log lithium abundance of 0.95. Such a modest abundance is quite compatible with Soderblom *et al.*'s (1993a) lithium values of mid-K stars, implying that HD 29697 has an age similar to the Pleiades.

6.7 HD 33363

Until Bidelman's (1991) detection of Ca II H and K emission in HD 33363, the limited information known about this star suggested that it was unremarkable. From a high-dispersion spectrogram Strassmeier (1994) recently confirmed that the H and K emission is relatively strong. Because of its emission features and the detection of velocity variability from our initial spectra, it was added to *CCABS II.* Several of the preliminary results stated in *CCABS II* were given by Fekel & Balachandran (1994), who classified it as a K0 III binary with $v \sin i = 9$ km s^{-1} and also noted that it has relatively little lithium. As part of an extensive Strömgren-photometry survey of G5-type HD stars, Olsen (1993) obtained $V = 7.55$, $b - y = 0.682$, and $c_1 = 0.324$.

Two seasons of photometric data and part of a third were obtained in our survey. The second season is plotted in Fig. 9. Periodogram analysis gives a rotation period $P = 41.5 \pm 0.2$ days while the range in brightness is 0.12 mag. The first season gives a similar period and amplitude. As can be seen in Fig. 9, there are slight cycle-to-cycle variations in maximum and minimum brightness. This is also true in the first season, and there may also be some long-term brightness variation over the 2.5 yr timespan of our photometry.

High-dispersion spectroscopic observations at red wavelengths show that the star is a single-lined spectroscopic binary. Our preliminary orbital period is 20.9 days while the eccentricity is 0.06, making the orbit almost circular. Such an orbital period is only one-half the rotation period, a highly unusual circumstance among chromospherically active binaries. In fact, of the 94 binaries with orbital periods less than 30 days that were listed in *CCABS I*, Fekel & Eitter (1989) found only 7% were asynchronously rotating. Such very different rotational and orbital periods suggest it may be in the same kind of evolutionary state as the well-known asynchronous rotator λ And, whose rotation period is also much longer than its orbital period, 54.0 vs 20.5 days. Measurement of additional spectra confirms the $v \sin i$ of 9 ± 1 km s^{-1} determined by Fekel & Balachandran (1994). An appropriately broadened spectrum of β Gem (K0 III) provides a very good fit to that of HD 33363. The measured $v \sin i$ and rotation period result in a minimum radius of 7.4 $R_\odot$, quite consistent with our luminosity classification. The Hα absorption feature of HD 33363 appears to be slightly filled in by emission.

6.8 HD 39743 = HR 2054

Bidelman (1983a) detected the fairly strong Ca II H and K emission of HD 39743. As a result, it was placed on the spectroscopic observing program at the David Dunlap Observatory where detection of its leisurely velocity variations suggested an orbital period of at least a month (Lyons 1988). Our additional observations led to the preliminary orbital elements (e.g., $P = 83.2$ days, $e = 0.18$) that are listed in *CCABS II.* Its moderately strong Ca II H and K emission is shown by Strassmeier (1994). Halliday (1955) and Fekel & Balachandran (1994) classified the star G8 III. The latter also found $v \sin i = 9$ km s^{-1} and a moderate log lithium abundance of 1.2. The F8 III classification listed by Dempsey *et al.* (1993) is presumably a misprint.

We have two full seasons of photometry and parts of two others for HD 39743. The observations for the first full season are plotted in Fig. 10. Periodogram analysis for this first season gives a period of 73.1±0.6 days, and the amplitude of variability is 0.17 mag. The amplitude is only about half that value in the other seasons. Figure 10 shows a pronounced asymmetry near the brightness maxima for the first season, indicating the presence of more than one spotted area. Light curves during the following two seasons reveal that the asymmetry developed into a shallow secondary minimum.

We continue to obtain spectroscopic observations of this single-lined binary to refine its orbital elements. Our present values of the period and eccentricity (Table 4) are only slightly different from the preliminary values given in *CCABS II.* A visual reexamination of red-wavelength spectra confirms Fekel & Balachandran's (1994) spectral type of G8 III, a type in complete agreement with that of Halliday (1955). From analysis of additional spectra, we find $v \sin i = 8 \pm 1$ km s^{-1}, slightly less than that of Fekel & Balachandran (1994). The $v \sin i$ and rotation period result in a mini-

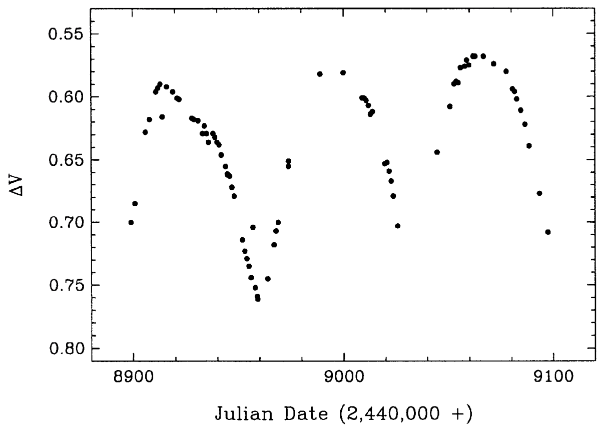

FIG. 10. Light curve of HD 39743 plotted against Julian date. The photometric period is 73.1 days, and the amplitude in V is 0.17 mag.

mum radius of 11.6 $R_\odot$, which is consistent with our luminosity classification. From our preliminary orbital elements, the pseudosynchronous rotation period (Hut 1981) is 69.5 days, within 5% of the observed rotation period. In Fekel *et al.*'s (1994) update of Hall's (1986) list, HD 39743 was identified as a fifth chromospherically active binary with one component as a pseudosynchronous rotator.

6.9 HD 51066

Table 1 of Fleming *et al.* (1989) lists HD 51066 as the optical counterpart to the x-ray source 1E0657.6+7529. They concluded it is an apparently single star, classified it K1 V, and found $v \sin i = 43$ km s^{-1}. Additional information on its x-ray properties is given by Stocke *et al.* (1991). From an examination of objective-prism spectra Bidelman (1991) found HD 51066 to have Ca II H and K emission. As a result, it became a candidate in *CCABS II.* From a high-dispersion spectrum Strassmeier (1994) noted that the H and K emission features each have a central absorption feature, presumably of interstellar origin, implying that the star is a giant. Fekel & Balachandran (1994) identified it as a single K0 III star with $v \sin i = 40$ km s^{-1} and a significant log lithium abundance of 1.5. Olsen (1993) observed it in the Strömgren system and obtained $V = 6.956$, $b - y = 0.614$ and $c_1 = 0.432$.

Two full seasons of photometric data for HD 51066 were obtained in our survey. The observations for the 67 day interval Julian date 2449407 to 2449474, which displayed the best cycle-to-cycle coherence in the data set, are plotted in Fig. 11. Periodogram analysis of those data gives $P = 16.2 \pm 0.3$ days. The observed amplitude, at a maximum during this interval, is 0.05 mag. Significant cycle-to-cycle changes in amplitude are observed over the rest of the data set and longer-term brightness variations are also present.

Eight spectra obtained at KPNO between 1991 November and 1993 April indicate that the star has a constant velocity of -21.1 ± 0.4 km s^{-1}. The results of Fekel & Balachandran (1994), $v \sin i = 40 \pm 2$ km s^{-1} and spectral type K0 III, have not been superseded. The Hα absorption feature of HD 51066 is somewhat filled by emission. While the $v \sin i$ is in

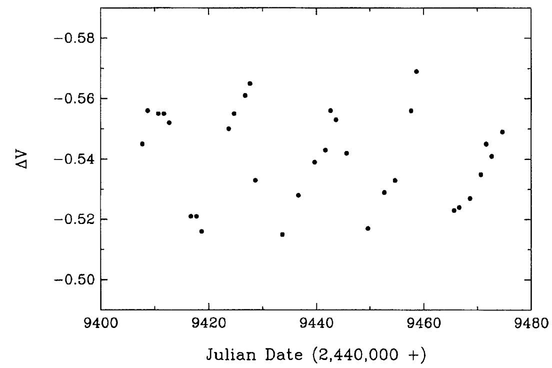

FIG. 11. Light curve of HD 51066 plotted against Julian date. The photometric period is 16.2 days, and the amplitude in V is 0.05 mag.

excellent agreement with that of Fleming *et al.* (1989) and we confirm the star is single, we classify it a giant rather than a dwarf, in agreement with the suggestion of Strassmeier (1994). The combination of our $v \sin i$ value and photometric period results in a minimum radius of 12.8 $R_\odot$, consistent with the giant classification and incompatible with the dwarf classification of Fleming *et al.* (1989).

Although this candidate in *CCABS II* should be dropped from future editions of the catalog, it is, nevertheless, a star of particular interest. HD 51066 is a newly identified member of a small group of moderately rapidly rotating chromospherically active *single* giants (Fekel & Balachandran 1993). The rapid rotation and relatively high lithium abundance of many of those stars is suggested to come from the transfer of angular momentum from a rapidly rotating core as opposed to the binary coalescence scenario suggested for FK Comae (Bopp & Rucinski 1981; Bopp & Stencel 1981). The large rotational broadening makes it a candidate for Doppler imaging.

6.10 HD 62668

The impetus for our work on this interesting system was the report of Bidelman (1991) that the spectrum of HD 62668 shows Ca II H and K emission. As a result of that detection, it was listed as a candidate in *CCABS II.* Working at Sonneberg Observatory, Hoffmeister (1949) claimed it as a new variable star with a range in photographic magnitude of 8.3–8.9 and a possible moderate period. The *New Catalogue of Suspected Variable Stars* (Kukarkin *et al.* 1982) references this work, gives it the designation NSV 3726, and classifies it as type *L*:, where "*L*" means "slow irregular variable" and ":" means "possible." The SIMBAD data base, apparently translating this information, lists HD 62668 as a pulsating variable. Although we discovered the system to have two types of variability, neither is the result of pulsations. As Table 2 shows, we could find no published *UBV* photometry.

We have been observing HD 62668 photometrically for two seasons. Its light curve shows rotational variability with an amplitude of 0.23 mag in the first season but only about 0.05 mag in the second season. In addition, eclipses of the otherwise unseen (presumably hotter) spectroscopic companion are easily detectable and are approximately 0.08 and 0.15

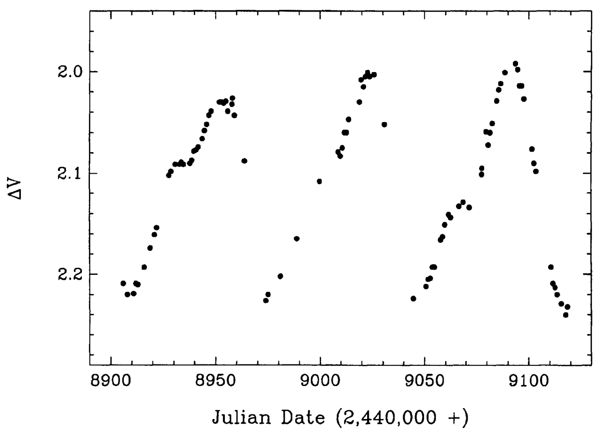

FIG. 12. First season light curve of HD 62668 plotted against Julian date with the few eclipse points not plotted. The photometric period is 69.7 days, and the amplitude in V is 0.23 mag.

mag deep in V and B, respectively. The data from the first observing season, excluding the few eclipse points, are plotted in Fig. 12. The distinctly asymmetric shape of the light curve indicates two spotted areas at different longitudes. Periodogram analysis of those data gives the rotation period $P=69.7\pm0.5$ days. Data from the second season are plotted against orbital phase in Fig. 13, where eclipses of the hotter companion are seen at phase 1.0 and have a duration between 3.4 and 6.9 days. No secondary eclipse is apparent at phase 0.5. While the rotational amplitude is much reduced from the first season, the light curve now shows two maxima and minima per rotation of the K star. The mean magnitudes of the two seasons are comparable, so a roughly constant spotted area has been redistributed around the star, possibly by differential rotation, to cause the double-humped, lower-amplitude light variation.

Additional evidence that HD 62668 is an active star is provided by an Hα line that is significantly filled by emission. At red wavelengths near 6430 Å and Hα, broadened lines of only one component are visible. Our preliminary

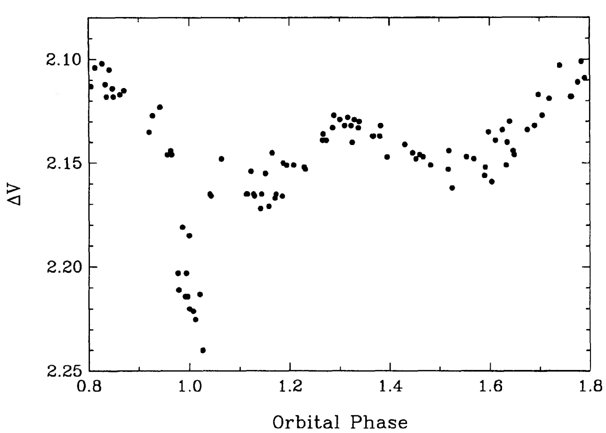

FIG. 13. Second season light curve of HD 62668 plotted against orbital phase calculated from the ephemeris $T(\text{conj.})=2449177.3744+69.323E$. Eclipse points a few percent deep are seen at phase 1.0. The rotational amplitude in V has decreased to 0.06 mag, and the light curve has developed two minima.

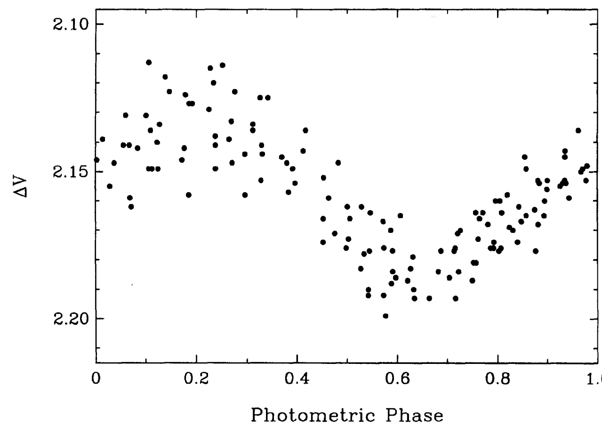

FIG. 14. Light curve of HD 70573 plotted against photometric phase calculated from the ephemeris HJD $2449200.0+3.296E$. The amplitude in V is 0.05 mag.

orbital elements indicate it has a 69.3 day period and circular orbit. Thus, the visible component is synchronized and the relatively long-period orbit is circularized. This system has the longest orbital period of any known eclipsing RS CVn binary. An appropriately broadened spectrum of β Gem (K0 III) provides an excellent fit to that of HD 62668. The $v \sin i$ of 14 ± 2 km s^{-1} and long rotation period result in a large minimum radius of 19.3 $R_\odot$. If a mass of 3 $\mathscr{M}_\odot$ is assumed for the K giant, the mass function of the orbit indicates that the unseen spectroscopic secondary is a late-A star. Thus, the system appears to be a more massive analog of HD 155638=V792 Her (Fekel 1991; Nelson *et al.* 1991).

6.11 HD 70573

Fleming *et al.* (1989) identified HD 70573 as the optical counterpart to the x-ray source 1E0820.2+0201. They classified it as an apparently single G6 V star and found $v \sin i = 14$ km s^{-1}. Olsen's (1993) Strömgren photometry gives $V=8.74$, $b-y=0.405$, and $c_1=0.319$.

Our photometric data for HD 70573 cover two observing seasons. Periodogram analysis of the first season finds a rotation period $P=3.296\pm0.002$ days and a somewhat weaker possibility at 1.432 ± 0.001 days. The phase plot for the first season with the 3.296 day period is shown in Fig. 14. Despite the modest rotational amplitude of 0.05 mag, the phase plot shows obvious and very coherent light variations. The light curve for the second season is very similar.

Our three spectrograms of HD 70573 cover a timespan of three years and have nearly identical radial velocities, the average of which is 19.8 ± 0.1 km s^{-1}. They support the conclusion of Fleming *et al.* (1989) that this star is apparently single. Its $v \sin i$ is 11 ± 1 km s^{-1}, slightly less than that determined by Fleming *et al.* (1989). The critical line ratios of its spectrum in the 6430 Å region are nearly identical to those of HR 483 (G1.5 V). Unfortunately, in this wavelength region we can not differentiate between an early-G dwarf and subgiant. Thus, from our spectra alone we classify it as G2 IV–V. In Table 4 we revise the luminosity classification to G2 V: because the c_1 value of HD 70573 (Olsen 1993) is consistent with that of a dwarf (Olsen 1984). Our spectral

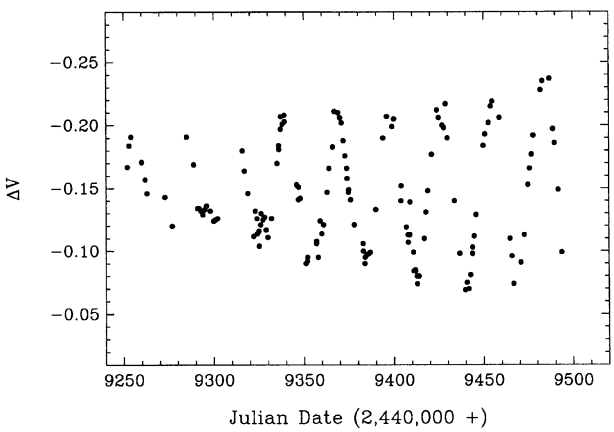

FIG. 15. Light curve of HD 72146 plotted against Julian date. The photometric period is 28.5 days, and the amplitude in V is 0.16 mag.

