

OBSERVATIONS OF ACTIVE CHROMOSPHERE STARS

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ABSTRACT

Since 1980, a program of spectroscopic and photometric monitoring of active-chromosphere RS CVn and BY Dra stars has been carried out at Cloudcroft and Kitt Peak Observatories. The results of the first 2 years of such monitoring, involving 10 stars, are presented here. Light curves are given for the RS CVn system HD 26337 and for the BY Dra variables HD 175742 and Gliese 410. The dK5e star BD +26°730, shown to vary on a 50–60 year time scale by Hartmann *et al.*, continues the decline in brightness it began in the late 1970s. A new photometric minimum (presumably a time of *maximum* chromospheric activity) is due near 1990.

Additionally, the FK Com star HD 199178 (G5 III–IV) is shown to be photometrically variable with a rotation period of 3.337 days. The behavior of the light curve of HD 199178 as well as the H α emission profile of the star suggest that starspots are the origin of this variability; there is no evidence that the light curve is the result of mass transfer in a binary of extreme mass ratio, which Walter and Basri suggest as a model for FK Com itself.

Seven active-chromosphere binaries were also observed with the *IUE* satellite in 1981 January. Mg II emission was detected in all the stars, and the emission-line surface flux increased with decreasing orbital (rotational) period. The system BD +26°730 ($P = 1.8$ days) proved to have the most interesting UV spectrum, with emission-line surface fluxes in He II, C IV, and N V 50–200 times the quiet-Sun values, making it the most chromospherically active dK–M star yet observed in the UV.

Subject headings: photometry — stars: binaries — stars: chromospheres — stars: variables — ultraviolet: spectra

I. INTRODUCTION

Spectroscopic signatures of stellar chromospheric activity are readily observable. In the optical, the emission lines of Ca II and H α are present in the spectra of BY Dra and RS CVn stars (Hall 1976); He I $\lambda\lambda$ 5876, 6678 and the Na D lines are found in emission in flare stars (Giampapa *et al.* 1978). In the ultraviolet, the chromospheric/transition-region emission spectrum is prominent in active-chromosphere stars, with emission-line surface fluxes enhanced by factors of 10–100 compared with the quiet Sun (Linsky *et al.* 1982). Thus the detection of any of these emission features will tag a star as surface active.

Broad-band photometry may be also used to discover (or confirm) a high level of chromospheric activity, through detections of light variability due to cool starspots on rotating stars. Historically this was the first

technique used to investigate the relationship between solar and stellar activity (Krzeminski 1969 and references therein).

Photometric and spectroscopic *monitoring* of stellar activity has been limited by human and other natural factors. Photometric observations over many seasons have yielded information on the global evolution of stellar active regions (Oskanyan *et al.* 1977; Vogt 1981; Dorren and Guinan 1982), and have hinted at starspot cycles analogous to the 22 year magnetic period of the Sun (e.g., Wilson 1978).

This paper presents new photometric and spectroscopic observations of active-chromosphere RS CVn, BY Dra, and FK Com stars. Deliberate emphasis has been placed on observations of stars that have been previously examined for variability. Combining these new data with the results of Bopp *et al.* 1981 (hereafter Paper I), we have a 2–3 year baseline of photometric data on several objects. This paper reports the first results of our synoptic monitoring program of many active chromosphere stars.

II. OBSERVATIONS

We obtained photometric and spectroscopic observations of 10 known or suspected active-chromosphere

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TABLE 1
STARS OBSERVED PHOTOELECTRICALLY

Name	Observation Interval	C1	C2	$\sigma_y(\text{Star} - \text{C1})$	$\sigma_y(\text{C1} - \text{C2})$	N	$P(\text{phot})$ days
HD 1833	7/80–1/81	HD 1680	HD 1834	0.007	0.004	15	34.46 ^a
HD 26337	10/80–2/81	HD 25852	HD 25954	0.016	0.003	14	2.049 ± 0.001
BD + 26° 730	12/80–3/81	+ 25° 720	+ 27° 683	0.003	0.002	17	...
Gliese 410	3/80–6/80	...	+ 23° 2297	...	...	16	2.935 ± 0.001
HD 136905	5/81–6/81	− 06° 4181	− 05° 4069	0.011	0.004	7	5.586 ± 0.002 ^b
HD 143313	1/81–5/81	+ 26° 2762	+ 27° 2563	0.008	0.002	17	...
BD + 18° 3497	3/81–6/81	+ 18° 3480	+ 19° 3442	0.004	0.002	16	...
BD − 06° 4738	3/81–6/81	− 05° 4622	− 05° 4620	0.004	0.003	12	...
HD 175742	3/81–6/81	+ 24° 3586	+ 24° 3579	0.013	0.002	12	2.900 ± 0.001
HD 199178	6/80–6/81	+ 43° 3780	+ 42° 3913	0.010	0.002	28	3.337 ± 0.001

^aLines *et al.* 1982.

^b11^d12 period equally possible (see text).