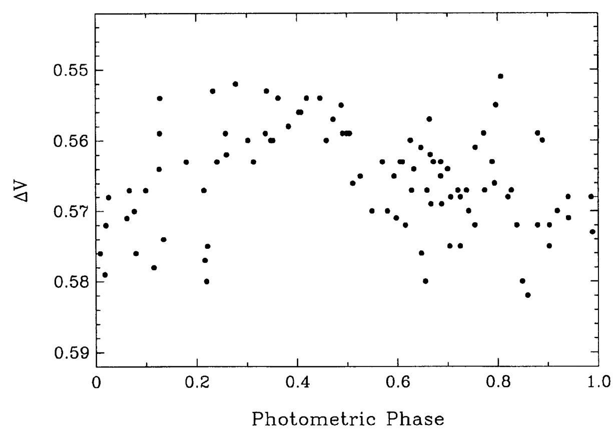

FIG. 16. Light curve of HD 72429 plotted against photometric phase calculated from the ephemeris HJD $2449200.0+9.37E$. The amplitude in V is only 0.015 mag.

class is somewhat earlier than that found by Fleming *et al.* (1989). The combination of our $v \sin i$ and rotation period results in a minimum radius of 0.7 $R_\odot$, also consistent with a solar-type dwarf. If the actual radius is 1 $R_\odot$, the rotational inclination is about 45°.

6.12 HD 72146

HD 72146 is yet another previously unremarkable star whose spectrum has Ca II H and K emission lines (Bidelman 1991). As a result of this detection, the star is noted as a candidate in *CCABS II*. Strassmeier's (1994) spectrum of this star shows very strong Ca II H and K emission features that reach the continuum. Fekel & Balachandran (1994) found the star to be a single G8 III with $v \sin i = 14$ and a significant lithium abundance. Strömgren photometry by Olsen (1993) gave $V=7.28$, $b-y=0.607$, and $c_1=0.374$.

Of our two full seasons and two partial seasons of photometry for HD 72146, the second full season is plotted in Fig. 15. Periodogram analysis gives $P=28.5\pm0.1$ days. The maximum photometric amplitude is 0.16 mag, and cycle-to-cycle variations in amplitude are evident. Similar behavior is seen in the other seasons.

From nine KPNO observations between 1991 November and 1994 November this star has a constant velocity of -1.2 ± 0.2 km s^{-1}. As found by Fekel & Balachandran (1994), at red wavelengths a broadened spectrum of κ Gem (G8 III) provides an excellent fit to the spectrum of HD 72146. Measurement of additional spectra confirms their $v \sin i$ of 14 ± 1 km s^{-1}. The rotation period and line broadening result in a minimum radius of 7.9 $R_\odot$. Thus, like HD 51066, it is a moderately rapidly rotating single late-type giant. Unlike most such stars of that group (Fekel & Balachandran 1993), the Hα line of HD 72146 is significantly filled in by emission, which varies in strength. One of three such spectra shows a blueshifted emission peak rising above the continuum.

6.13 HD 72429

HD 72429 is another star identified as an optical counterpart to an x-ray source, 1E0830.3+1126, by Fleming *et al.* (1989). They concluded HD 72429 is apparently single, classified its spectrum G0 III, and obtained $v \sin i$ of 14 km s^{-1}. Strömgren photometry by Olsen (1983) resulted in $V=7.946$, $b-y=0.445$, and $c_1=0.421$. Earlier Olsen (1980) had used its unusual Strömgren indices to suggest a spectral type of sgG0.

One season of photometry from our survey is in hand for HD 72429. Periodogram analysis of the V data shows a distinct periodicity at $P=9.37\pm0.04$ days. The identical period is seen in the B data. The phase plot against this period is shown in Fig. 16. The amplitude of the rotational modulation is quite small, only about 0.015 mag.

Figure 17 shows our spectrum of the star's Ca II H and K emission, showing that the star is chromospherically active. From six observations obtained between 1992 June and 1995 April, we get a mean velocity of 79.1 ± 0.4 km s^{-1}, supporting the claim of Fleming *et al.* (1989) that the star is single. Our $v \sin i$ of 16 ± 2 km s^{-1} confirms the rapid rotation found by Fleming *et al.* (1989). The red spectrum of HD 72429 most closely resembles that of 84 Her (G2 IV, Strassmeier & Fekel 1990). Unfortunately, the spectra of early-G dwarfs and subgiants in the 6430 Å region are nearly iden-

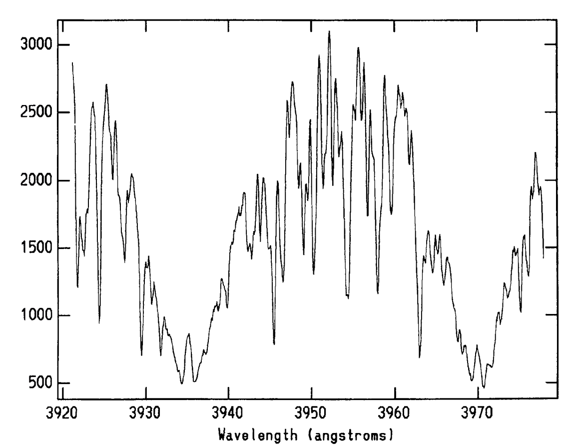

FIG. 17. A portion of the spectrum of HD 72429 in the Ca II H and K region with counts plotted vs rest wavelength.

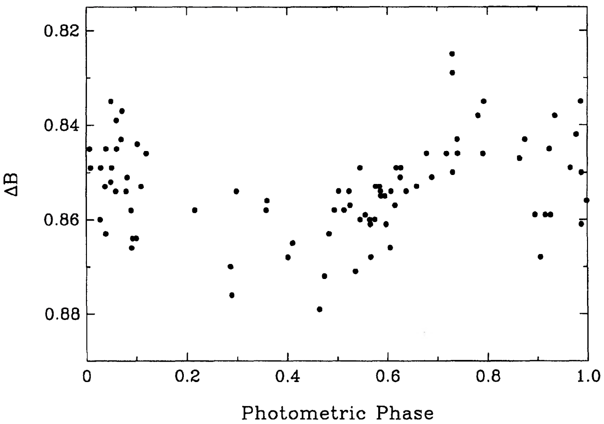

FIG. 18. Light curve of HD 80953 plotted against photometric phase calculated from the ephemeris HJD $2449600.0+97E$. Differential magnitudes are in the sense HD 80953 minus HD 84179. The amplitude in B is 0.03 mag.

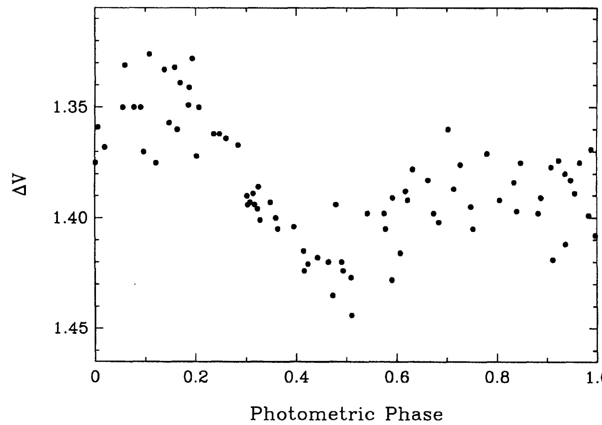

FIG. 19. Light curve of HD 82286 plotted against photometric phase calculated from the ephemeris HJD $2449600.0+3.270E$. Differential magnitudes are in the sense HD 82286 minus HD 84179. The amplitude in V is 0.09 mag.

tical so we cannot discriminate between those classes. From our spectra alone we classify it as G2 IV–V. However, combining our $v \sin i$ with the rotation period of 9.37 days results in a minimum radius of 3.0 $R_\odot$, indicating that the star is not a dwarf, and so in Table 4 we have revised it to G2 IV: compared with G0 III of Fleming *et al.* (1989). Olsen (1980) estimated a subgiant luminosity class from his Strömgren indices.

The above properties of HD 72429 pose a significant question about its evolutionary status. The very large radial velocity of 79 km s^{-1} indicates the star is rather old but, if that is the case, why hasn't this single star on the blue side of the Hertzsprung Gap lost its angular momentum? Could it be a coalesced binary, the evolutionary status suggested for FK Comae?

6.14 HD 80953=HR 3722

Relatively little has been published about HD 80953, which we used as the comparison star for HD 82286 and also found to be variable. Aside from the HD-catalog type, the only spectral types we could find in the literature are K3 from Young (1945) and K2 III in *The Bright Star Catalogue* (Hoffleit 1982). Brown *et al.* (1989) used T_e and M_u values consistent with a mid-K giant. Young (1945) gave 8.1 km s^{-1} as a mean of four radial velocity measures, noting that the total range of 10 km s^{-1} was somewhat greater than expected but not concluding that it was a velocity variable.

In this instance, our photometric B data of HD 80953 minus HD 84179, which were somewhat cleaner than the V data, were used. Periodogram analysis results in $P=97\pm3$ days. Those data are plotted against the 97 day period in Fig. 18. The amplitude is about 0.03 mag.

The $B-V$ and $U-B$ colors (Table 2) imply a spectral type later than K2 III, confirmed by our classification below. One might regard 97 days as rather long for the "rapid" rotation needed to produce starspot variability, but the convective turnover time for a K-type giant is correspondingly long. Thus, as Table 4 shows, the Rossby number for HD 80953 is <0.65, namely, 0.27.

We have obtained one red-wavelength spectrum of HD 80953. Our radial velocity of 12.2 km s^{-1} is within the range found by Young (1945) and differs by 4 km s^{-1} from his mean value. The spectral type of HD 80953 is clearly later than that of ϵ CrB (K2 III) and is quite similar to that of β Cnc (K4 III) and HR 4954 (K5 III). We classify it as K4 III and determine $v \sin i=4\pm2$ km s^{-1}. The relatively large uncertainty is the result of line crowding, which makes it difficult to find weak unblended lines. Assuming that the photometric period results from rotation, the minimum radius is 7.7 $R_\odot$.

6.15 HD 82286

Pounds *et al.* (1993) identified HD 82286 as the optical counterpart of the *ROSAT* wide-field *EUVE* source RE J0933 +624, making it similar to other stars examined by Mulliss & Bopp (1994) for evidence of chromospheric activity. Bopp & Mulliss (1994) have obtained spectroscopic observations indicating that it is indeed a very active late-type system. Strömgren photometry by Olsen (1993) resulted in $V=8.351$, $b-y=0.628$, and $c_1=0.229$.

We have one full season of photometric data for HD 82286. However, both HD 82286 and its comparison star HD 80953 proved to be photometrically variable. Thus, our periodogram analysis for HD 82286 is of the variable minus check star data and gives a rotation period $P=3.270$ ±0.005 days. The phase curve is shown in Fig. 19. The amplitude is about 0.09 mag while the light-curve shape is very asymmetrical, with a suggestion of a secondary minimum near phase 0.9.

Our spectroscopic observations show HD 82286 to be a double-lined binary although so far the components have not been completely resolved. Lines of the secondary are about half as strong as the primary. We estimate similar $v \sin i$'s, about 35 km s^{-1} for each star. The lines of the primary show significant asymmetries due to spots and, thus, the system may be a candidate for Doppler imaging despite its faintness and double-lined nature. The above properties make the spectrum of HD 82286 somewhat difficult to classify al-

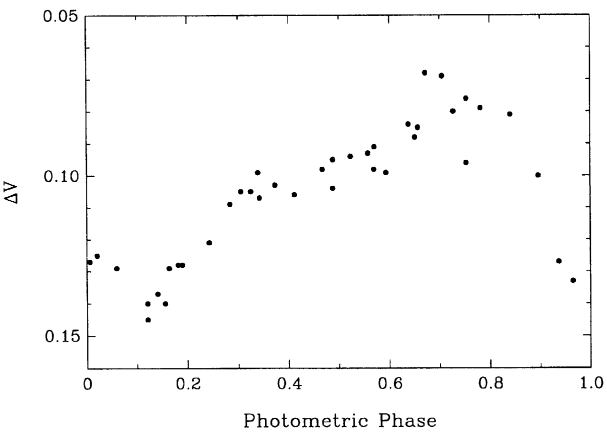

FIG. 20. Light curve of HD 82443 plotted against photometric phase calculated from the ephemeris HJD $2449600.0+5.43E$. The amplitude in V is 0.06 mag.

though the critical-line ratios indicate that the stars are subgiants. The approximate spectral type of the primary is K0 IV while that of the secondary is similar. With such a short rotation period the system is almost certainly synchronously rotating and, thus, the orbital period should be about 3.3 days. The combination of $v \sin i$ and rotation period results in a minimum radius of 2.3 $R_\odot$, which is consistent with the subgiant classification. Improvement in such preliminary results will be made once sufficient additional spectroscopic observations have been obtained.

6.16 HD 82443

While HD 82443 has been included in several surveys of stellar activity (e.g., Vaughan & Preston 1980; Soderblom 1985), Basri *et al.* (1989) were the first to show a spectrum of its Ca II K emission feature. Bidelman (1991) later noted its Ca II H and K emission in an objective-prism spectrum. HD 82443 is one of the stars Baliunas *et al.* (1995) are monitoring to determine Ca II H and K long-term emission cycles, continuing the seminal work of O. C. Wilson. Griffin (1994) confirmed the result of Duquennoy *et al.* (1991) that HD 82443 is single and also measured $v \sin i=4.6\pm1$ km s^{-1}. Using such information, Griffin (1994) discussed the properties of HD 82443 in the context of Soderblom's (1985) rotation period of 2.5 days, which was predicted from its emission intensity. Griffin (1994) concluded it is statistically unlikely that the rotation period is as short as 2.5 days. He pointed out that the assumed spectral type of K0 V was likely the result of combining the HD classification with the known parallax of 0."054 (van Altena 1995). We suspect that the $V=7.10$ mag listed by Panagi & Mathioudakis (1993) may be a misprint of the $V=7.01$ repeated elsewhere in the literature.

Periodogram analysis of our photometry of HD 82443 gives a period of approximately 5.5 days in each of four seasons. The amplitude varies from year to year, between about 0.03 and 0.08 mag, while the maximum brightness remains nearly constant. Data from the fourth season, which give the cleanest phase curve, are plotted in Fig. 20 modulo the rotation period of $P=5.43\pm0.03$ determined for that season. The amplitude is approximately 0.06 mag. The noticeable asymmetry of this phase curve implies that at least two spotted areas at different longitudes on HD 82443 are responsible for the light variation.

Our spectroscopic results are in accord with those of Duquennoy *et al.* (1991) and Griffin (1994). From 11 spectra we obtain an average radial velocity of 8.25±0.07 km s^{-1} and find $v \sin i=5\pm1$ km s^{-1}. From a visual comparison of standards in the 6430 Å region, the spectral type is K0 V in agreement with the spectral type previously assumed by most astronomers. The rotation period of 5.43 days and the $v \sin i$ of 5 km s^{-1} result in a minimum radius of 0.54 $R_\odot$, leading to an approximate inclination of 32° for this single early-K dwarf.

6.17 HD 85091

Our attention was focused on HD 85091 by the work of Latham *et al.* (1988) who found a period of 3.39 days and a circular orbit for this short-period binary although Carquillat *et al.* (1983) had previously determined a similar orbit for it. The latter also suggested a spectral type of K1 or later for the unseen secondary and estimated an inclination greater than 27°. According to Laird *et al.* (1988), the system is significantly metal poor with [m/H]$=-1.09$. G. P. Kuiper (Bidelman 1985b) has classified the star G0. Despite the solar-type classification, spectra obtained by Pasquini *et al.* (1991) showed a Ca II K emission feature of modest strength and a filled in Hα line. Spite *et al.* (1994) made a detailed analysis of their high-resolution, high signal-to-noise spectrum of HD 85091. They concluded the star is somewhat evolved from the main sequence, with $\log g=3.5$, and found [Fe/H] $=-0.52$, a value significantly more metal rich than that of Laird *et al.* (1988). Spite *et al.* (1994) also obtained $v \sin i =9\pm3$ km s^{-1} for the primary star. As part of extensive searches for metal-poor stars, both Sandage & Kowal (1986) and Carney & Latham (1987) have obtained photometry (Table 2). A small trigonometric parallax of 0."016±0.011 (*s.e.*) (van Altena 1995) has been determined.

Our survey yielded two years of photometric data for HD 85091. Periodogram analysis of the second year gives the rotation period $P=3.416\pm0.009$, indicating that the system is synchronously rotating. However, we see a significant amplitude only in the last few weeks of the observing season. Consequently, we plot the data in the abbreviated Julian-date range 2449766–2449805 against the 3.416 day rotation period in Fig. 21, where an amplitude of 0.03 mag can be seen. Similar behavior occurred in the first observing season.

Our six spectroscopic observations at 6430 Å show that, despite the primary's modest mass function of 0.014 $\mathcal{M}_\odot$ (Latham *et al.* 1988), the system is a double-lined spectroscopic binary with a line ratio for B/A of about 0.1. Preliminary analysis suggests a mass ratio for B/A of 0.67. The primary's $v \sin i=7\pm1$ km s^{-1} while the secondary's $v \sin i =6\pm3$ km s^{-1}. The very weak lines of the secondary combined with blends and noise make determination of its line broadening more difficult and uncertain and result in a probable overestimate of its value. The minimum radius of the

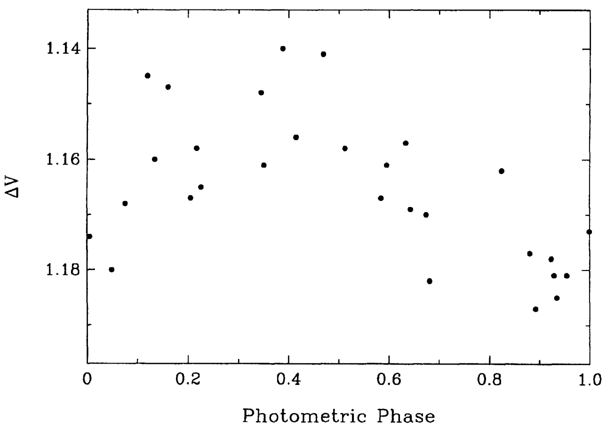

FIG. 21. Light curve of HD 85091 plotted against photometric phase calculated from the ephemeris HJD $2449600.0+3.416E$. The amplitude in V is 0.03 mag.