^cBopp *et al.* 1981 find $P(\text{phot}) = 9^{d}60 \pm 0.01$ during the interval 1979 Sep–1980 Oct.

objects during 1980–1982. Most of the data are photometric, obtained as part of the Cloudcroft Observatory Guest Investigator program. Differential Strömgren b and y measures were made following the observing procedures described in Bopp, Noah, and Klimke (1980). The program and comparison stars are listed in Table 1. As in Paper I, we also tabulate the quantity σ , the standard deviation of the series of N nights of observation. Table 1 gives the values of σ in magnitudes for the differential measures (program star minus C1) and (C1 minus C2). Significant variability is present when $\sigma > 0.01$ mag, as was the case in prior surveys (Paper I).

Spectroscopic observations of a few of the stars in Table 1 were obtained using the coude Feed Telescope at Kitt Peak National Observatory. Photographic spectra of the blue region, including the Ca II H and K lines, were obtained at a dispersion of 17 \AA mm^{-1} . The resolution of these spectrograms was 0.3 \AA , with signal-to-noise of order 40:1. Some objects were observed near the H α region using an RCA CCD detector at a dispersion of 15 \AA mm^{-1} , yielding a resolution of 0.9 \AA with a signal-to-noise of 40–50:1.

Seven objects, including the highly active BY Dra star BD + 26° 730, were also observed using the low-resolution short wavelength (SWP) and long wavelength (LWR) modes of the *International Ultraviolet Explorer* (IUE) satellite (Boggess *et al.* 1978). The resolution of these data is about 6 \AA , and the data were obtained using the large ($10'' \times 20''$) aperture. Reduction to absolute fluxes was performed using reduction facilities at JILA and the recommended calibrations. The Mg II fluxes were extracted from LWR-LORES spectra by integrating the monochromatic flux points above zero flux, between the absorption minima flanking the emission (short wave to long wave). We chose to integrate all flux above zero following suggestions by the Colorado group that the chromospheric flux is best measured this

way because simple extrapolation to line center of the photospheric line wings overlooks the fact that a non-chromospheric star would possess a zero intensity Doppler line core. Admittedly, at low resolution, the Mg II features are not precisely determined with scattered light effects, etc. In a sense our measures may be upper limits of emission fluxes derivable from LWR-LORES data, but by measuring from zero we hope to avoid ambiguities associated with repeatability of photospheric line wing extrapolations, particularly for the hotter stars.

The objects observed with IUE and the relevant exposure data are given in Table 2.

III. OPTICAL RESULTS

We discuss the optical photometric and spectroscopic results on individual stars below.

a) HD 1833

This star has been assigned the composite spectral type K1 III+F by Bidelman and MacConnell (1973), who also noted the presence of Ca II H and K emission on objective prism spectra. Fekel (1980) obtained high-resolution Reticon and image-tube spectrograms of HD 1833, noting rotationally broadened absorption lines ($v \sin i \sim 20\text{--}25 \text{ km s}^{-1}$) and H and K emission a bit weaker than that seen in V711 Tau (HR 1099). The star is very likely an RS CVn variable.

A single KPNO spectrogram of the H and K region that we obtained on 1980 September 24 shows strong emission reversals (Fig. 1). Quantitative measures of Ca II emission fluxes are possible using the relation between $(V - R)$ color and the surface flux in the interval $\lambda\lambda 3925\text{--}3975$ (Linsky *et al.* 1979). The H and K surface fluxes seen in HD 1833 are in fact comparable to the values observed for V711 Tau and other active RS CVn stars (Table 3).

TABLE 2
IUE OBSERVATIONS OF ACTIVE-CHROMOSPHERE STARS

Star	Type	IUE Image	Year/Day	Start Time (UT)	Duration (min)
BD + 26° 730 ...	dK5e	LWR 9654	81/006	23:46	3
		SWP 10987	81/006	23:55	150
HD 26337	G0 III-IV	LWR 9658	81/007	07:39	6
HD 184467	dK0	LWR 9641	81/005	05:33	6
HD 185151	K2 III	LWR 9637	81/005	01:20	3
		LWR 9638	81/005	02:03	8
HD 223778	dK3 + dK3	SWP 10958	81/005	01:29	90
		LWR 9639	81/005	03:51	5
		SWP 10959	81/005	04:00	60
HD 283882	dK3 + dK3	LWR 9657	81/007	06:09	8
		SWP 10989	81/007	05:04	100
		LWR 9642	81/005	06:13	5
AS Dra.....	dG3 + dK0	LWR 9643	81/005	06:59	8
		SWP 10960	81/005	06:24	70

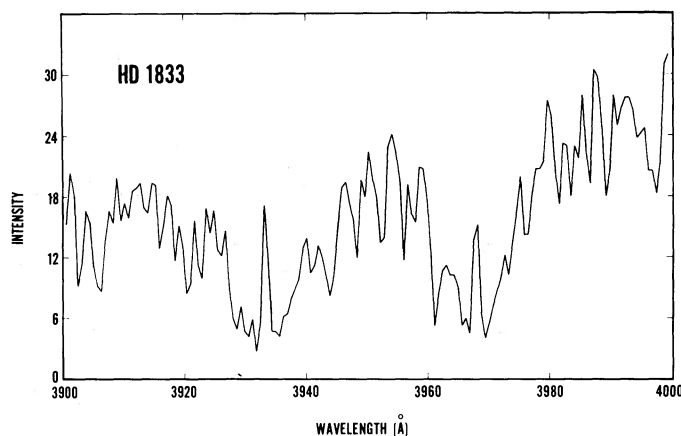


FIG. 1.—Ca II emission in HD 1833, from a KPNO coude spectrogram obtained 1980 Sep 24 UT

TABLE 3
Ca II SURFACE FLUXES OF ACTIVE CHROMOSPHERE STARS

Star	$V - R^a$	$F(K_2)$ ($\text{ergs cm}^{-2} \text{s}^{-1}$)	$F(H_2)$
HD 1833	(0.69)	3.1(+6)	3.3(+6)
HD 199178	0.67	5.6(+6)	5.4(+6)
BD + 26° 730 ...	(1.00)	1.1(+6)	9.3(+5)
V711 Tau ^b	(0.77)	2.9(+6)	2.6(+6)
EQ Vir ^c	(1.00)	8.4(+5)	6.3(+5)

^a Estimates from spectral type in parentheses.

^b Bopp 1982.

^c Linsky *et al.* 1979.

The absorption lines on our plate are not absolutely sharp, which would be consistent with Fekel's estimate of rotational broadening near 25 km s^{-1} . There is no sign of a secondary spectrum in the blue, and overall the spectrum is a close match to that of 39 Cet (G5 III), Ca II emission and all. In view of the recent discovery of flare activity on 39 Cet and the presence of a hot

companion (Simon, Fekel and Gibson 1982), IUE observations of HD 1833 might well prove interesting.

The photometric behavior of HD 1833 is puzzling. During 1980 July–October, our data suggest the star is variable, though we have too few observations to determine a reliable period. During 1980 late December–1981 January, however, the star showed *no* variability.

Lines *et al.* (1982) report photometry of HD 1833 over the interval 1980 September–December, using the same comparison star, that shows the star to be variable with $P = 34.46$ days, and an amplitude 0.1 mag. It appears that HD 1833 ceased its variability rather abruptly near the end of 1980. Such behavior is rare, but not unprecedented, among active-chromosphere stars, having been reported in the BY Dra star HD 175742 in Paper I.

b) HD 26337

This star was classified as G5 IV by Bidelman and MacConnell (1973); Fekel (1980) noted the presence of

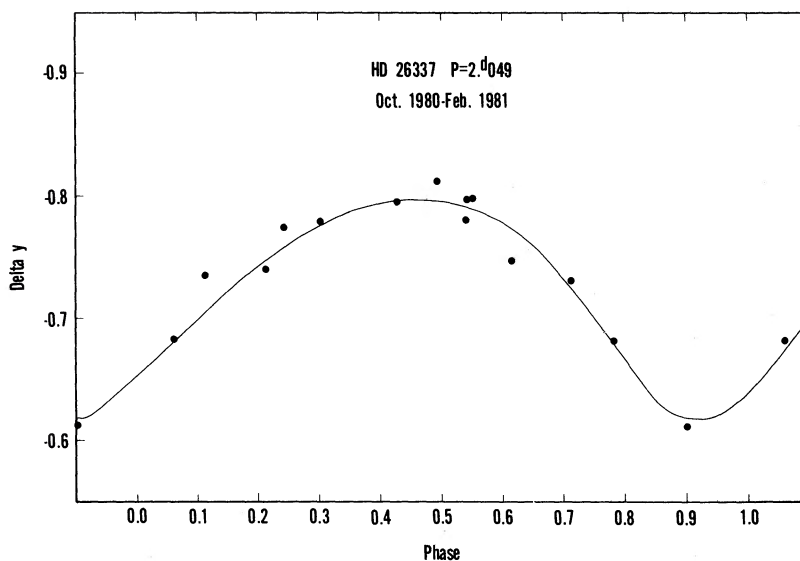


FIG. 2.—Differential y measures of HD 26337 (in the sense HD 26337 minus HD 25852). Phase is computed from $\phi = \text{JD } 2,444,635.65 + 2.049E$.

somewhat weak H and K reversals, and Reticon observations of the red region showed a large $v \sin i$ ($35\text{--}40 \text{ km s}^{-1}$). Additional spectroscopy and photometry of the star have been reported by Fekel *et al.* (1982), who gave a preliminary orbital period $P = 2.044$ days, while the star varied by 0.2 mag in V with a period of 2.038 days.

Our photometric observations of HD 26337 extend over 3 months, partially overlapping the observing interval of Fekel *et al.* We find HD 26337 to be variable by 0.2 mag in y ; standard period finding techniques applied to our measures yield $P(\text{photometric}) = 2.049$ days (Fig. 2). We note that neither the orbital nor the photometric periods given by Fekel *et al.* will fit our data set. The lack of agreement between the orbital period and our photometric period is not surprising; in few, if any, RS CVn systems do we find the stars rotating *precisely* in synchronism. The differences between our photometric period and that given by Fekel *et al.* may well reflect the difficulty of deriving rotation periods for active stars from data sets obtained over long time intervals, over which spot evolution must surely occur. The data presented by Fekel *et al.* bridge nearly 200 rotational/orbital cycles of HD 26337, and splicing such data together has its uncertainties.

c) $BD + 26^\circ 730$

This remarkable dK5 star shows strong Ca II H and K emission as well as H α emission that is generally characteristic of BY Dra stars. The star was shown to be photometrically variable in Paper I. A more complete discussion of the star may be found in Hartmann *et al.*

(1981). Of particular interest is the smooth variation in mean light suggestive of a 60-year spot cycle.