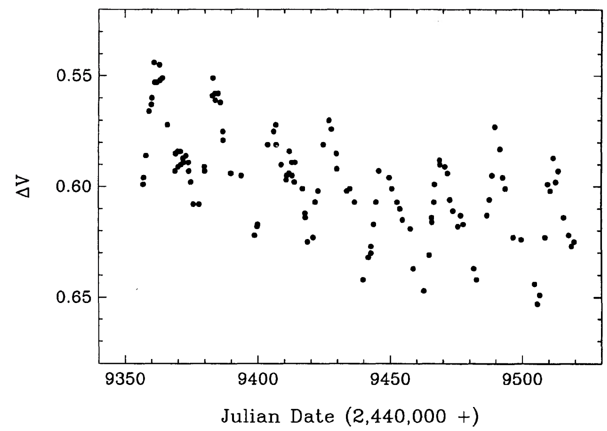

FIG. 22. Light curve of HD 89546 plotted against Julian date. The photometric period is 21.5 days, and the amplitude in V is 0.10 mag.

primary is 0.47 $R_\odot$. Despite the low $v \sin i$ values, spectrum addition was used to determine the spectral types of the components. A very good fit to the primary is obtained with an appropriately broadened and weighted spectrum of HR 4098 (F9 V), which has a value of [Fe/H]$=-0.48\pm0.21$ (Taylor 1994). Our only moderately metal-poor dwarf with a later spectral type is τCet (G8 V), which has a mean [Fe/H] $=-0.38\pm0.04$ (Taylor 1994). Spectrum-addition analysis with appropriately broadened and weighted spectra of HR 4098 and τCet results in a reasonable fit to the very weak lines of the secondary, although a slightly later type is likely. Thus, we classify the components of HD 85091 F9 V and K0: V. Unfortunately, we have no metal-poor subgiants to compare with HD 85091. Nevertheless, our results are in reasonable agreement with those of Spite *et al.* (1994) and confirm that the iron abundance is much closer to the solar value than that found by Laird *et al.* (1988). Spectroscopic observations are continuing and will improve the parameters of this system.

6.18 HD 89546

HD 89546 is another of the stars for which Bidelman (1991) found Ca II H and K emission. Strassmeier's (1994) spectrum shows emission nearly as strong as that of HD 72146. It is identified as a single-lined binary in the main tables of *CCABS II.* Fekel & Balachandran (1994) found it to be a binary G5 IV star with $v \sin i = 15$ km s^{-1} and moderate lithium abundance. As Table 2 shows, we could find no published photometry of it.

We have four seasons of photometry for HD 89546. Data from the last two-thirds of the third season, when the light curve was most coherent, are plotted in Fig. 22. Periodogram analysis of those data results in a rotation period $P=21.5 \pm 0.3$ days. The range in brightness during this interval is approximately 0.10 mag. However, the amplitude of rotational modulation varies over our four observing seasons from as small as 0.04 mag to as large as 0.15 mag. Gradual increases and decreases in mean brightness also are seen throughout the timespan of the observations.

Only one component of HD 89546 is detected in our red-wavelength observations. Dadonas (1993) reported an orbital period of 21.3 days and a circular orbit, results that are confirmed by our data. Thus, the system is both synchronized and circularized. From measurements of additional spectra we confirm the rotational broadening found by Fekel & Balachandran (1994): $v \sin i = 15\pm2$ km s^{-1}. A number of subgiant and giant standards were appropriately broadened and compared with HD 89546. Neither the critical line ratios nor the line strengths of G5$-$K2 giants fit the spectrum of HD 89546. Instead, the best fit to its spectrum is an appropriately broadened spectrum of β Aql (G8 IV) rather than the G5 IV type assigned to it by Fekel & Balachandran (1994). Although the critical line ratios appear to be about right, some of the strong lines in the standard are too weak. The Hα absorption line is significantly filled with emission and is variable. It has no absorption wings and in one spectrum a blueshifted emission feature rises above the continuum. A minimum radius of 6.4 $R_\odot$ results from the rotational broadening and photometric period. Such a radius indicates that luminosity class III–IV might be more appropriate.

6.19 HD 98800

Skinner *et al.* (1992) and Zuckerman & Becklin (1993) have emphasized the uniqueness of this late-type "Vega-excess" system first identified by Walker & Wolstencroft (1988). The star is actually a close visual binary, ADS 8191 AB, each component of which is now known to consist of a spectroscopic binary (Torres *et al.* 1995). Whether the visual components make up a gravitationally bound physical system or whether the visual binary is a chance projection remains the subject of conjecture. Gregorio-Hetem *et al.* (1992) first found the strong lithium line of this system. From an analysis of high-dispersion spectroscopic observations Fekel & Bopp (1993b) concluded that the system is in a pre-main-sequence evolutionary stage and suggested an age of 10 million years or less. The composite spectral type is K5 V according to both Upgren *et al.* (1972) and Fekel & Bopp (1993b) or K4 V according to Houk & Smith-Moore (1988). Recently, Soderblom *et al.* (1995) have obtained

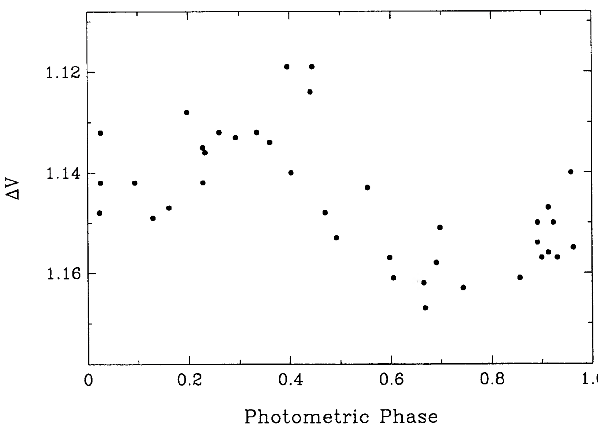

FIG. 23. Light curve of HD 98800 plotted against photometric phase calculated from the ephemeris HJD 2449600.0+14.8E. The amplitude in V is 0.03 mag.

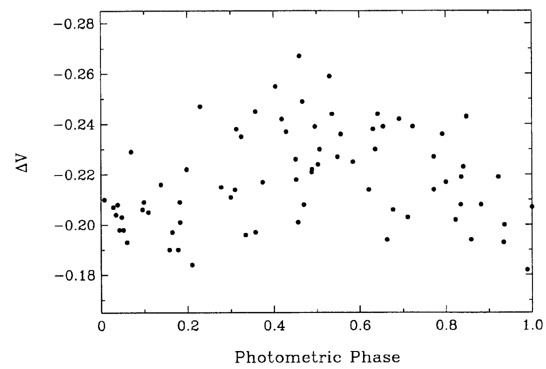

FIG. 24. Light curve of HD 99267 plotted against photometric phase calculated from the ephemeris HJD 2449200.0+0.575E. Differential magnitudes are in the sense HD 99267 minus HD 96778. The amplitude in V is 0.03 mag. The cause of variability in this star is unknown.

spectrograms that resolve the individual components and, as a result, have reevaluated the evolutionary status of the system. Our photometry of this unusual infrared-excess star, to search for the BY Dra-type variability predicted by Fekel & Bopp (1993a), resulted in the discovery of variability reported by Henry & Hall (1994). We include HD 98800 in this paper because our photometry has continued beyond that which led to the initial discovery of variability. Henry & Hall (1994) found a range of 0.07 mag in V with a photometric period of 14.7 days and interpreted this as a result of rotational modulation of light from the primary star, its surface darkened unevenly by a few large spots. It is interesting that in Table 2 the range of 0.24 mag in V is considerably greater than the 0.07 mag range Henry & Hall (1994) had found with their differential photometry. Nevertheless, HD 98800 has not yet been assigned a variable star designation.

We have now observed HD 98800 for three seasons; our photometry of it includes both components of the close visual binary ADS 8141 AB. Periodogram analysis of the third season gives $P=14.8\pm0.2$ days, identical within the errors to the rotation period found by Henry & Hall (1994) from the first season's data. The third season is plotted versus the 14.8 day period in Fig. 23 and is seen to have an amplitude of about 0.035 mag, half the amplitude observed in the first season. Scatter in the phase plot suggests some cycle-to-cycle variation in spot coverage.

Our spectroscopic observations of this star were discussed by Fekel & Bopp (1993b). According to the orbits of Torres *et al.* (1995) those observations occurred at phase 0.4 in the 262 day orbit for component Aa and at phase 0.25 in the 315 day orbit for component Ba and Bb. In each case the phases are computed from periastron since both orbits are rather eccentric, with Aa having $e=0.48$ and Ba and Bb having $e=0.78$. The lines of the various components are not often well separated and in our observations the velocities of all three stars happened to be within 15 km s^{-1} of each other. The single broadened features of our spectra, which have $v \sin i=11$ km s^{-1}, actually consist of the lines of all three stars. We note for a K5 V star a radius of 0.7 $R_\odot$ (Gray 1992), combined with the rotation period of 14.7 days (Henry & Hall 1994), results in a rotational velocity of 2.4 km s^{-1}. Any evidence of significant rotational broadening would clearly identify HD 98800 as a pre-main-sequence system. For example, a $v \sin i$ of 5 km s^{-1} gives a radius for the primary of 1.45 $R_\odot$, twice the canonical value for such a main-sequence star.

6.20 HD 99267

We used HD 99267 as the check star for BD +30°2130, and it also turned out to be variable. It was one of 500 stars observed at the David Dunlap Observatory whose velocities were published by Young (1939). From five radial velocities he concluded its velocity was probably variable and had a mean of -4.8 ± 4.2 (p.e.) km s^{-1}. However, he cautioned that its many lines were difficult to measure. A spectral class of A8 was also estimated from those spectrograms.

Periodogram analysis of our photometric V observations of HD 99267 minus HD 96778 for the first season gives $P=0.575\pm0.001$ days with somewhat weaker possibilities at 1.354±0.001 and 3.282±0.002 days. Separate periodogram analyses of the B and V data for the first and second seasons all gave the same results. A phase plot of the V data from the first season with the 0.575 day period is shown in Fig. 24. A sine-curve fit to the data gave a full amplitude of 0.030±0.006 mag. The same amplitude was found in the other data sets.

To determine whether the light variations of HD 99267 might be the result of the ellipticity effect in a short period binary (e.g., Mantegazza & Poretti 1995), two red-wavelength spectra of this star were obtained 4 hr apart on 1995 April 28. The two radial velocities result in an average of 2.2 km s^{-1}, differ by only 1.2 km s^{-1}, and appear to rule out a possible short-period binary. Our mean velocity is reasonably consistent with that of Young (1939). As might be expected from Young's (1939) comment about the appearance of the lines, our red spectrum of HD 99267 shows relatively broad lines having $v \sin i=93\pm4$ km s^{-1}. Standards from A9 to F5 were rotationally broadened in an attempt to match the spectrum of HD 99267. A very good fit was found with HR 6844 (F1 V; Gray & Garrison 1989) and so we

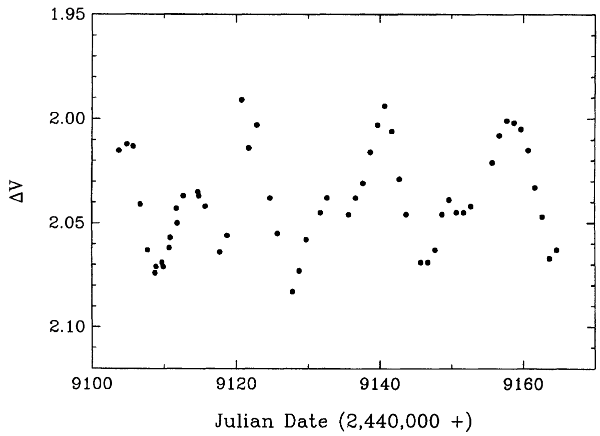

FIG. 25. Light curve of HD 112859 plotted against Julian date. The photometric period is 18.5 days, and the amplitude in V is 0.08 mag.

assign it that classification. If the period results from rotation, the minimum radius would be 1.06 $R_\odot$.

HD 99267 appears to have properties similar to a small but growing group of early-F main-sequence stars with short-period, low-amplitude variability (Krisciunas *et al.* 1993; Mantegazza *et al.* 1994; Hall 1995; Rodriguez & Zerbi 1995) for which the cause is unknown. With a spectral type of F1 V the mechanism for variability in HD 99267 is not obviously spot modulation or δ Scuti pulsation. The puzzle has been solved by Mantegazza & Poretti (1995) for one member of the group, HD 96008. They demonstrated that its variability is the result of the ellipticity effect in a close binary system.

6.21 HD 112859

Our interest in HD 112859 resulted from Bidelman's (1991) detection of its Ca II H and K emission. Recently, Strassmeier (1994) confirmed the strong Ca emission. Over two decades ago, as part of his survey of G–K giants at the North Galactic Pole, Schild (1973) obtained Johnson photometry (Table 2) and classified the star G8 III–IVp. Its spectrum was peculiar because its G band was too weak for the spectral type indicated by the metal and hydrogen lines. Because of our detection of double lines, it was added to *CCABS II*.

We observed HD 112859 photometrically for four observing seasons. The last half of the second season is plotted in Fig. 25. Periodogram analysis of those data gives $P=18.5\pm0.4$ days with an amplitude of 0.08 mag. Figure 25 reveals two maxima and two minima for each rotation cycle. Thus, HD 112859 has spotted areas at two widely separated longitudes. In the third observing season, the light curve displays a single maximum and minimum, and the amplitude shrinks for a time to only 0.02 mag before increasing again. During the time of low amplitude, the minimum brightness increased while the maximum brightness remained roughly the same, suggesting that the low amplitude resulted from the temporary dissipation of spots on the darker hemisphere.

The preliminary information given in *CCABS II* comes from our spectroscopic observations. At red wavelengths the spectrum is double lined but the components have vastly different line strengths. The primary is well fitted by the spectrum of β Gem (K0 III) while the secondary requires a late-F star to reproduce the strength of its lines in the combined spectrum. We confirm the preliminary $v \sin i=17\pm2$ km s^{-1} for the K0 III. A $v \sin i$ value from the weak and often blended lines of the F star is difficult to determine but we estimate a rotational broadening of $\leqslant 6$ km s^{-1}. From velocities of the primary star Dadonas (1993) has determined a period of 18.7 days and a nearly circular orbit, results identical to our independent solution. Thus, the system is likely circularized and the K-giant primary is synchronized. The minimum radius of the K giant is 6.2 $R_\odot$.

6.22 HD 113816

Buckley *et al.* (1987) identified HD 113816 as the optical counterpart of an *HEAO 1* hard x-ray source. Their spectroscopic observations showed that it has strong Ca II H and K emission and low-amplitude velocity variations. They concluded that it probably has a long orbital period, certainly greater than 20 days, and possibly has a low orbital inclination. They also obtained $V=8.27$, $B-V=1.15$, $V-R=0.93$, and $V-I=1.57$ (see Table 2) as well as DDO photometry from which they classified the star as K2 III–IV. Finally, Buckley *et al.* (1987) estimated its $v \sin i$ as 30 km s^{-1}. Being a known chromospherically active binary, it was included in *CCABS II*. Dadonas (1993) confirmed some of the conclusions of Buckley *et al.* (1987) and has determined an orbital period of 23.7 days, a semiamplitude of 6.7 km s^{-1}, and an essentially circular orbit. Randich *et al.* (1994) observed the system as part of a lithium survey of RS CVn binaries. They obtained a significantly lower $v \sin i$ of 10 km s^{-1} and claimed the star is quite metal poor, with [Fe/H]$=-0.9$. Recently, Strassmeier (1994) showed that, in addition to the extremely strong Ca II H and K emission lines, the Balmer Hϵ line of HD 113816 is in emission.

We have obtained six seasons of photometric data for HD 113816. Because the comparison star, HD 113449, exhibited long-term brightness variations of about 0.02 mag, we used the variable minus check star differential magnitudes for the analysis of HD 113816. The last two-thirds of the fifth season displayed the most coherent light variation, so we performed the periodogram analysis on those data. The resulting period was $P=23.5\pm0.2$ days, making the star a synchronous rotator. The phase curve is plotted in Fig. 26 where the photometric amplitude is 0.04 mag. Long-term brightness variations in HD 113816 are also seen with an amplitude of about 0.1 mag.

Since we could not find any periodicity for the observed variations of HD 113449, it is not included in Table 3. We did obtain one spectrum of it from which we determine a spectral type of K0 V and $v \sin i=5\pm1$ km s^{-1}.

From our spectroscopy to date, we find HD 113816 to be a single-lined binary with orbital elements quite similar to those of Dadonas (1993). We determined $v \sin i=5\pm1$ km s^{-1}, a much smaller value than the estimate of Buckley *et al.* (1987) and even smaller than the value of Randich *et al.* (1994). An examination of critical line ratios compared

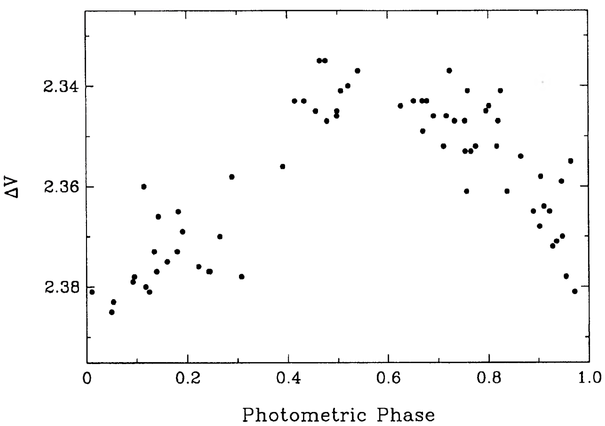

FIG. 26. Light curve of HD 113816 plotted against photometric phase calculated from the ephemeris HJD 2449400.0+23.5E. Differential magnitudes are in the sense HD 113816 minus HD 111998. The amplitude in V is 0.04 mag.