In contrast to the erratic fluctuations of 0.07 mag that were seen during 1979 October–1980 October (Paper I), our photometry during the first part of 1981 shows the star to be quite constant in brightness. The observed σ of only 0.003 mag is comparable to the scatter in the (C1 minus C2) measures. However, $BD + 26^\circ 730$ was about 0.1 mag *fainter* in y in early 1981 compared with a year before. This significant result is consistent with the downward trend in brightness that the star began in the late 1970s (Hartmann *et al.* 1981). If the star behaves in a fashion similar to that seen in the interval 1920–1940, then a new photometric minimum is due about 1990.

We observed $BD + 26^\circ 730$ at KPNO in 1980 September, and have reported radial velocity results from our spectrograms in Hartmann *et al.* These data led to a derived orbital (and assumed rotational) period of 1.8 days, a much shorter period than the 4–5 average for the BY Dra group. The rotation-activity connection argues that the level of chromospheric activity on $BD + 26^\circ 730$ should be quite high, and this is apparently borne out by the intensely strong emission at Ca II H and K (Fig. 3). The Ca II emission surface flux measure (Table 3) shows comparably high values for $BD + 26^\circ 730$ and the active BY Dra star EQ Vir.

d) *Gliese 410*

This star is classified dM1 by Joy and Abt (1974), implying that Balmer emission is *not* visible in the blue region of the spectrum. However, Young (private communication) has observed Gliese 410 in the red, and

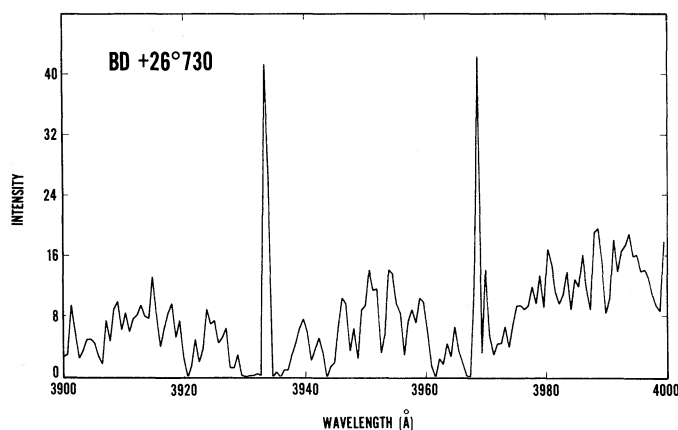


FIG. 3.—Ca II emission in BD +26°730, from a KPNO coude spectrogram obtained 1980 Sep 30 UT. Balmer H ϵ emission is visible \sim 2 Å longward of Ca II H.

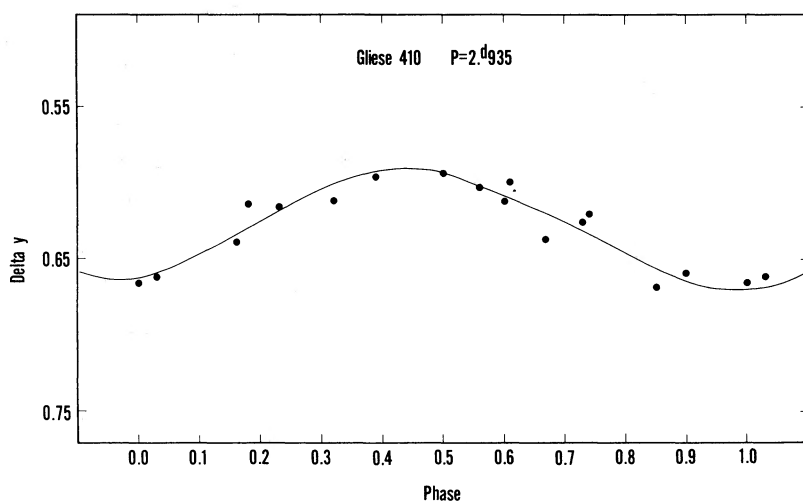


FIG. 4.—Differential y measures of Gliese 410 (in the sense Gliese 410 minus BD +23°2297). Phase is computed from $\phi = \text{JD } 2,444,311.74 + 2.935E$.

finds the H α line to be filled by chromospheric emission, implying the star should be a BY Dra variable. We observed Gliese 410 during the spring of 1980, and found it to vary by 0.1 mag in y . The photometric period we derive is 2.935 days, and our data are plotted with respect to this period in Figure 4. (The C1 originally chosen was BD +23°2293; this star appears variable by 0.1 mag in y .)

e) HD 136905

This star was classified K1 III+F by Bidelman and MacConnell, who noted the presence of Ca II emission in the spectrum. Burke *et al.* (1982) report the results of spectroscopy and photometry which indicate HD 136905 is a binary with a likely period of 11.12 days. The spectral type indicated on their high-resolution scans is

K0 III-IV, and the star was found to be an RS CVn with an amplitude of 0.1 mag in V .

Our Cloudcroft photometry was obtained over the same interval as that of Burke *et al.*, using the same comparison stars. The amplitude of variability is confirmed, and our y data points fit the double-peaked light curve given by Burke *et al.* quite nicely. However, all the photometric data may be somewhat better fitted using a period $P = 5.586$ days, about half the likely orbital period (Fig. 5). This same possibility was broached by Burke *et al.*, and it is clear that the orbital and rotational period of 11 days is quite tentative.

f) HD 143313

This dK double-line spectroscopic binary was first suggested as a likely BY Dra variable by Griffin (private

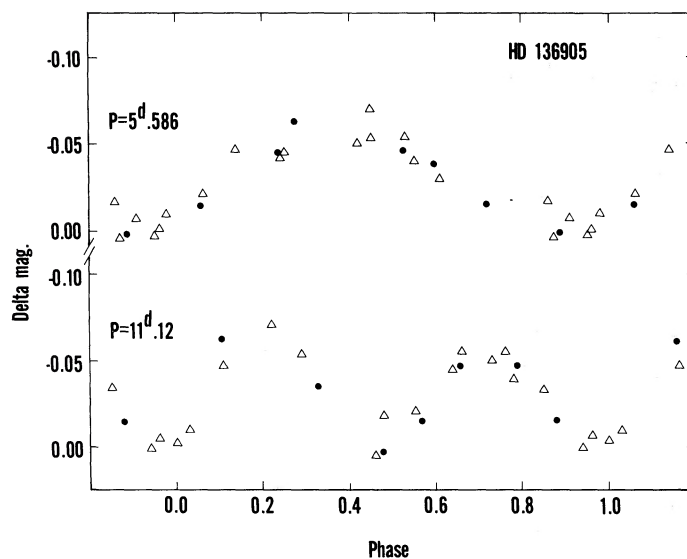


FIG. 5.—Photometry of HD 136905 plotted with respect to periods of $5^{\text{d}}.586$ (upper) and $11^{\text{d}}.12$. The solid circles are Cloudcroft differential y measures, the open triangles differential V measures from Burke *et al.* (1982). All the photometry is in the sense HD 136905 minus BD $-06^{\circ}4181$, with zero phase at JD = 2,444,678.4.

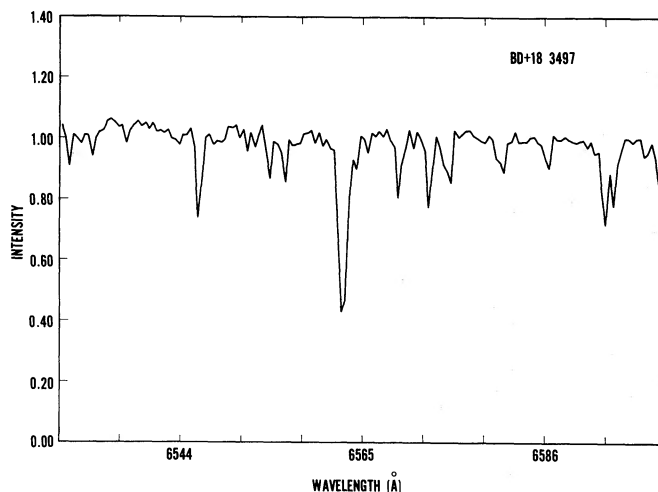


FIG. 6.—The $H\alpha$ region of BD $+18^{\circ}3497$, recorded with an RCA CCD detector at a resolution of ~ 0.9 Å. Despite relatively strong Ca II emission, $H\alpha$ shows no abnormalities. The star was constant in brightness over the interval of our observations.

communication) and subsequent photometry and $H\alpha$ spectroscopy (Paper I) confirmed its variability.

Although the value of $\sigma = 0.008$ mag given in Table 1 for HD 143313 would suggest it did not vary appreciably during the first half of 1981, our data actually show the star to vary by 0.1 mag during 1981 January–March. At the beginning of April, however, this behavior abruptly ceased; the star remained a constant 0.07 mag fainter than C1 (BD $+26^{\circ}2762$) for the next month. In contrast, HD 143313 varied from 0.03 to 0.15 mag fainter than C1 in 1980 (Paper I).

g) BD $+18^{\circ}3497$, BD $-06^{\circ}4738$

Both these stars of spectral type dK were included in our photometric program because of their relatively strong Ca II emission (+3 and +4, respectively, on Wilson and Woolley's 1970 scale). Despite this similarity with all the other BY Dra stars, these two objects showed no trace of light variability. Significantly, the $H\alpha$ profiles of the two stars appear completely normal (Figs. 6 and 7); there is no hint that the profiles are affected by any sort of chromospheric emission, as is