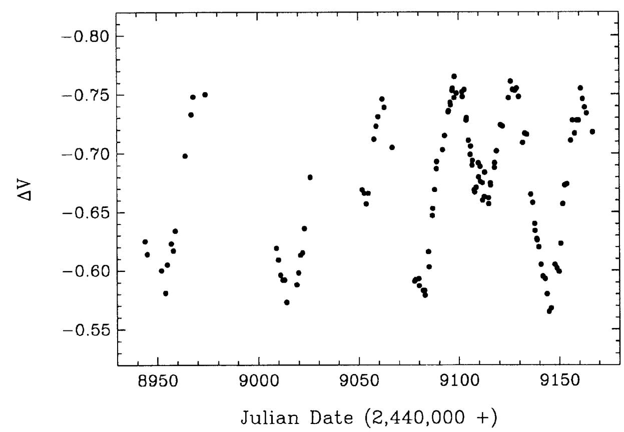

FIG. 27. Light curve of HD 118234 plotted against Julian date. The photometric period is 64 days, and the amplitude in V is 0.20 mag.

with stars of solar abundances indicates that HD 113816 has a spectral type of about K0 III. While the line strengths do indicate that the star is metal poor, a comparison with a spectrum of HR 1907 (K0 III*b*), which has [Fe/H]$=-0.58\pm0.06$ (Taylor 1991), shows that most lines of HD 113816 are somewhat stronger. Unfortunately, we do not have an extensive grid of metal-poor giants for additional comparisons. The combination of very strong chromospheric activity and rather low projected rotational velocity suggests a low rotational inclination. The $v \sin i$ and photometric period result in a minimum radius of 2.3 $R_\odot$, a value likewise consistent with a low rotational inclination. For example, an assumed radius of 12 $R_\odot$ results in an inclination of 11°.

6.23 *HD 118234*

Griffin (1988a) found this moderately bright star to be a single-lined binary with an orbital period of 59.054 days and an eccentricity of 0.59. From a discussion of existing multibandpass photometry, he concluded that the star is a giant with a spectral class between K0 and K1 while its secondary may be a star of earlier spectral type. We had it on our program because Griffin (1988a) had noted that the 59 day period is quite short for a giant star and, thus, should show photometric variability of the RS CVn variety. For the same reason it was a candidate in *CCABS II*, awaiting only the detection of manifestations of chromospheric activity. Since then, Strassmeier (1994) has observed Ca II H and K emission lines well above the nearby continuum, confirming the suspected chromospheric activity, and Strassmeier *et al.* (1994) have determined $v \sin i=4$: km s^{-1}.

The second of three seasons of photometry from our survey is plotted in Fig. 27. Periodogram analysis of those data gives $P=64\pm1$ day for the rotation period. Figure 27 shows two maxima and minima per rotation cycle, indicating that HD 118234 had large spotted areas on opposite hemispheres during the second observing season. The amplitude at that time was 0.20 mag. During the first observing season, HD 118234 was nearly constant, with almost no rotational modulation of its brightness! At that time the mean brightness was essentially equal to the mean brightness for the second season. This suggests that the total spotted area was the same for the first and second seasons but with spots distributed much more uniformly in longitude during the first season. HD 118234 had an intermediate amplitude during the third season, with a mean brightness about 0.03 mag brighter than in the first two observing seasons.

Because Griffin (1988a) suggested that HD 118234 might have a composite spectrum consisting of a K giant and an early-F star, we carefully examined our lone red-wavelength spectroscopic observation of this system. Although that wavelength region is not optimal for the detection of a hotter companion, such companions have been detected for several of the stars in our survey. From a visual examination of the spectrum the critical line ratios do not quite fit any of the standards. The best fit appears to be intermediate between β Gem (K0 III) and ϵ CrB (K2 III) and so we classify HD 118234 K1 III. Those two standards were appropriately broadened and overplotted on our spectrum, which was obtained close to maximum velocity separation at phase 0.074. From this comparison we conclude that there is no evidence of any lines of a second star nor that the primary's lines in this red-wavelength region are weakened by the continuum of a second star. We determine $v \sin i=5.5\pm1.0$ km s^{-1}, a value consistent with Griffin's (1988a) statement that his photoelectric-velocity dip widths do not suggest unusually rapid rotation and Strassmeier *et al.*'s (1994) somewhat uncertain value. When our $v \sin i$ is combined with the rotation period, the resulting minimum radius is 7.0 $R_\odot$, quite consistent with the giant classification. Although our photometric rotation period and the orbital period are similar, the orbit is quite eccentric, $e=0.59$, resulting in a pseudosynchronous rotation period of 15.1 days. Thus, the rotation period of HD 118234 is four times greater than pseudosynchronous.

6.24 *HD 118981*

Our interest in HD 118981 stems from the work of Latham *et al.* (1988) who found it to be a single-lined binary with a period of 14.50 days and an eccentricity of 0.48. Laird *et al.* (1988) obtained [m/H]$=-0.43$, suggesting a modest

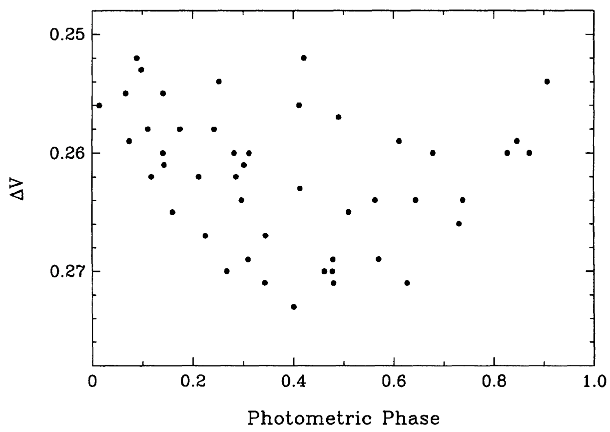

FIG. 28. Light curve of HD 118981 plotted against photometric phase calculated from the ephemeris HJD $2449600.0+5.94E$. The amplitude in V is only 0.01 mag.

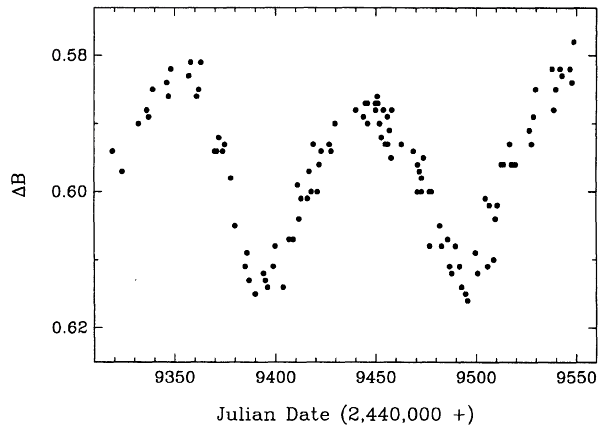

FIG. 29. Light curve of HD 122767 plotted against Julian date. The photometric period is 96 days, and the amplitude in B is 0.03 mag.

metal deficiency. As part of extensive surveys for metal-poor stars, both Sandage & Kowal (1986) and Carney & Latham (1987) have obtained photometry (Table 2).

Although photometric data from three observing seasons are available from our survey, the data from the first season are too sparse to consider. Periodogram analysis of the third season results in a rotation period $P=5.94\pm0.04$ days. Those data are plotted in the phase curve of Fig. 28. A sine-curve fit to those data gives a full amplitude of 0.009±0.002 mag. While the phase curve looks rather noisy because the amplitude is quite small, we believe in the reality of this result for several reasons. (1) The amplitude found in the least-squares sine fit is significantly larger than the formal error. (2) The second observing season and the B data for both the second and third seasons all give similar results. (3) A 5.94 day period is not found in the check minus comparison data. (4) The 5.94 day period found is very close the 5.53 day period predicted for pseudosynchronous rotation in this eccentric binary system. (5) The derived minimum radius is consistent with the radius assumed from the primary's spectral type.

Our spectra of HD 118981 show very weak secondary lines with a line ratio for B/A of about 0.1. From the abundance analysis of Laird *et al.* (1988) we anticipated that the stars would be somewhat metal weak and so compared the primary's lines with spectra of HR 4098 (F9 V), having [Fe/H]$=-0.48\pm0.21$ (Taylor 1994), and HR 5914 (F8 V), having [Fe/H]$=-0.43\pm0.05$ (Taylor 1994). In both cases the diluted lines of the primary were significantly stronger than those of the metal-poor standards. Instead, the best fit to the spectrum of HD 118981 was with appropriately broadened and weighted combinations of spectra that have essentially solar abundances. A representative best fit was with 10 Tau (F9 IV–V) and 12 Oph A (K0 V; Wilson 1962), so we classify the components F9 V and K0 V. The uncertainty of the latter classification is perhaps several subclasses because the secondary's lines are so weak. The primary has $v \sin i=7 \pm 1$ km s^{-1} while the weak secondary lines give $v \sin i=7 \pm 4$ km s^{-1}. Presumably, the secondary's rotational broadening is actually less than the primary's but the former's lines are broadened by blends and noise, resulting in our large estimated uncertainty. The observed rotation period combined with the $v \sin i$ of the primary results in a minimum radius of 0.7 $R_\odot$. The pseudosynchronous rotation period is 5.53±0.13 days compared with our photometric period of 5.94±0.04 days. Although quite similar, the two periods and their errors do not formally overlap. Nevertheless, we believe that the difference could result from differential rotation in such a star and conclude that the star is pseudosynchronously rotating.

6.25 HD 122767

Our suspicion of the light variability of HD 122767 dates back to Fekel & Hall (1985), who became interested in it as a result of its velocity variability (Heard 1956) and spectral type of K3 III (Heard 1956). We have continued to observe this star because Hooten & Hall (1990), in their search for variability, had concluded only that it was possibly variable. Despite an observed range of 0.25 mag in V, they were unable to determine a period. Griffin (1988b) showed it to be a single-lined binary with an orbital period of 1189.2 days and a huge eccentricity of 0.871. Strassmeier (1994) found weak Ca II H and K emission with sharp central reversals, and Strassmeier *et al.* (1994) determined $v \sin i=4$ km s^{-1}.

We now have five seasons of photometric data for HD 122767. We chose to analyze the B data for this star because the amplitude in B is considerably greater than in V. The fourth season's data plotted against Julian date are shown in Fig. 29. Periodogram analysis gives $P=96\pm1$ days. The amplitude in B was approximately 0.03 mag while the amplitude in V was only about 0.01 mag. Similar periods and amplitudes are seen in the other seasons. The low amplitude but definitely periodic variation reported here is in contrast to the 0.25 mag range and lack of an identifiable period reported previously by Hooten & Hall (1990). The orbital elements of Griffin (1988b) result in a pseudosynchronous rotation period (Hut 1981) that is about twice as fast as the observed period, 49 vs 96 days.

One spectroscopic observation of HD 122767 has been obtained. Visual examination of this red-wavelength spec-

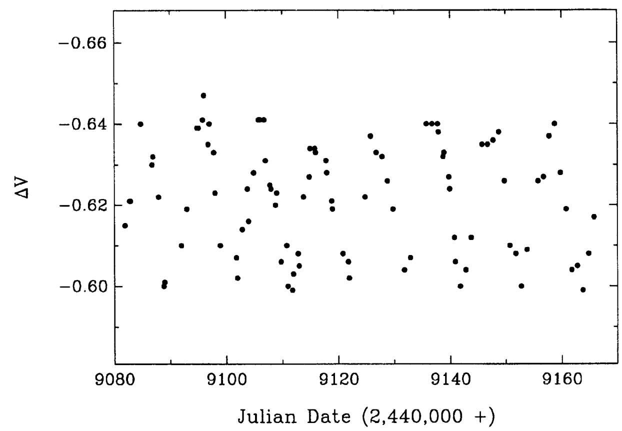

FIG. 30. Light curve of HD 131511 plotted against Julian date. The photometric period is 10.39 days, and the amplitude in V is 0.04 mag.

trum indicates a spectral type between that of ϵ CrB (K2 III) and β Cnc (K4 III) so we classify it K3 III in agreement with the classification given in Heard (1956). The lines have a modest but significant rotational broadening of 8 ± 1 km s^{-1}, somewhat larger than that found by Strassmeier *et al.* (1994). Our $v \sin i$ and rotation period result in a minimum radius of 15.2 $R_\odot$, quite consistent with its spectral type.

6.26 HD 131511 = HR 5553

HD 131511 is important as a bright single-lined binary containing a K-type dwarf with emission of moderate strength in the Ca II H and K lines; for those reasons it appeared in *CCABS II*. The absence of established photometric variability, evidenced by a blank in Table 2 of that catalog, was responsible for it being on our observing program. Two independent spectroscopic orbits resulted in elements consistent with each other: Kamper & Lyons (1981) found $P = 125.374$ days and $e = 0.494$, and Beavers & Salzer (1983) found $P = 125.369$ days and $e = 0.512$. Except for the old G8 of G. P. Kuiper (Bidelman 1985b) and the K0.5 V of Keenan & McNeil (1989), the many other published classifications have been either K1 V or K2 V. From various indirect considerations, Stockton & Fekel (1992) determined that the unseen secondary must be M0 V or earlier. The star is relatively nearby, having a trigonometric parallax of 0\".086 (van Altena 1995). Photometric variability has been suspected for some time. The NSV 6847 designation can be traced to Golay (1973), who listed it as a suspected variable but gave no range of variability. Later, Petit (1990) did much the same, considering it a "variable or microvariable" but again giving no range. The full range of values in our Table 2, taken at face value, suggests HD 131511 is variable by at least 0.07 mag in V.

At the present time we have obtained three seasons of photometry for HD 131511. The second half of the second season is plotted in Fig. 30. Periodogram analysis gives the rotation period $P = 10.39 \pm 0.03$ days. The analyzed data have an amplitude of 0.04 mag while a similar amplitude and mean light level are observed in the other two seasons. The pseudosynchronous rotation period (Hut 1981) of this eccentric binary is 43.2 days, about four times greater than our observed rotation period. It is ironic that if the system were old enough for pseudosynchronous rotation to have developed, its rotation would not be fast enough for chromospheric activity and variability due to large starspots (Hall 1991, 1994). The relatively rapid rotation period of this K dwarf and the absence of pseudosynchronous rotation indicates that it is fairly young.

Over the years we have obtained several spectroscopic observations to search for lines of the secondary but, despite the moderate mass function of 0.06 $\mathcal{M}_\odot$, no secondary is evident (Stockton & Fekel 1992). From our red-wavelength spectra we determine a spectral type of K1 V, quite consistent with that of K0.5 V found by Keenan & McNeil (1989). Strassmeier *et al.* (1990) determined $v \sin i = 4 \pm 1$ km s^{-1} from our spectra of the 6430 Å region. The rotation period and rotational broadening result in a minimum radius of 0.82 $R_\odot$, suggesting the rotational inclination of this K dwarf is close to 90°. If the orbital inclination is likewise close to 90°, then the mass of the secondary is about 0.45 $\mathcal{M}_\odot$, which corresponds to an early-M dwarf (Gray 1992) and makes it about three magnitudes fainter than the primary (Stockton & Fekel 1992). Such a magnitude difference is consistent with the nondetection of its secondary spectrum.

6.27 HD 141690

Although observed first at Mt. Wilson (Wilson & Joy 1950), it was the additional variable velocity measurements of HD 141690, obtained at David Dunlap Observatory (Heard 1956), that convinced us to initiate our own photometric and spectroscopic observations. Hooten & Hall (1990) searched for variability but, despite finding a range of 0.082 mag in V, were unable to find a period and were forced to conclude that it was only "possibly variable." As a result of our initial spectroscopic observations and the discovery of Ca II H and K emission (Strassmeier 1994), HD 141690 appeared with limited information in *CCABS II*. Almost simultaneously, Griffin & Duquennoy (1993) published an extensive analysis of this interesting system, concluding that this well-known visual binary, ADS 9799 AB, is actually quadruple. Two stars they called A*a* and A*b* orbit each other with a period of 4.67 days and a small but real eccentricity of 0.05. A*a*, A*b*, and a third star they called A*c* orbit each other with a period they deduced to be roughly 100 years or less. The fourth star, B of the visual binary ADS 9799 AB, is 14\" away and orbits those three with a period they estimated to be "many millenia." They arrived at spectral types for all four components by inference from *UBV* photometry and/or by modeling the relative masses: A*a* = G2 IV–V, A*b* = M2 V, A*c* = G8 V, and B = G8 V. Component A*a* dominates the combined spectrum, having a V mag about 2 mag brighter than A*c* or B. Griffin & Duquennoy (1993) also determined $v \sin i = 18.5$ km s^{-1} for A*a*. They showed that the 4.67 day orbit has a high inclination and provided an ephemeris for possible eclipses between A*a* and A*b*.

Our photometry of HD 141690 included light from all four components of the quadruple system. Data from the first of three seasons, plotted modulo the rotation period $P = 4.64$

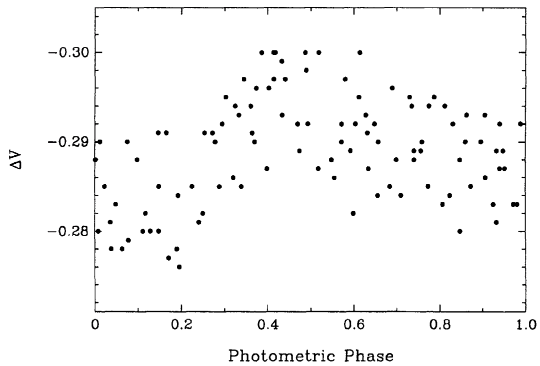

FIG. 31. Light curve of HD 141690 plotted against photometric phase calculated from the ephemeris HJD 2449000.0+4.64E. The amplitude in V is only 0.01 mag. A few very shallow primary eclipse points are not shown.

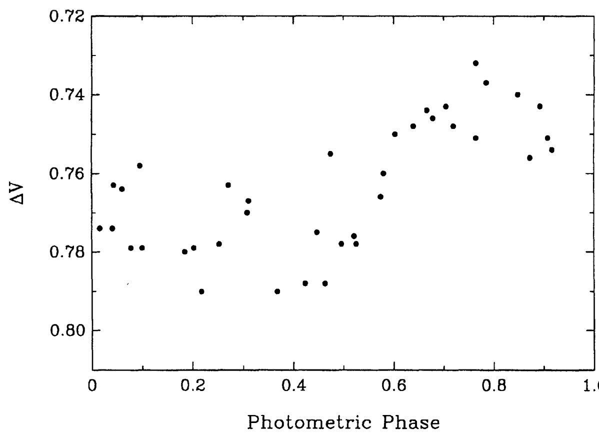

FIG. 32. Light curve of HD 144110 plotted against photometric phase calculated from the ephemeris HJD 2449400.0+1.651E. The amplitude in V is 0.05 mag.

±0.02 days determined from those same data, are shown in Fig. 31. While similar amplitudes of only 0.01 mag are seen in each season, periods for the second and third seasons are 4.60±0.02 and 4.51±0.03, respectively, lending additional confidence to the reality of the light variations. The weighted mean of those three periods is 4.58±0.013 days. In addition to an analysis for the rotational modulation seen in the light curves, a search was made for eclipses as a result of the prediction of Griffin & Duquennoy (1993). Our data show that very shallow primary eclipses are present. Eclipse depths in V and B are only about 0.025 and 0.028 mag, respectively. Total duration of the eclipse is 4 or 5 hr. The check star for HD 141690 is the low amplitude variable δCrB (Fernie 1991).

The photometric variability we find surely arises from Aa, the G2 IV–V primary. The very modest but real eccentricity of 0.050±0.004 (Griffin & Duquennoy 1993) results in a pseudosynchronous rotation period (Hut 1981) of 4.60±0.01 days, slightly less than the orbital period of 4.67 days. Since the mean rotation period is 4.58±0.01 days, we conclude that this system is pseudosynchronously rotating.

Our spectroscopic results are in good agreement with those of Griffin & Duquennoy (1993). As reported in *CCABS II*, one of our red-wavelength observations shows lines from two components. The $v \sin i$ for Aa is 17±2 km s^{-1}. Lines of Ac are clearly narrower than Aa but are weaker and partially blended with those of Aa. Therefore, we can estimate only an upper limit of 6 km s^{-1} for its $v \sin i$. Our velocity of Ac for 1992 June 1 is −33.5 km s^{-1}, which is consistent with the mean velocity of −35.0 km s^{-1} found by Griffin & Duquennoy (1993). To examine the spectral types of Aa and Ac, we used the results of Griffin & Duquennoy (1993) as a starting point. The spectra of several different G stars were compared to that of HD 141690. In the 6430 Å region, line ratio differences between a G2 IV and G2 V star are almost nonexistent. When the lines of such spectra are appropriately broadened either one provides a relatively good fit to the spectrum of component Aa, the primary. For Ac a fit with a G5 V star is slightly better than with G8 V. Appropriate combinations of the above four spectral types provide a reasonable fit to the observed spectrum of HD 141690. Thus, our spectral types G2 IV–V and G5–8 V are quite consistent with those that Griffin & Duquennoy (1993) derived from photometry. The mean rotation period and our $v \sin i$ result in a minimum radius of 1.5 $R_\odot$, indicating that the primary, component Aa, is indeed somewhat evolved.

6.28 HD 144110

Pounds *et al.* (1993) identified HD 144110 as the optical counterpart to the extreme ultraviolet *ROSAT* source RE J1601+512 and listed it as a G5 star. Surveying some of the late-type stars in the *ROSAT EUV* source list, Mulliss & Bopp (1994) obtained several red-wavelength spectra of it and discovered it to be a double-lined binary. They concluded that both the Hα and Ca II 8542 Å lines were partially filled in by emission.

We have two seasons of photometric data for HD 144110. Periodogram analysis of the first season gives P=1.651 ±0.003 days, but slightly weaker periods are also found at P=0.622±0.001 and P=2.525±0.007 days. We adopt P=1.651 days as the rotation period because it also gives the most reasonable minimum radius for the star when combined with our spectroscopic results. After making this assumption, we discovered the work of Jeffries *et al.* (1994), who independently discovered its duplicity and found it to have a circular orbit and an orbital period of 1.671 days. While their observations may be subject to the same aliasing problems and they gave no details of their analysis, if their orbital period is right, we have identified the correct rotation period. Thus, the system is synchronously rotating, as expected for such a short-period system. The first season's data are phased against this period in Fig. 32. The rotational amplitude is approximately 0.05 mag, but considerable scatter occurs around the light-curve minimum. Similar periods and amplitudes are found in the other V and B data sets. The system has undergone a 0.03 mag brightening between the first and second observing seasons.

Our red-wavelength spectroscopic observations show double lines having an estimated line-strength ratio for B/A of 0.67. The $v \sin i$'s are 26±2 and 22±2 km s^{-1}, respectively, for the primary and secondary. The best fit to the

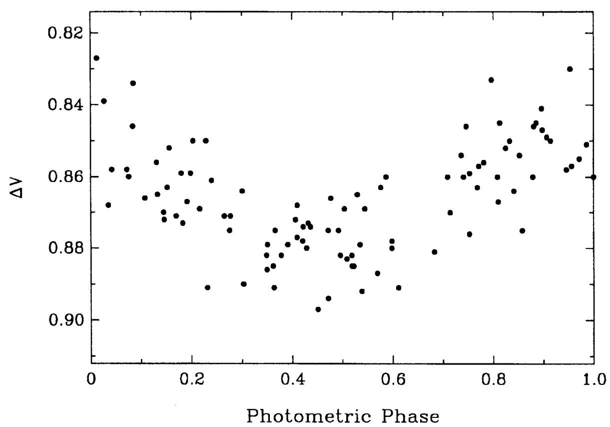

FIG. 33. Light curve of HD 148127 plotted against photometric phase calculated from the ephemeris HJD 2449300.0+13.80*E*. Differential magnitudes are in the sense HD 148127 minus HD 148554. The amplitude in *V* is 0.05 mag.

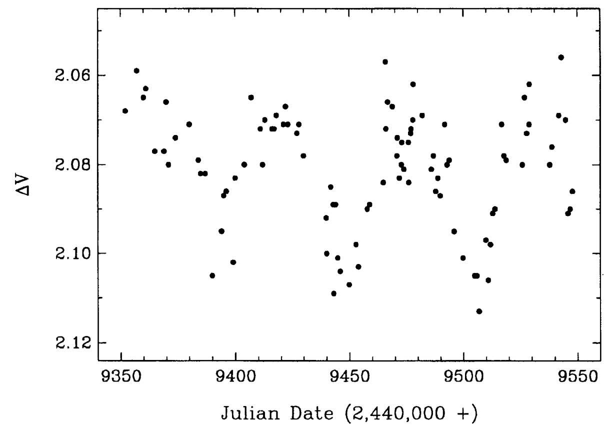

FIG. 34. Light curve of HD 148405 plotted against Julian date. Differential magnitudes are in the sense HD 148405 minus HD 148554. The photometric period is 56.9 days, and the amplitude in *V* is 0.04 mag.

spectrum of HD 144110 is with appropriately broadened and weighted spectra of 61 UMa (G8 V) and σ Dra (K0 V) although the secondary appears to be slightly later. Thus, we classify the stars G8 V and K1 V. The dwarf classification rules out the 2.5 day period, which would result in a minimum radius of 1.3 $R_\odot$ for the primary. From our $v \sin i$ and a rotation period of 1.651 days the minimum radius is 0.85 $R_\odot$.

6.29 HD 148127

This star appears in our paper by virtue of being the comparison star for HD 148405 and proving to be variable as well. Remarkably little is known about this reasonably bright star. The spectral type is K5 according to the HD catalog.

Periodogram analysis of our fourth season of photometric data for HD 148127 minus HD 148554 results in $P=13.80 \pm 0.06$. Those data are plotted in Fig. 33, phased with this period. An amplitude of 0.05 mag is observed, probably the largest of the four seasons.

In the 6430 Å region we have obtained three spectroscopic observations of HD 148127 over an interval of two months, which have an average velocity of -16.3 ± 0.2 km s^{-1}. While our limited results are consistent with a constant velocity, we have no knowledge about possible long-term velocity variations. A visual examination of its spectra shows it is quite similar to β Cnc (K4 III) so we assign it the same type. Its lines are slightly broadened with $v \sin i=4 \pm 1$ km s^{-1}.

If we assume that our photometric period is the result of rotation, the combination of that period and the projected rotational velocity produces a minimum radius of 1.1 $R_\odot$. While this minimum radius indicates that the rotational inclination is quite low, our results for HD 113816 demonstrate that rotational variability can be detected on giants with very low inclinations. HD 148127 is one of the two single K-type giants, discussed in Sec. 5, whose rather short-period variability we attribute with some hesitation to spot modulation.

6.30 HD 148405

Our suspicion of photometric variability dates back to Fekel & Hall (1985). This star remained on our program because Hooten & Hall (1990), in their search for variability, had concluded that it was possibly variable. The only published spectral classification we could find is the K0 in the HD Catalog, while Griffin (1982) has argued that it is likely to be a giant. He also showed it to be a single-lined binary with an orbital period of 52.453 days and a very small eccentricity of 0.021. *UBV* photometry (Table 2) was obtained by Oja (1984) as part of a project to observe stars with accurately known positions. It was a candidate in *CCABS II*, awaiting only detection of manifestations of chromospheric activity. Subsequently, Strassmeier (1994) did find weak, and very asymmetric, emission lines that might indicate an active chromosphere. Finally, Dempsey *et al.* (1993) reported a null detection of x-ray emission, and Strassmeier *et al.* (1994) determined $v \sin i=4$ km s^{-1}.

We have five seasons of photometric coverage for HD 148405. Since HD 148405 and its comparison star, HD 148127, have been discovered to be photometrically variable, we analyzed the light variations of HD 148405 relative to the check star. The light curve of the fourth season for HD 148405, in the sense variable minus check, is shown in Fig. 34. Periodogram analysis of those data gives $P=56.9\pm0.8$ for the rotation period, which is quite close to the orbital period of 52.453 days given by Griffin (1982), indicating that the star is synchronously rotating. The amplitude is approximately 0.04 mag the largest for the four observing seasons.

Our one red-wavelength spectrum obtained for this star shows modest rotational broadening of 7 ± 1 km s^{-1}. A visual comparison with various standard spectra indicates a spectral type between o UMA (G5 III; W. W. Morgan in Stebbins & Kron 1956) and κ Gem (G8 III). Thus, we classify it as a G6 III. Its minimum radius from its rotation period and $v \sin i$ is 7.9 $R_\odot$.

6.31 HD 160934

This star is the optical counterpart to the extreme ultraviolet *ROSAT* source RE J1738+611 (Pounds *et al.* 1993),

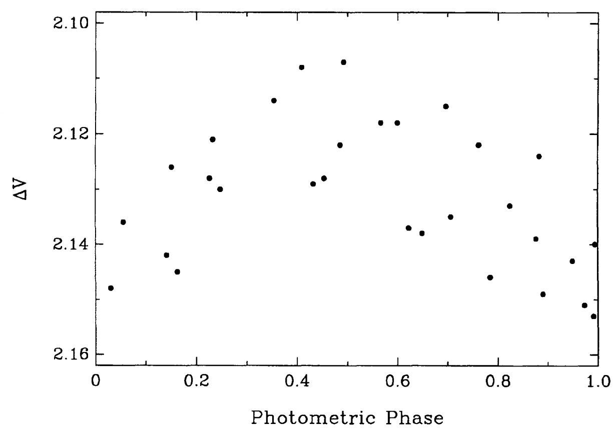

FIG. 35. Light curve of HD 160934 plotted against photometric phase calculated from the ephemeris HJD $2449400.0+1.842E$. The amplitude in V is only 0.02 mag.

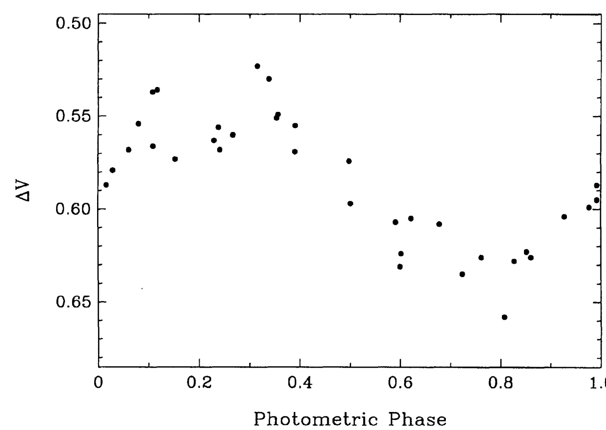

FIG. 36. Light curve of HD 171488 plotted against photometric phase calculated from the ephemeris HJD $2449400.0+1.338E$. The amplitude in V is 0.10 mag.

whose spectral type, following Vyssotsky (1956), they listed as K8 V. Follow-up spectroscopy by Mulliss & Bopp (1994) resulted in the detection of a strong Hα emission feature. Weis (1993) recently obtained UBV magnitudes (Table 2) of HD 160934 as part of a survey of dwarf K and M stars.

We have two seasons of photometric data for HD 160934. Periodogram analysis of the first season gives $P=1.842 \pm 0.005$ days, but a second period nearly as strong as the first occurs at $P=2.181 \pm 0.007$ days. The same two periods are also seen in the second season as well as in the B data from both seasons. At present, we cannot unambiguously decide which period represents the true rotation period and which is an alias. Since the 1.842 day period is slightly stronger, we plot the phase curve in Fig. 35 against this period. The rotation amplitude is only about 0.02 mag. The second observing season shows an amplitude of about 0.04 mag and a mean brightness level about 0.02 mag above the first season. Since the level of minimum brightness remains about the same for both seasons, the larger amplitude of the second season must result from an decrease in the spottedness of the brighter hemisphere.

We note that the $U-B$ and $B-V$ indices (Table 2) imply a dwarf with an ultraviolet excess of $\delta(U-B)=0.2$ mag or else reddening of $E(B-V)=0.2$ mag, but a late-K dwarf of $V=10.3$ mag should be only about 30 pc away and hence insignificantly reddened.

This star is one of the faintest ones on our program. Nevertheless, we recently obtained three spectroscopic observations over a four-night period. The average velocity is -26.7 ± 0.1 km s^{-1}, which excludes any velocity variations with a period similar to that found from our photometry. Although long-term velocity variations can not be ruled out, we conclude that the star probably has a constant velocity. Since it is not a short-period binary, the strong chromospheric activity noted by Mulliss & Bopp (1994) and its significant rotational broadening of 13 ± 1 km s^{-1} indicate it is likely a ZAMS or possibly a pre-main-sequence star. Its spectrum was compared with appropriately broadened spectra of 61 Cyg A (K5 V) and 61 Cyg B (K7 V). The strong line wings clearly indicate a spectral type of K7 V. Our chosen rotation period and $v \sin i$ value give a minimum radius of 0.5 $R_\odot$, which results in a rotational inclination of approximately 50°.

6.32 HD 171488

Pounds *et al.* (1993) identified HD 171488 as the optical counterpart to the extreme ultraviolet *ROSAT* source RE J1834+184. Mulliss & Bopp (1994) obtained spectra that showed both its Hα and Ca II 8542 Å lines are partially filled by emission. They also claimed that the lithium line of this star has an equivalent width that is 50% greater than similar Pleiades stars. Mulliss & Bopp (1994) concluded that this G0 V (Harlan 1969) star is quite young with an age less than that of the Pleiades. Perry (1969) and Olsen (1983, 1994) have obtained Strömgren photometry of it, with Olsen's (1983) values being $V=7.39$, $b-y=0.394$, and $c_1=0.320$.

We acquired two seasons of photometric data for HD 171488. Periodogram analysis of the first season gives $P=1.338\pm0.002$ days for the rotation period. The phase curve with this period is plotted in Fig. 36 and shows an amplitude of about 0.1 mag with some cycle-to-cycle scatter. A strong alias at 3.942 days is also evident in the periodogram but we prefer the 1.338 day period based on the dwarf luminosity classification.

We obtained four red-wavelength spectra of HD 171488, which have an average radial velocity of -22.6 ± 0.3 km s^{-1}. Our sole observation of the Hα region shows that the line core of Hα is partially filled by emission, a result similar to that shown by Mulliss & Bopp (1994). The lines are quite broad with $v \sin i=33\pm2$ km s^{-1}. The large $v \sin i$ and solar type make classification difficult because small line-strength differences are smeared out. Spectral standards from G0 V to G5 V fit the spectrum of HD 171488 reasonably well. Since there is little difference between the spectra of early-G dwarfs and subgiants in the 6430 Å region, we classify the star as G2: IV–V from the spectra alone. However, all additional information indicates that the star is a dwarf and so it is listed as G2: V: in Table 4. The c_1 index of Olsen (1983) identifies the star as a dwarf (Olsen 1984), supporting the classification of Harlan (1969). From our $v \sin i$ and a

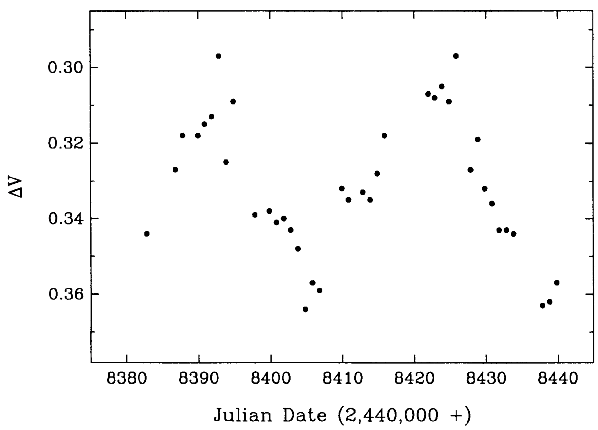

FIG. 37. Light curve of HD 181475 plotted against Julian date. The photometric period is 31 days, and the amplitude in V is 0.06 mag. The cause of variability in this star is likely due to pulsations.

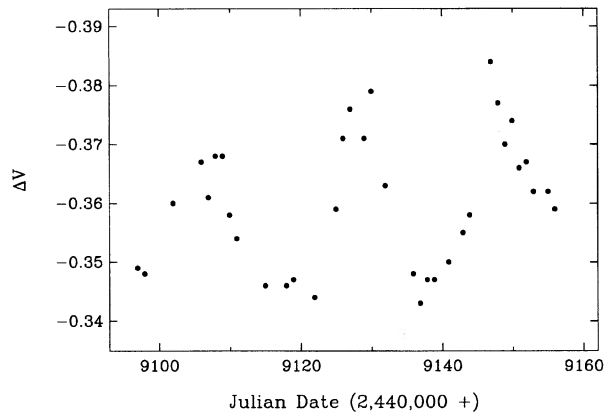

FIG. 38. Light curve of HD 202951 plotted against Julian date. The photometric period is 21.6 days, and the amplitude in V is 0.03 mag.

rotation period of 1.34 days, the minimum radius is 0.87 $R_\odot$. Such a radius implies an indication of about 60°. In addition to the photometric variability, filled Hα, and rapid rotation, the line bottoms appear to be too flat compared to the broadened standards, yet another indication of the extensive activity of this star. Thus, Doppler imaging should produce an interesting starspot map.