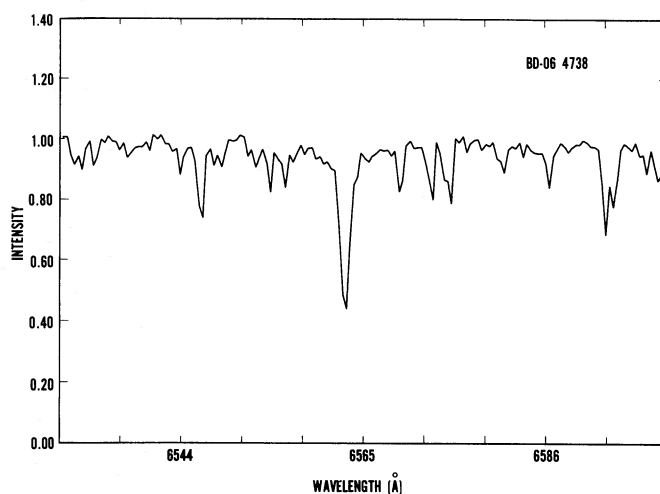


FIG. 7.—Same as Fig. 5, for the star BD $-06^{\circ}4738$ (also not photometrically variable)

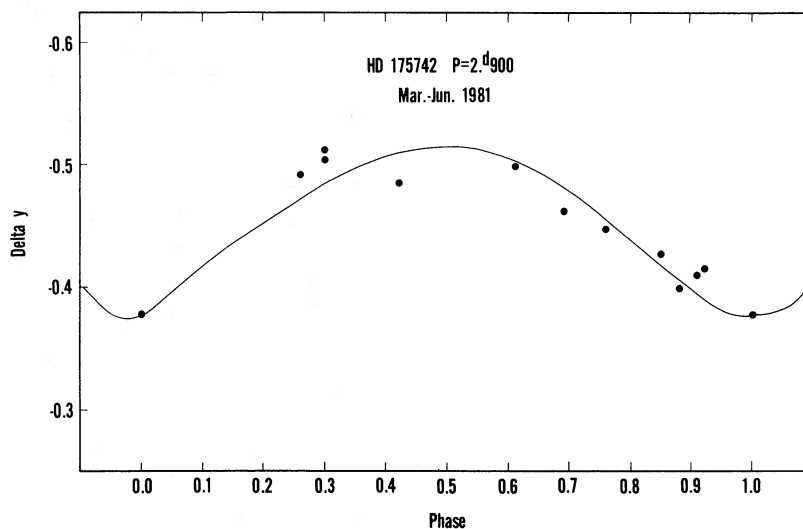


FIG. 8.—Differential y measures of HD 175742 (in the sense HD 175742 minus BD $+24^{\circ}3586$) during the interval 1981 March–June. Phase is computed from $\phi = \text{JD } 2,444,338.94 + 2.900E$.

commonly seen at $H\alpha$ in other BY Dra stars. We have noted this important difference in behavior of the Ca II and $H\alpha$ features in dK–M stars in Paper I: there is a continuous range of Ca II H and K emission intensities in late-type MS objects, but $H\alpha$ changes abruptly from a normal feature to a pure emission line. Only the stars with $H\alpha$ emission are BY Dra variables.

h) HD 175742

In Paper I we showed this dK star to have $H\alpha$ in emission and to be photometrically variable with a period $P = 2.898$ days, significantly longer than the 2.879 day orbital period derived by Imbert (1979).

Our Cloudcroft data from the spring of 1981 show the amplitude and mean light level to be equal to that given in Paper I, but the period is now 2.900 days (Fig. 8). Neither the orbital period nor the earlier photometric period provides an adequate fit to the 1981 data.

i) HD 199178

This rapidly rotating G5 IV star shows very strong H and K emission (Herbig 1958) as well as strong UV emission lines (Bopp and Stencel 1981). The lack of any velocity variations greater than $\pm 3 \text{ km s}^{-1}$ (Bopp 1982) argues that the star is not a conventional RS CVn star but rather a member of the FK Com class (Bopp and Stencel 1981). While FK Com itself has a well-

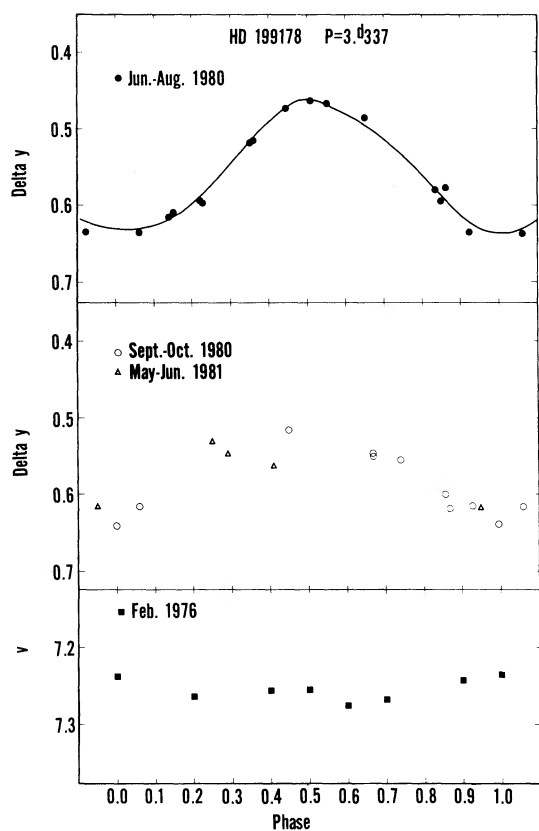


FIG. 9.—The light curve of the FK Com star HD 199178 over several time intervals. The differential y measures are in the sense HD 199178 minus BD +43°3780. Phase is computed from JD 2,444,395.70 + 3.337 E for the 1980–1981 measures; an arbitrary zero phase of JD 2,442,719.58 is used for the 1976 absolute photometry.

determined photometric period of 2.400 days (Rucinski 1981), the existing photometric data on HD 199178 was sufficient only to establish variability of 0.03 mag in V , with a likely period of 3–4 days (Bopp 1982).

The Cloudcroft data presented here are the first intensive set of photometric observations of HD 199178 and establish the period as 3.337 days (Fig. 9). There is evidence that the light curve shows sudden changes in shape: the 1980 June–August observations show a well-defined curve with y amplitude 0.16 mag. However, the data from 1980 September–October show the amplitude to have decreased to ~ 0.1 mag. Lastly, there are apparently intervals when HD 199178 may effectively cease to vary: photometry obtained at KPNO in 1976 (reduced to the Johnson system) shows no variation greater than ± 0.02 mag (Fig. 9).

The Ca II and H α profiles in HD 199178 have received limited attention from spectroscopic observers, but our latest results indicate that these lines are variable with unusual features. The Ca II reversals are extremely strong (Fig. 10). Though the *peak* Ca II intensity appears only comparable to the emission seen in typical RS CVn stars, marked rotational broadening has actually reduced their intensity with respect to the continuum by nearly a factor of 2. The surface flux in the H and K lines is nearly twice as great as what is seen in V711 Tau (Table 3). The Ca II lines are broadened to about the same degree as the photospheric absorption features; we measure $v \sin i = 80 \pm 10$ km s $^{-1}$ from our tracings. However, we see no central reversals or structure in the Ca II lines as has been reported by Herbig (1958). Though his single spectrogram of HD 199178 was of somewhat higher dispersion (10 Å mm $^{-1}$), our results presumably indicate a real profile change. Such profile variability has been seen to occur at H and K in FK Com (Bolton, private communication).

The H α profile exhibits similar variability. Figures 11 and 12 show two CCD scans of the red region of HD

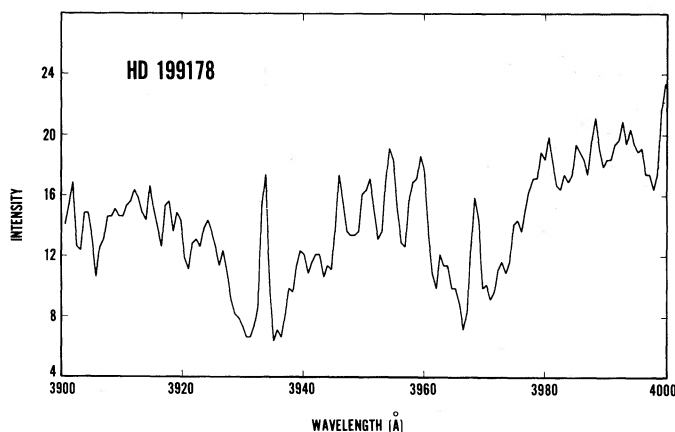


FIG. 10.—Ca II emission in HD 199178, from a KPNO coude spectrograph obtained 30 September 1980 UT

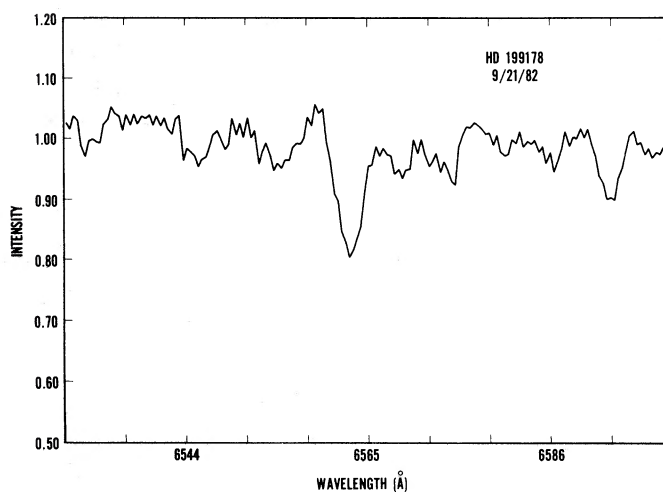


FIG. 11.—The $H\alpha$ region of HD 199178 on 21 September 1982 UT recorded with an RCA CCD detector at a resolution of $\sim 0.9 \text{ \AA}$.