6.33 HD 181475

HD 181475 was originally chosen as the comparison star for our photometry of 26 Aql=HD 181391, which is now known to lack significant chromospheric emission (Strassmeier *et al.* 1993). The two V mag values in Table 2 differ by 0.05 mag, but it is not clear if this should be regarded as an early indication of variability. Three similar spectral classifications can be found in the literature: K5 II by Moore & Paddock (1950), M0 II by Morgan & Keenan (1973) and Keenan & Pitts (1980), and, finally, a revision to K7 II*a* by Keenan & McNeil (1989). Velocities from the Dominion Astrophysical Observatory (Redman 1938) and Lick Observatory (Moore & Paddock 1950) are 1 and 3 km s^{-1}, respectively. A low-resolution infrared spectrum was presented by Olnon & Raimond (1986) and mass loss from this bright giant was discussed by Jura & Kleinmann (1990).

We analyzed the light variations of HD 181475 relative to HD 180086. For approximately two months in 1991, two cycles of coherent variability were seen (Fig. 37). Periodogram analysis of those data gives $P=31\pm1$ days, with an amplitude of 0.06 mag. We presume that the variability in this late-type high-luminosity star is the result of pulsations.

We obtained two red-wavelength observation of HD 181475. Our average velocity of 4.3 km s^{-1} is in agreement with the previous results. However, if the star is indeed pulsating it may have detectable velocity variations. The spectrum is clearly later in type than any of our evolved standards (K5 III is the latest) and thus, appears quite consistent with Keenan's K7 II*a* classification (Keenan & McNeil 1989). The lines have a total broadening of 8.4 km s^{-1}. With an assumed macroturbulence of 8–6 km s^{-1} (Gray & Toner 1986, 1987), the rotational velocity would range from 2 to 6 km s^{-1}, so we conclude that $v \sin i=4\pm3$ km s^{-1}.

6.34 HD 202951=HR 8149

HD 202951 appears in our paper because we chose it as the comparison star for HD 202908, which we could not confirm as variable. For such a bright star, relatively little is known about it. Young (1945) reported four velocities obtained at David Dunlap Observatory. An apparent constant velocity of −35.3 km s^{-1} was found but the mean velocity had a range of 9 km s^{-1}, greater than that of many of the 680 other stars in the survey. Young (1945) gave a spectral class of K6 while the *The Bright Star Catalogue* lists K5 III but its giant classification seems to rest on the general belief that HR 8149 belongs to the so-called Hyades Moving Group. A low-resolution infrared spectrum is presented by Olnon & Raimond (1986) and McAlister *et al.* (1987) obtained a negative result in their search for duplicity using speckle interferometry.

We have five seasons of photometric data for HD 202951, which were analyzed in the sense HD 202951 minus HD 203842. We chose a 60 day interval of the fourth season (Fig. 38) for periodogram analysis because it displayed the most coherent variability. The resulting period was 21.6±0.5 days, and the amplitude was approximately 0.03 mag. Later in the same season, the period apparently decreased to half that reported here, suggesting that spots on opposite hemispheres were dominating the rotational modulation.

Two red-wavelength spectroscopic observations of HD 202951 obtained on consecutive nights have nearly identical radial velocities, the mean of which is −36.6 km s^{-1}. Such a value is in excellent agreement with the average velocity found by Young (1945), supporting the view that its velocity is constant. Its spectrum is quite similar to that of HR 4954 (K5 III) and we assign it the same classification, coincidentally identical to the one in *The Bright Star Catalogue* (Hoffleit 1982). Its lines are slightly broadened, with $v \sin i=4\pm2$ km s^{-1}. The relatively large uncertainty is the result of line crowding, which makes it difficult to find weak unblended lines. Our rotation period and projected rotational velocity result in a minimum radius of 1.7 $R_\odot$. This is the

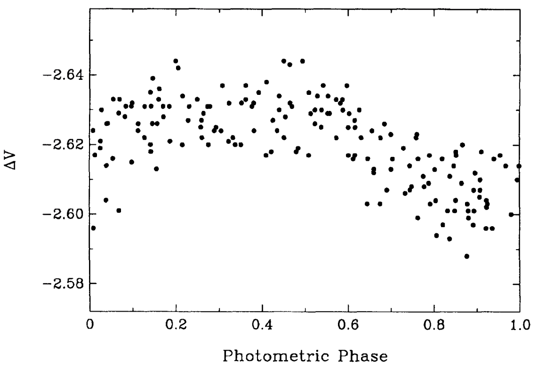

FIG. 39. Light curve of HD 203387 plotted against photometric phase calculated from the ephemeris HJD 2448700.0+68.0E. The amplitude in V is 0.03 mag.

second of the two single K-type giants, discussed in Sec. 5, whose rather short-period variability we attribute with some hesitation to spot modulation.

6.35 HD 203387=HR 8167=32 ι Cap

The bright star HD 203387 was on our program because of its significant Ca II H and K emission (Wilson 1976). Strassmeier (1994) displayed a high-dispersion spectrum of the emission. While we had suspected it of variability some time ago (Fekel & Hall 1985), Hooten & Hall (1990) could conclude only that it was possibly variable. For this bright star numerous spectral classifications of G8 III or G7 III are found in the literature, although Gray (1989) argued G5.6 might be more accurate than G7 or G8. Campbell & Moore (1928), Beavers & Eitter (1986), and Young *et al.* (1987) all have concluded the star has a constant velocity. This yellow giant is relatively nearby, having a trigonometric parallax of 0.″031 (van Altena 1995). It means $v \sin i$ is 6.1 km s^{-1} according to Gray & Pallavicini (1989) or 5.7 km s^{-1} according to Gray (1989). From the $v \sin i$ and assumed values for the inclination and the radius, Strassmeier (1994) estimated a rotation period of 90 days. Very recently, Choi *et al.* (1995) have determined a rotation period of 68±6 days from modulation of Ca II H and K emission. The significant number of V-magnitude determinations listed in Table 2 show relatively little dispersion, a full range of less than 0.03 mag.

HD 203387 has been monitored by the 0.4 m APT for 7 yr. Variability is unambiguously detected only in the final three observing seasons after the new precision photometer became operational. Periodogram analysis of these last three observing seasons, taken together, yields a photometric rotation period $P=68.0\pm0.3$ days, in excellent agreement with the value Choi *et al.* (1995) determined from calcium emission variations. Those three seasons are plotted against the 68 day rotation period in Fig. 39, where we find an amplitude of approximately 0.03 mag. That three years of data phase together so well in Fig. 39 indicates that long-lived spot activity has persisted at one longitude.

The average of our three radial velocities is 12.3±0.2 km s^{-1}, consistent with the constant velocity found by several observers. A visual comparison with our spectral type standards results in a classification of G6 III, which is in good agreement with G7 III of Keenan & McNeil (1989) and also consistent with the earlier spectral type suggested by Gray (1989). The Hα line of HD 203367 appears to be a strong absorption feature that is filled with little or no emission. Our $v \sin i$ of 6±1 km s^{-1} is in excellent agreement with the most recent value of Gray (1989). Gray (1989) has argued that the rapid decline of surface rotational velocity, seen in single giant stars as they begin to cross the Hertzsprung gap, is the result of a dynamo-generated magnetic brake. The very modest chromospheric and spot activity of HD 203387 are consistent with the resulting rotational velocity decrease. The rotation period and $v \sin i$ result in a minimum radius of 8.1 $R_{\odot}$.

6.36 HD 206301=HR 8283=42 Cap

HD 206301 has been of interest to us as a suspected variable for some time (Hall 1983). With the Ca II H and K emission (Young & Koniges 1977) and the spectroscopic orbit (Abt & Levy 1976), it was a clear case of a chromospherically active binary and, thus, has appeared in both *CCABS I* and *II*. However, Fernández-Figueroa *et al.* (1994) described the H and K emission as weak, a statement confirmed by the spectrum in their Fig. 6. The most recent spectroscopic orbit, that of Abt & Levy (1976), shows it to be single lined with $P=13.1740$ days and $e=0.18$. Four earlier orbits are all cited in the catalog of Batten *et al.* (1989). As reported in *CCABS II*, we found that the system shows double lines at red wavelengths and determined a preliminary $v \sin i=5.5$ km s^{-1} for the primary in agreement with a value of 5 km s^{-1} according to Huisong & Xuefu (1987). Speckle interferometry by McAlister *et al.* (1987) found no evidence of any widely separated companions. Roman (1952) and Keenan & McNeil (1989) classified it G2 IV, while Houk (Houk & Smith-Moore 1988) found G2 V from an objective-prism spectrum. It is rather strangely listed as G1 V+G0 V in the Fourth Edition of *The Bright Star Catalogue* (Hoffleit 1982). Randich *et al.* (1993, 1994) list G2 V, a misprint since they cite *CCABS I* as the source, which itself gives G2 IV. The full range of magnitudes in our Table 2, taken at face value, suggests HD 206301 is a photometric variable by at least 0.05 mag in V.

Our photometric data for HD 206301 proved to be the most difficult to analyze. The G2 spectral type and the expected short rotation period of 11 days if it is pseudosynchronous, point to a Rossby number small enough that HD 206301 should be a starspot variable. The small overall amplitude, obvious from the outset, indicated small and hence short-lived (Hall & Henry 1994) starspots. Thus, we divided our 4.2 yr of B and V photometry into eight data sets, the longest spanning only 106 days. To allow for the possibility of two spots being present and producing a double-humped light variation, we did the period search by successive fits with a curve containing terms in both $\sin\theta$ and $\sin 2\theta$. The resulting periodograms showed multiple periodicities, clustered around 9, 10.5, 12, 14, 16, and 17.5 days but absent in between. Only in the vicinity of 12 days, however, did periodicities appear in all eight data groups and in both the V and the B light curves. We conclude that the true rotation period,

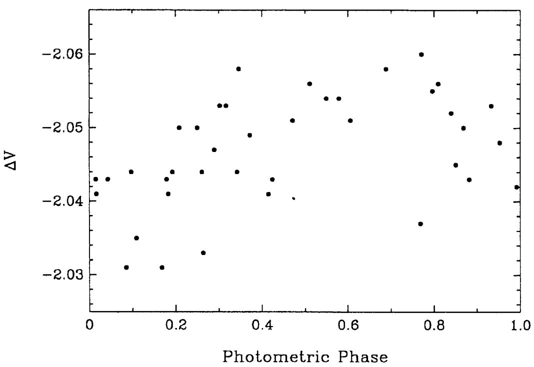

FIG. 40. Light curve of HD 206301 plotted against photometric phase calculated from the ephemeris HJD $2449200.0+12.1E$. The amplitude in V is only 0.01 mag.

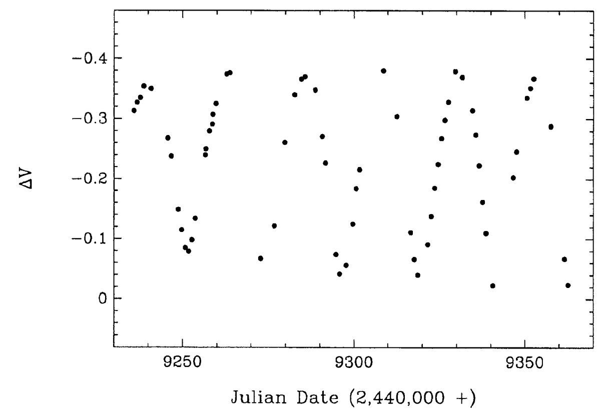

FIG. 41. Light curve of HD 208472 plotted against Julian date. The photometric period is 22.54 days, and the amplitude in V is 0.36 mag.

as manifested by starspot modulation, is around 12 days. The average of the 16 values (8 data sets each of V and B) is 12.2 days with a standard deviation of 0.5 day. If we discount the first and fourth data sets, which contained only 10 and nine points, respectively, the full amplitudes of the analytical sin θ and sin 2θ fits ranged from 0.006 to 0.017 mag in V and from 0.009 to 0.018 mag in B. The entry chosen for illustration in Fig. 40 and Table 3 comes from the seventh data set's V light curve, with a full amplitude of 0.011 mag and a period of 12.1 ± 0.2 days. The spot rotation period of 12.2 ±0.5 days is midway between the 13.1740 ± 0.0001 day orbital period and the $11.1-0.5/+0.3$ day pseudosynchronous rotation period implied by the 0.18 ± 0.02 eccentricity, suggesting that HD 206301 is aiming for pseudosynchronism but has not yet arrived.

We have obtained a number of spectra in the 6430 Å region that show weak lines of the secondary with a line-strength ratio for B/A of about 0.2. The preliminary mass ratio for B/A is 0.7 while the $v \sin i$ values are 5 ± 1 km s^{-1} for the primary and 4 ± 2 km s^{-1} for the secondary. A spectrum of the Hα region was also obtained, which shows that Hα core is somewhat filled in by emission. Comparison with similar spectra of solar-type dwarfs and subgiants indicates that the Hα wings are consistent with a subgiant classification. An appropriately weighted spectrum of HR 6608 (G2 IV; Strassmeier & Fekel 1990) provides a very good fit to the primary lines. For the secondary a range of spectral types from G2 V to K0 V was tried. The weakness of the lines makes classification difficult, but slightly better fits resulted with the earlier spectral types. As a result, we classify the components as G2 IV and G2−5 V. The mean 12.2 day rotation period and $v \sin i=5$ km s^{-1} result in a minimum radius for the primary of 1.2 $R_{\odot}$, a value consistent with the subgiant classification.

6.37 HD 208472

Bidelman (1991) first launched HD 208472 into significant notoriety with his detection of its strong Ca II H and K emission features. Previous to this important revelation, almost nothing other than astrometric information was known about the star. The only spectral type is K0 from the HD catalog, and one radial velocity was obtained at the Dominion Astrophysical Observatory (Redman 1938). We were unable to locate any *UBV* photometry of this star.

We have photometric data from three observing seasons for HD 208472. The second half of the second season is plotted in Fig. 41. Periodogram analysis of those data gives the rotation period $P=22.54\pm0.05$ days. The amplitude is relatively large, 0.36 mag, consistent with the star being quite active. Light curves from the other seasons have the same shape and period, but with slightly larger and smaller amplitudes. The maximum brightness remains approximately constant, and the changing amplitude results from variations in minimum brightness.

Our numerous spectroscopic observations show this star is a single-lined spectroscopic binary with $v \sin i=21\pm2$ km s^{-1}. It has an orbital period of 22.6 days and a nearly circular orbit. Its relatively large rotational broadening makes it more difficult to determine the best spectral type. However, an appropriately broadened spectrum of κ Gem (G8 III) provides a slightly better fit than β Gem (K0 III) to the spectrum of HD 208472 and so we classify it as the former spectral type. From its $v \sin i$ and rotation period the minimum radius is 9.4 $R_{\odot}$. Its nearly identical rotation and orbital periods make the giant star a synchronous rotator. That HD 208472 is a very active star, as suggested by its large amplitude spot variations, is confirmed by its Hα profile. Our lone spectrum of Hα shows that this line has modest emission above the continuum. Such emission strength has been found only in roughly a half dozen of the most chromospherically active giants and subgiants. Thus, despite its moderate rotational broadening, this system is a good candidate for Doppler imaging.

6.38 HD 223971

We put HD 223971 on our program after Griffin *et al.* (1991) showed it to be an eclipsing binary in a circular orbit with an orbital period of 50.119 days. A similar value for the period had been reported earlier by Griffin (1990). It was listed as a candidate in *CCABS II* because a late-type giant with a 50 day rotation period is spinning fast enough to become chromospherically active (Hall 1991, 1994) and have rotational modulation caused by large dark starspot re-

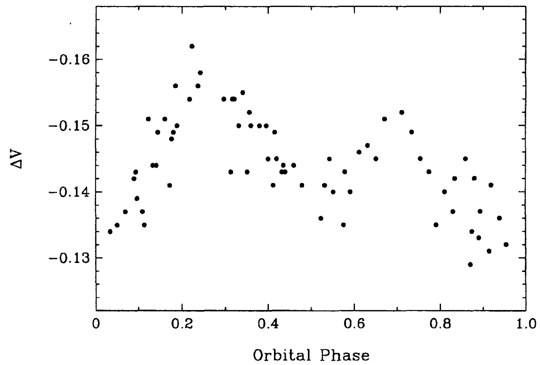

FIG. 42. Light curve of HD 223971 plotted against orbital phase calculated from the ephemeris $T(\mathrm{conj})=2447174.85+50.119E$. A couple of eclipse points are not shown. The light variability is caused by a combination of the ellipticity effect and spots, each with an amplitude of just over 0.01 mag in V. The spot rotation period is 53 days.

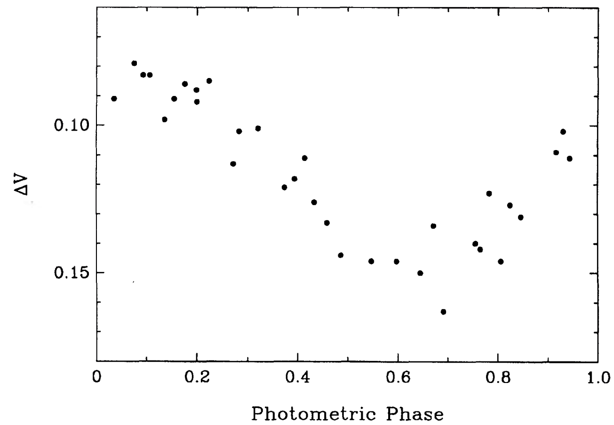

FIG. 43. Light curve of HDE 337518 plotted against photometric phase calculated from the ephemeris HJD $2449400.0+2.693E$. The amplitude in V is 0.06 mag.

gions. Primary eclipse has a depth of 0.40 in V, 0.65 in B, and 0.85 in U, lasts about two hours from first to fourth contact, and might be total for about 0.5 hr (Griffin *et al.* 1991). Spectral classifications found in the literature are Am +F9 III, (Abt 1984), gG+A (Bidelman 1985a), G0 III (Sato & Kuji 1990), and F8 (Abt & Willmarth 1994). The latter also noted that it was a double-lined spectroscopic binary. HD 223971 has not yet been assigned a variable star designation, as of The 72nd Name List of Variable Stars (Kazarovets & Samus 1995).

Only one complete season of photometry from our survey is available for HD 223971. The low-amplitude light variations that are present suggest the existence of both ellipticity and spots. We also find a couple of observations taken during primary and secondary eclipse, which show a fading of a few percent in each case, but we do not include them here because they were taken during marginal photometric conditions. Periodogram analysis finds a period at 24.6±0.3 days, a value very close to one-half the orbital period and presumably the result of ellipticity. Fourier analysis places the minimum of the cos 2θ variation at orbital phase 0.97±0.04, confirming the liklihood that this variation, having a full amplitude of 0.013±0.002 mag, is the result of the ellipticity effect. A second, stronger period is found at 53±1.3 days, near the orbital period, and therefore is presumably the spot rotation period. A Fourier fit assuming the orbital period places the spot minimum at orbital phase 0.84 with an amplitude of 0.012±0.002 mag. In Fig. 42 the data are plotted against orbital period, since the spot rotation period indicates essentially synchronous rotation. This figure clearly shows the ellipticity and spot rotation effects despite their very low amplitudes.

In 1990 we obtained two spectra near maximum velocity separation of this composite-spectrum eclipsing binary. At red wavelengths, lines of the late-type star are significantly diluted by the continuum of the hotter star. Visual comparison with our standards indicates a spectral type of G6 III for the cooler star. We also determine $v \sin i=6\pm1$ km s^{-1}. This value and the rotation period result in a minimum radius of 6.3 $R_\odot$. Weak broadened lines of the hotter star also appear in our red-wavelength spectra. Preliminary results of spectrum subtraction suggest the residual spectrum is that of a late-A star since a number of Fe I lines are visible despite a rotational broadening of roughly 50±10 km s^{-1}.

6.39 HDE 337518=BD+27° 3245

An indication that HDE 337518 is an active system first came from Bidelman's (1983b)) detection of weak Ca II H and K emission. Thus, it is listed with other candidates in *CCABS II*. Pounds *et al.* (1993) identified it as the optical counterpart to the *ROSAT* extreme ultraviolet source RE J1906+274. Follow-up spectroscopy by Mulliss & Bopp (1994) found the star to be a double-lined binary with Hα and Ca II 8542 Å lines partially filled by emission. Jeffries *et al.* (1994) also detected the duplicity of this star and provided a brief summary of their optical results. They concluded it has an orbital period of 2.73 days and a circular orbit. As Table 2 shows, we could find no published photometry of it.

We have photometry for HDE 337518 from two observing seasons. Periodogram analysis of the first season's data gives the period $P=2.693\pm0.005$ days. Those data are plotted modulo this period in Fig. 43. The rotational amplitude is approximately 0.06 mag. Another period nearly as strong as the first appears at 1.59±0.002 days. We assume $P=2.693$ because this period is more probable when our own spectroscopic results are considered. However, if the orbital inclination is particularly low, around 24°, then the 1.59-day period could represent the true rotation period. After making the above choice we discovered the work of Jeffries *et al.* (1994). Their summary, however, gave no details of their analysis and their observations may be subject to the same aliasing problems that we encountered. Nevertheless, their results support our choice of period and indicate that this short-period system is synchronously rotating as expected. The amplitude of light variations in the second observing season is only about half as great as in the first season, primarily because of a 0.04 mag decrease in the level of maximum brightness. This implies additional spot coverage in the second season with a distribution more uniform in longitude so that the rotational modulation is lessened.

Our spectra at 6430 Å show that the stars are K dwarfs with a line intensity ratio of about 0.25. Unfortunately, the line strengths of our K-dwarf standards are weak compared to those of HDE 337518 and so various combinations of the K dwarfs are not completely satisfactory. Despite this problem, spectral types of K0 V and K3 V for the primary and secondary, respectively, appear to be reasonably well determined. We also found $v \sin i = 11 \pm 2$ km s^{-1} for the primary and 11 ± 3 km s^{-1} for the secondary. The primary's $v \sin i$ combined with a period of 2.69 days results in a minimum radius of 0.58 $R_\odot$.

6.40 BD −0°4234

The most important paper pertaining to BD −0°4234, even today, is that of Peterson *et al.* (1980), who found it to be a double-lined binary in a circular orbit with an orbital period of 3.7569 days. Based on their derived temperatures for the two components, they classified the stars as K3 V*e* +K7 V*e*, where the "*e*" refers to Hα emission, which was constant in the spectrum. The strong Ca II H and K emission present in both components, the Hα emission, and the Mg II emission (Rucinski 1985) earned BD −0°4234 a listing in both *CCABS I* and *CCABS II*. Spite *et al.* (1984) stressed that this system is chemically and kinematically old but, somewhat oddly, has measurable lithium abundance. They additionally found it highly probable that the orbital period is variable, determining $P = 3.7584$ days at a later epoch. Spite *et al.* (1994) found the system to be moderately metal poor with [Fe/H]=−0.75 and determined $v \sin i = 10 \pm 3$ km s^{-1}. The system is close enough to have a measurable trigonometric parallax of 0″025 (van Altena 1995). As NSV 13768 (Kukarkin *et al.* 1982), BD −0°4234 is a suspected variable. The original suspicion has been attributed to Sandage (1969), who found evidence for probable light variability amounting to about 0.15 mag in V. A little later, Krzeminski (1973) reported detecting definitive variations of a few hundredths of a magnitude. Despite the 0.12 mag range seen in the V magnitudes listed in our Table 2, BD −0°4234 has not yet been given a variable star designation as of The 72nd Name List of Variable Stars (Kazarovets & Samus 1995).

Our photometric data cover two observing seasons for BD −0°4234. However, those data are sparse because the star comes to opposition with the Sun during mid-summer when our APT site is shut down to protect against lightning storms and because we do not observe this faint star when the moon is up. Periodogram analysis of the second half of the first season gives $P = 4.03 \pm 0.02$ days. The corresponding phase plot appears in Fig. 44, where the amplitude is about 0.05 mag. Scatter in the phase plot is significant, but we find similar periods in all of the other data sets. Also, we do not find any reliable periodicities in the check minus comparison data. Comparison of the photometric and orbital periods indicates that the system is synchronously rotating.

As noted previously by Sandage (1969), the $U-B$ and $B-V$ indices imply a large ultraviolet excess of about E($U-B$)=0.25 mag. Sandage (1969) proposed that this was the result of a hot companion, a result which Peterson *et al.*

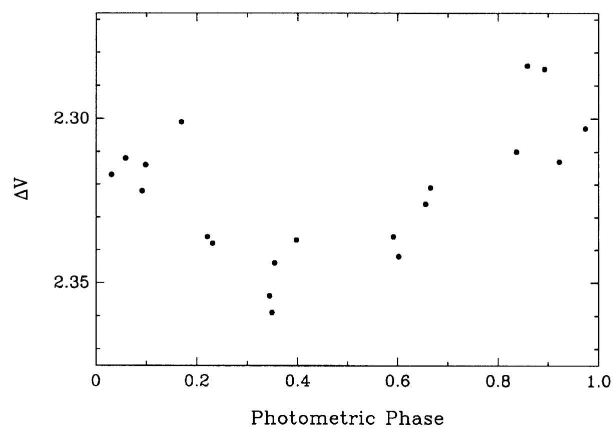

FIG. 44. Light curve of BD −0°4234 plotted against photometric phase calculated from the ephemeris HJD 2449200.0+4.03E. The amplitude in V is 0.05 mag.

(1980) proved not to be the case. Instead, it is likely this excess is the result of a combination of the chromospheric activity and the old chemical composition. The observed $B-V$ is almost exactly right for an unreddened K3 V star, and the distance of about 60 pc suggests that there should be little reddening.

During our most recent spectroscopic observing run at KPNO, we obtained one spectrum of this system at a double-lined phase. In the 6430 Å region, the line-strength ratio for B/A is about 0.25. The $v \sin i$'s are 7 ± 1 km s^{-1} for the primary and 6 ± 2 km s^{-1} for the secondary. The star is clearly metal poor and unfortunately we do not have any significantly metal-poor K dwarf standards. The components were compared to the slightly metal-poor stars ϵ Eri (K2 V) and HD 156026 (K5 V; Houk 1982). The critical line ratios and the broadening of the line wings suggest that those spectral types are approximately correct, and so we classify the spectra as K2: V and K5: V. Thus, our rough types are nearly identical to those derived from a spectroscopic-abundance analysis by Peterson *et al.* (1980). The minimum radius of the primary, resulting from the rotation period and projected rotational broadening, is 0.56 $R_\odot$.

6.41 BD +13°13

BD +13°13 has had an interesting and slightly checkered history. As a result of its identification as an optical counterpart to an Einstein x-ray source, Bergoffen *et al.* (1988) obtained an ultraviolet spectrum of it that showed emission features typical of chromospherically active stars. They also obtained high-resolution optical spectra from which they noted a strong Ca II K emission line, velocity variations, and a $v \sin i$ of 22 km s^{-1}. They listed its spectral type as G5 V and obtained *UBVRI* magnitudes. The star also was detected in the extreme ultraviolet with *ROSAT* (Pounds *et al.* 1991). Our interest in this system stems from the work of Latham *et al.* (1988), who determined an orbital period of 1.844 days and circular orbit for this single-lined system. Laird *et al.* (1988) determined a metallicity [m/H]=−2.12, making BD +13°13 an extremely metal-poor star and presumably identifying it with the halo Population II. Such a metallicity ap-

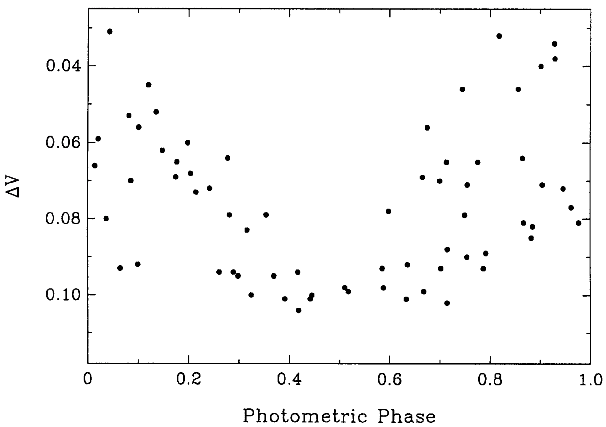

FIG. 45. Light curve of BD +13°13 plotted against photometric phase calculated from the ephemeris HJD $2449200.0+1.852E$. The amplitude in V is 0.05 mag.

peared to confirm that of Carbon *et al.* (1987), who used spectrum synthesis of intermediate-resolution spectra to determine an [Fe/H]$=-2.14$. More recent studies, however, found much higher abundances. Pilachowski *et al.* (1993) obtained [Fe/H]$=-1.3$, which has recently been revised as discussed below. Spite *et al.* (1994) in a more extensive abundance study determined [Fe/H]$=-0.5$, identified the primary as a subgiant, and also obtained $v \sin i=23\pm3$ for the primary. Pasquini & Lindgren (1994) detected Ca II K emission from both the primary and secondary. The three sets of UBV magnitudes in Table 2 show a range of 0.09 in V, and Rodono *et al.* (1994) published a brief note about the discovery of this system's photometric variability. Their eight observations obtained over a 10 day interval produced a quasisinusoidal variation and a peak-to-peak amplitude of about 0.08 mag in V when a period nearly identical to the orbital period of 1.844 days was used.

Pilachowski *et al.* (1995) reported the following revision in the abundance results for BD +13°13. Due to a misidentification of another observation as G30−52=BD +13°13, Pilachowski *et al.* (1993) inadvertently used the wrong equivalent widths in their abundance analysis. Using equivalent widths from a second spectrum of this star and correcting for the light of the secondary star following Spite *et al.* (1994), they obtain an iron abundance [Fe/H]$=-0.62$, consistent with Spite *et al.*'s results. They also find an equivalent width, corrected for secondary light, of 47 mÅ for the Li+Fe feature at 6707 Å.

Periodogram analysis of the first of our two seasons of photometric data gives comparably strong periodicities at 0.649 ± 0.001, 0.684 ± 0.001, 1.852 ± 0.003, and 2.171 ± 0.003 days. Of those, we presume that 1.852 days represents the rotation period because it closely agrees with the orbital period of Latham *et al.* (1988) while the other periods are assumed to be aliases of the true period. The data from the first season are plotted versus the 1.852 day period in Fig. 45, where the amplitude is seen to be approximately 0.05 mag. There is considerable scatter in the phase curve because of short-term variations in the light curve. The light curve from the following season closely resembles that of the first.

In our red-wavelength spectra we have detected weak absorption features of the secondary. Lines of both components are rotationally broadened with $v \sin i=19\pm2$ km s^{-1} for the primary and $v \sin i=14\pm5$ km s^{-1} for the very weak secondary features. Our value for the primary is consistent with that of Bergoffen *et al.* (1988) and Spite *et al.* (1994) and Favata *et al.* (1995). The absorption line-strength ratio for B/A is about 0.1 at 6430 Å, accounting for the significantly increased estimated uncertainty for the secondary. Because of the conclusion from spectrum-synthesis abundance work that the primary of BD +13°13 is a subgiant (Spite *et al.* 1994), we first compared its spectrum to those of G5−K0 subgiants. Although the spectrum of β Aql (G8 IV), which has a solar iron abundance, proved to be the most similar, the agreement is poor for one of the critical line ratios, resulting in an unsatisfactory fit. Unfortunately, we have no spectra of significantly metal-poor subgiants so we next compared the spectrum of BD +13°13 with those of metal-poor dwarfs. A weighted spectrum of the slightly metal-poor dwarf ξ Boo (G8 V; Wilson 1962) with [Fe/H]$=-0.20\pm0.08$ (Taylor 1994) provides a very good fit to the primary's critical line ratios and overall spectrum in the 6430 Å region. A comparison with τ Cet (G8 V), which has [Fe/H]$=-0.38\pm0.04$ (Taylor 1994), was tried as well. However, its lines are too weak compared to the *diluted* lines of the primary, and one of the critical line ratios does not fit. If the primary is indeed a dwarf, then the secondary must be of considerably later spectral type. Although the lines of the secondary are quite weak and broad, a reasonable combined fit can be obtained with an appropriately weighted spectrum of ξ Boo (G8 V) and HD 156026 (K5 V; Houk 1982). Thus, our spectrum comparison suggests that both stars are dwarfs and that the metallicity of this system is rather close to the solar value. We caution, however, that the spectrum of BD +13°13 has not been compared with those of metal-poor subgiants, which might produce a different result.

Our minimum radius of 0.7 $R_\odot$ for the primary, determined from our $v \sin i$ and rotation period, is consistent with either a dwarf or subgiant. Our estimated abundance is in rough agreement with recent determinations from high-dispersion spectrograms. Those recent results suggest that BD +13°13 has an iron abundance much closer to the solar value than the extremely large metal deficiency attributed earlier to this system by two different groups who used different techniques. The dilution of the primary's lines by the continuum of the much fainter secondary is unlikely to be enough to cause such a discrepancy.

6.42 BD +30°2130

Our interest in BD +30°2130 was aroused by Pasquini *et al.* (1991), who showed that it has weak Ca II K emission. Previously, in a radial-velocity survey of metal-poor stars, Latham *et al.* (1988) discovered it to be a single-lined binary with a period of 6.57 days and a circular orbit. Laird *et al.* (1988) found it to be somewhat metal poor with [m/H]$=-0.67$. From a spectroscopic analysis Spite *et al.* (1994) concluded the star is probably a subgiant and obtained [Fe/H]$=-0.4$. They also determined $v \sin i=5\pm3$ km s^{-1}.

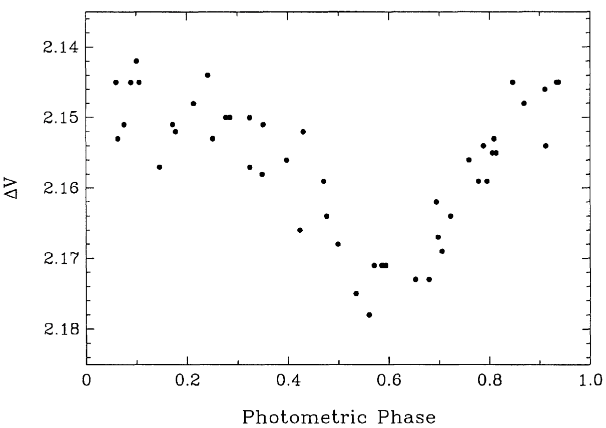

FIG. 46. Light curve of BD +30°2130 plotted against photometric phase calculated from the ephemeris HJD $2449300.0+6.80E$. The amplitude in V is 0.03 mag.

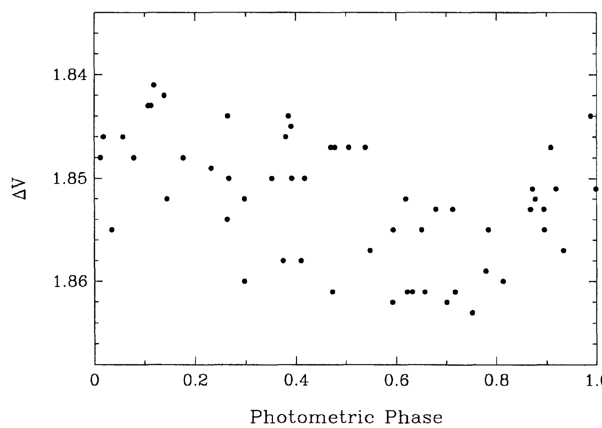

FIG. 47. Light curve of BD +36°2193 plotted against photometric phase calculated from the ephemeris HJD $2449300.0+8.31E$. The amplitude in V is only 0.015 mag.

So far, we have collected two seasons of photometry for BD +30°2130. Periodogram analysis of the first season gives $P=6.80\pm0.02$ days, making the star synchronously rotating. Because the amplitude decreased to nearly zero during the observing season, we show a phase plot (Fig. 46) of only the data between Julian date 2449285 and 2449440. For that interval, the amplitude was approximately 0.03 mag, a maximum for the two seasons of data we have. Our check star HD 99267 is also variable and is discussed separately.

Our two high-dispersion red-wavelength spectrograms of BD +30°2130 show only one set of lines. Visual comparison with several different G stars indicates an early-G spectral type. A comparison with an appropriately broadened spectrum of HR 4098 (F9 V), with [Fe/H]$=-0.48\pm0.2$ (Taylor 1994), shows that the lines of BD +30°2130 are significantly stronger. Its spectrum was then compared with broadened spectra of β CVn (G0 V), having [Fe/H]$=-0.18\pm0.06$, and HR 483 (G1.5 V), with [Fe/H]$=-0.0\pm0.06$, and appears to be intermediate in both spectral type and abundance. However, as noted previously, in the 6430 Å region there is little difference between the spectra of such dwarfs and subgiants, and so we classify the star G1 IV–V and estimate [Fe/H] $=-0.1$. The lines of BD +30°2130 have $v \sin i=7\pm1$ km s^{-1}, consistent with the result of Spite *et al.* (1994). The minimum radius of 0.94 $R_\odot$, computed from our photometric period and $v \sin i$, is consistent with either a dwarf or subgiant.

6.43 BD +36°2193

From a survey of metal-poor stars, Latham *et al.* (1988) identified BD +36°2193 as a single-lined spectroscopic binary with a period of 7.15 days and a circular orbit. Laird *et al.* (1988) determined [m/H]$=-0.64$. G. P. Kuiper (Bidelman 1985b) classified the star G2.

We have two seasons of photometric data for BD +36°2193. The last half of the first season displays the most coherent light variations, which have a period $P=8.31\pm0.04$ days, resulting in a rotation period that is 16% greater than the orbital period. For that portion of the data set, shown modulo that period in Fig. 47, the amplitude is only about 0.015 mag. Identical periods and amplitudes were found in the second season and also for the B data in both seasons. Season-two data are approximately 0.01 mag fainter on average than data from season one.

Our two red-wavelength spectra of BD +36°2193 show no evidence of secondary lines. Comparison of its spectrum with that of the metal-poor dwarf τ Cet (G8 V), with [Fe/H]$=-0.38\pm0.04$ (Taylor 1994), results in an excellent fit of the line depths, but the critical line ratios indicate that BD +36°2193 has a somewhat earlier spectral type. A second metal-poor dwarf, μ Cas (G5 V), with [Fe/H]$=-0.60\pm0.06$ (Taylor 1994), has lines that are significantly too weak compared to those of BD +36°2193. Thus, we classify the star as G6 V and estimate that [Fe/H]$=-0.4$. The lines of BD +36°2193 are slightly broadened, with $v \sin i=4\pm1$ km s^{-1}. Our $v \sin i$ and rotation period result in a minimum radius of 0.66 $R_\odot$.

6.44 BD +48°3686=SAO 51891

Pounds *et al.* (1991) identified BD +48°3686 as the optical counterpart to the *ROSAT* extreme ultraviolet source RE J2220+493. As part of a search for chromospherically active stars, Mulliss & Bopp (1994) obtained high-dispersion spectroscopic observations of the star, finding that both its Hα and Ca II 8542 Å lines were filled in by emission. They also noted that the lithium line was unusually strong in this star and pointed out that, if the star is a dwarf, it is very young. Jeffries & James (1994) likewise found a strong lithium line as well as a $v \sin i$ of 20 km s^{-1}, and suggested that the star is a single dwarf. Jeffries (1995) presented updated results including individual velocities and a revised $v \sin i$ of 15 km s^{-1}. As Table 2 shows, we could find no published *UBV* photometry.

We have two seasons of photometry for BD +48°3686. Periodogram analysis of the second season finds comparably strong periods at $P=2.42\pm0.01$ days and $P=1.70\pm0.01$ days. Since either of these periods, combined with the spectral type and $v \sin i$, would give a reasonable minimum radius, we simply adopt the slightly stronger 2.42 day period as the rotation period of BD +48°3686. In the B data this

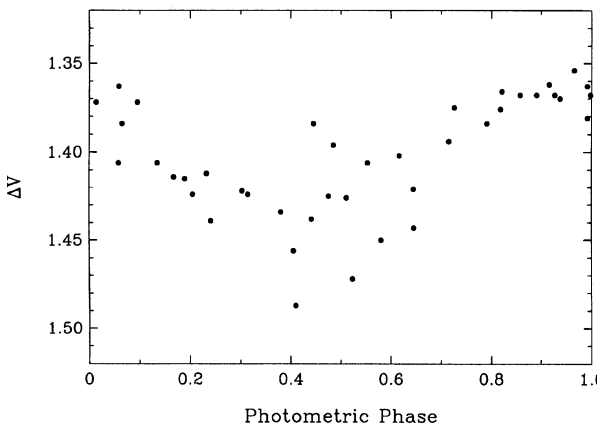

FIG. 48. Light curve of BD +48°3686 plotted against photometric phase calculated from the ephemeris HJD 2449600.0+2.42*E*. The amplitude in *V* is 0.08 mag.

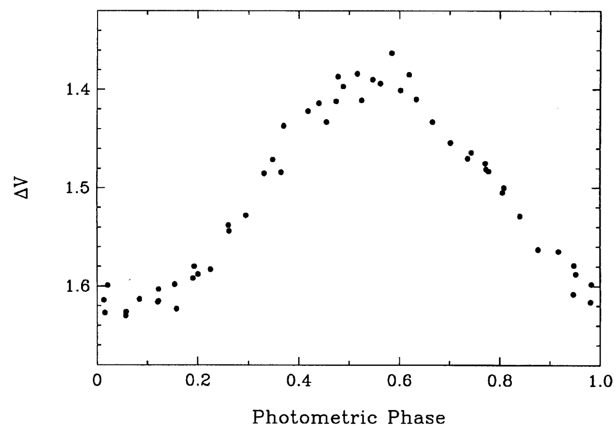

FIG. 49. Light curve of BD +70°959 plotted against photometric phase calculated from the ephemeris HJD 2449300.0+14.24*E*. The amplitude in *V* is 0.23 mag.

period is also found as the somewhat stronger of the two. Data in *V* from the second observing season are plotted against the 2.42 day period in Fig. 48. The amplitude is approximately 0.08 mag, but with significant cycle-to-cycle variation in the depth of minimum. The light curve from the first observing season is essentially the same as the second.

So far we have obtained four spectroscopic observations of BD +48°3686. Our average velocity of -19.8 ± 0.2 km s^{-1} shows no evidence for variability and is in excellent agreement with Jeffries (1995) average of -19.4 km s^{-1} from four observations, supporting the conclusion that the star is single. Comparison with standards indicates a spectral type of K1 V. We determine an equivalent width of the lithium line similar to that of Mulliss & Bopp (1994) and Jeffries & James (1994) while our $v \sin i = 16\pm1$ km s^{-1} is nearly identical to the revised value of Jeffries (1995). The $v \sin i$ and rotation period result in a minimum radius of 0.77 $R_\odot$, indicating an inclination close to 90°. We agree with the conclusion of Mulliss & Bopp (1994) and Jeffries & James (1994) that BD +46°3686 is similar to the age of the Pleiades cluster or possibly younger.

6.45 BD +70°959=ET Dra

BD +70°959 is a strongly emitting x-ray source that was on our program and included as a candidate in *CCABS II* because Silva *et al.* (1985) had detected strong Ca II H and K emission, estimated a rapid rotation of $v \sin i = 30-40$ km s^{-1}, and despite an apparently constant radial velocity, suspected it might be a synchronously rotating star in a binary with a period less than a few days. Shortly thereafter, Fleming *et al.* (1987) concluded that BD +70°959 is a single rapidly rotating star of type K5 IV. Significantly revised spectroscopic parameters for BD +70°959, including $v \sin i = 19$ km s^{-1} and a spectral type of K0 III as well as the conclusion that the star is single, first appeared in Ambruster *et al.* (1991), where followed by Fekel & Balachandran (1993), and are more extensively discussed in Ambruster *et al.* (1995). Those authors also determined that this giant has a relatively large log lithium abundance. Ambruster *et al.* (1995) showed the star to be 200–400 pc above the galactic plane, indicating that it belongs to the Intermediate- or even Old-Disk population. In an abstract, Bergin *et al.* (1988) reported low amplitude photometric variability with a period of a few days. More recently, Jetsu *et al.* (1992) presented extensive *UBVRI* photometry that showed definite variability, with a full range of almost 0.3 mag in *V* and a photometric period of 13.982 ± 0.008 days. They concluded that their *UBVR* photometry was consistent with a K0–1 III spectral type. From 9 radial velocities they also found a period of 13.91 ± 0.02 days and an amplitude of 5 km s^{-1}, but could not decide whether this was evidence of orbital motion in a single-lined binary or merely a consequence of line profile asymmetries in a single spotted star. On the strength of the photometry of Bergin *et al.* (1988) and Jetsu *et al.* (1992), BD +70°959 was designated ET Dra, as a variable of the FK Comae type, in The 72nd Name List of Variable Stars (Kazarovets & Samus 1995). The magnitudes in our Table 2 are means taken from Jetsu *et al.* (1992, Table II, subset 2).

The third of our three seasons of photometry for BD +70°959 is plotted in Fig. 49. Periodogram analysis of those data gives the rotation period $P = 14.24\pm0.02$ days, slightly longer than the value of Jetsu *et al.* (1992). For the third season the amplitude of variability is 0.23 mag while the first two seasons have slightly smaller amplitudes of 0.17 mag.

As mentioned above, the conclusion that the star is single as well as our spectral type of K0 III and $v \sin i = 19\pm2$ km s^{-1} are extensively discussed by Ambruster *et al.* (1995). We note that the mean velocity of our seven observations alone is 12.2 ± 0.3 km s^{-1}, consistent with the assumption that it is a single star. Apparent velocity variations probably result from the moderate line broadening combined with the distorted line profiles due to the changing spot distribution on this very active star. The minimum radius of this unusual giant is 5.3 $R_\odot$. This star is another member of the group of moderately rapidly rotating chromospherically active single giants (Fekel & Balachandran 1993).

The unusual rapid rotation and lithium abundance of BD +70°959 make its evolutionary state uncertain since the

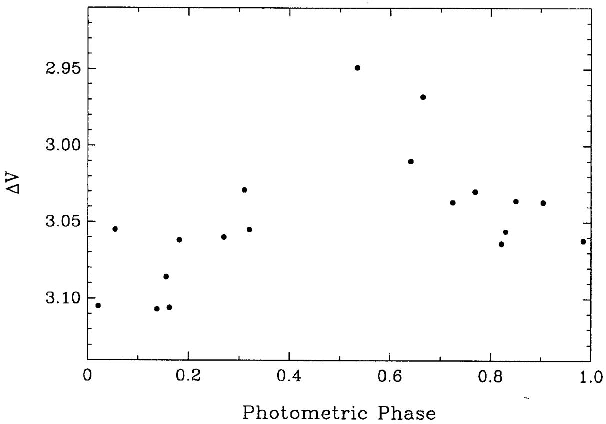

FIG. 50. Light curve of 1E2349.8−0112 plotted against photometric phase calculated from the ephemeris HJD 2448900.0+1.145E. The amplitude in V is 0.12 mag.

single giant is located well above the galactic plane. While the rapid rotation might result from a coalesced binary, similar to the scenario argued for FK Comae (Bopp & Rucinski 1981; Bopp & Stencel 1981), such coalescence should have depleted the surface lithium.

6.46 *1E2349.8−0112*

Fleming *et al.* (1989) identified a late-type star with the x-ray emission source 1E2349.8−0112. They concluded that it was apparently single, classified it K0 III, and determined a $v \sin i$ of 50 km s^{-1}. Favata *et al.* (1993) found that the star has a strong lithium line and proposed that it is a likely pre-main-sequence candidate. In a recent paper Favata *et al.* (1995) determined $v \sin i = 64$ km s^{-1} from their spectrum. As Table 2 shows, we found no published *UBV* photometry of this star.

We have two seasons of photometry for 1E2349.8−0112, the faintest star on our observing program. The data are sparse because its relative faintness makes it difficult for our APT to acquire it and because it is not observed when the moon is up. Therefore, aliases in the periodogram complicate the identification of the true period. The four strongest periods in the first season are 0.525, 0.884, 1.145, and 7.76 days. The second season gives nearly identical results. The considerations discussed below lead us to prefer the 1.145 day period. The first season is plotted modulo this period in Fig. 50. The amplitude is roughly 0.12 mag but the scatter in the phase plot indicates significant cycle-to-cycle variation.

From six spectroscopic observations we determine a mean velocity of 13.6±0.2 km s^{-1}, supporting Fleming *et al.*'s (1989) claim that the star is single. We determine $v \sin i = 41 \pm 3$ km s^{-1}, significantly smaller than previous values. Because of this line broadening, it is rather difficult to determine an accurate spectral type in the 6430 Å region, but mid-G is estimated. While the Hα line core is significantly filled in by emission, it has rather broad wings. The strength of the wings indicates that the star is not a giant but more likely a dwarf or perhaps subgiant. Thus, we give a preliminary classification of G5: V. Observations of additional standards obtained at Hα are needed to constrain its spectral type further.

Our dwarf spectral classification eliminates the photometric period of 7.8 days because that period would imply a minimum radius of 6 $R_{\odot}$. Likewise, we have assumed that the shortest period, 0.525 days, is also an alias; if its radius equaled the solar value, an extremely large rotational velocity of 95 km s^{-1} would result. A similar assumption with the two remaining periods, 0.88 and 1.145 days, results in rotational velocities of 57 and 44 km s^{-1}, respectively. Soderblom *et al.* (1993b) have found three G dwarf rapid rotators in the Pleiades with rotational velocities of nearly 40 km s^{-1}. On this somewhat arbitrary basis we have assumed the period of 1.145 days, which results in a minimum radius of 0.93 $R_{\odot}$, although the 0.88 day period is certainly also possible. Obviously, additional observations will be necessary to confirm or reject our assumed period.

6.47 *Wa Tau 1*

Our interest in this star was aroused by the work of Walter (1986). In that paper he discussed x-ray, photometric, and spectroscopic data for a number of possible post-T Tauri stars. The object he called Tau 1 was the only early-K non-T Tauri star found to be a bright x-ray source in the Taurus fields, although its x-ray flux was highly variable. His low-resolution spectroscopic observations showed Hα and the Ca II H and K lines in emission while the upper Balmer series was observed to be in emission on one occasion. However, he found no lithium absorption, indicating that the star was not a pre-main-sequence star. Walter (1986) concluded by suggesting that the star is likely an RS CVn or related system with a spectral type of K0 IV. On the basis of its obviously strong activity, Strassmeier *et al.* (1993) made it a candidate in *CCABS II*. Its association with possible T Tauri stars has prompted additional observations of this star by others. Martin *et al.* (1994) obtained a spectrum that confirmed its lack of lithium and revealed it to be a double-lined spectroscopic binary. They also mentioned a private communication from R. Mathieu, who reported a short orbital period and that the system was not a member of the Taurus cloud. Comparison of the *UBV* photometry (Table 2) of Walter (1986) and Martin *et al.* (1994) may hint at variability. Finally, in the course of a long-term monitoring program of a sample of supposed weak T Tauri stars, Grankin (1994) claimed it to be variable with a period of 3.06 days, although he presented no phase diagram nor light curve of any sort.

Wa Tau 1 is one of the faintest stars on our photometric menu and, thus, for two seasons has tested the observing limits of our telescope. Periodogram analysis of the first season's data gives the rotation period $P = 1.487 \pm 0.002$ days but an alias of comparable power exists at $P = 3.04 \pm 0.01$ days. In fact, the latter period is practically identical to that claimed by Grankin (1994). On the basis of the results discussed below, we believe that the shorter period is correct. Data from the first season are plotted modulo our 1.487 day period in Fig. 51. The rotational amplitude is approximately 0.04 mag. The second season gives the same results except

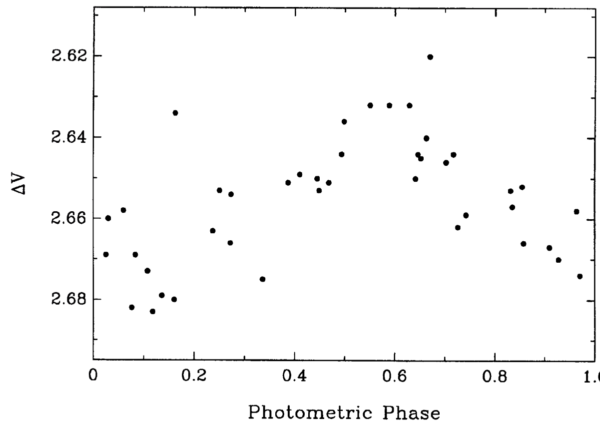

FIG. 51. Light curve of Wa Tau 1 plotted against photometric phase calculated from the ephemeris HJD $2449200.0+1.487E$. The amplitude in V is 0.04 mag.

the mean magnitude of the star has decreased about 0.04 mag.

Wa Tau 1 was, likewise, one of the faintest stars we observed spectroscopically and could be observed only on nights with seeing about 1″ or better. Our high-dispersion red spectra also show that it is double lined. The line-strength ratio is about 0.67 and both stars have similar rotational broadenings of 16 ± 2 km s^{-1}. The critical line ratios of late-G and early-K subgiants, including the K0 IV type suggested by Walter (1986), do not fit those of Wa Tau 1. Instead the best fit appears to be with HR 511 (K0 V; Wilson 1962) and HR 8832 (K3 V) for the primary and secondary, respectively. Even with this combination, however, many of the lines of the combined spectrum fit are not strong enough, suggesting that Wa Tau 1 is more metal rich than the Sun. A 3.04 day photometric period results in a minimum radius of 1 $R_\odot$ for both stars, obviously too large for K dwarfs, indicating that period to be an alias. The alternate period of 1.49 days reduces the minimum radius to 0.5 $R_\odot$, quite consistent with the dwarf luminosity class. On the assumption that the stars have synchronized rotation, we predict a similar orbital period, a prediction confirmed by Mathieu & Torres (1995).

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