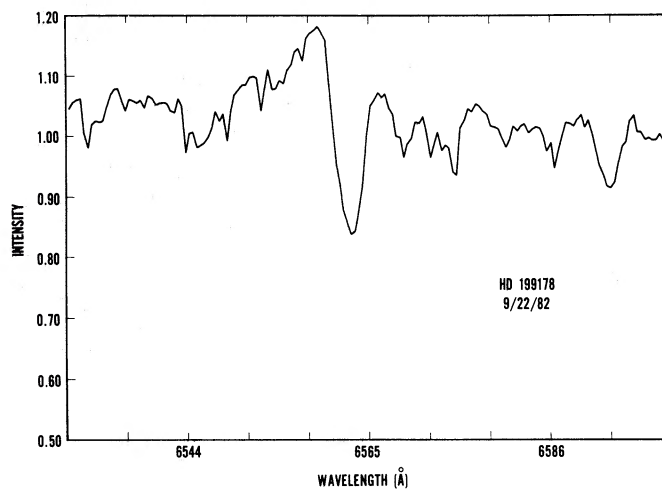


FIG. 12.—Same as Fig. 10, but one day later. Note the prominent blue emission wing of $H\alpha$.

199178 which show a striking change in the $H\alpha$ profile on successive nights. We suspect the enhanced emission seen on the night of 1982 September 22 UT is not a flare-related (transient) event, since two scans on that evening separated in time by 40 minutes show identical $H\alpha$ profiles. However, transient features at $H\alpha$ in FK Com are known to persist, varying slowly, over time scales of hours, so we cannot absolutely exclude the possibility of a flare. On the other hand, the profile variability may be caused by an active region rotating across the line of sight.

On both nights, the emission peak is blueshifted by $\sim 190 \text{ km s}^{-1}$ with respect to the $H\alpha$ absorption feature, which is at the photospheric velocity of the star. The origin of the velocity shift is not clear, but similar

behavior has been seen to occur in the spectra of several RS CVn stars (Bopp 1982).

IV. ULTRAVIOLET RESULTS

The seven stars that we observed with *IUE* are all spectroscopic binaries, with known orbital periods ranging from 1.8 days (BD +26°730) to 40.1 days (HD 185151). One object, HD 184467, has shown spectral line doubling on one occasion (McClure, private communication), and though the orbit has not been derived, the period is probably on the order of several weeks.

We detected Mg II $\lambda 2800$ emission in all of these objects; the SWP exposures to look for higher excitation chromospheric/transition-region features met with vary-

TABLE 4
IUE OBSERVED FLUXES (ergs cm⁻² s⁻¹)

Star	O I λ 1305	C IV λ 1550	Si II λ 1812bl	Mg II λ 2800bl
HD 26337	...	...	...	4.1 (-12)
HD 184467	...	...	...	5.2 (-13)
HD 185151	1.3 (-13)	< 9 (-14)	< 5 (-14)	4.1 (-12)
HD 223778	< 6 (-14)	2.0 (-13)	1: (-13)	6.5 (-12)
HD 283882	< 6 (-14)	< 2 (-14)	< 7 (-14)	4.9 (-13)
AS Dra	1.3 (-13)	< 4 (-14)	1.9 (-13)	1.9 (-12)

ing degrees of success, and sometimes we were only able to place upper limits on short-wavelength line fluxes. The detected emission line fluxes, or upper limits, for six of the objects (BD +26°730 to be discussed separately below) are given in Table 4.

The conversion of observed fluxes to the more astrophysically useful surface fluxes requires knowledge of the stellar angular diameter. To determine these values, we follow the technique outlined by Linsky *et al.* (1979), which uses the relationship between visual-band surface flux and ($V-R$) color (we assume no interstellar reddening or extinction for any of our objects) that has been found by Barnes, Evans, and Moffett (1978). In that case the stellar angular diameter ϕ' is related to V and ($V-R$) by:

$$\log \phi' = 0.7594 - 0.2V + 0.642(V - R)$$

for ($V-R$) > 0.80; a corresponding relation exists for bluer objects (Linsky *et al.* 1979). The ratio of surface flux \mathcal{F} to observed flux f is then given by:

$$\frac{\mathcal{F}}{f} = \left(\frac{4.125 \times 10^8}{\phi'} \right)^2.$$

We list in Table 5 the values of V and ($V-R$) for these stars that we have obtained from the literature, as well as the resulting values for ϕ' and \mathcal{F}/f . We must caution that in many cases ($V-R$) data have not been published for the stars, and it was necessary to use values appropriate for the (combined) spectral type; such values are given in parentheses in Table 5.

TABLE 5
 STELLAR PARAMETERS

Star	Other Names	Orbital P (days)	V	($V-R$)	ϕ' (milli-arcsec)	\mathcal{F}/f	
+26°730	Gl 171.2A	1.8	8.42	(1.00)	0.522	6.25 (17)
HD 26337	2.0	7.08	(0.50)	0.462	7.97 (17)
HD 184467	6.70	(0.64)	0.677	3.71 (17)
HD 185151	40.1	7.69	1.05	0.786	2.75 (17)
HD 223778	...	HR 9038	7.8	6.39	(0.82)	1.018	1.64 (17)
HD 283882	...	+24°692	11.9	9.67	(0.82)	0.225	3.37 (18)
AS Dra	HD 107760	5.4	8.2	(0.60)	0.320	1.66 (18)

The relevant line surface fluxes for six of the stars are given in Table 6. Of the four dwarf binary systems (HD 184467, 223778, 283882, and AS Dra), HD 184467 is clearly of much lower activity, judging by the weakness of its Mg II emission (six times less than the solar value). Despite its binary nature, the star is not a BY Dra variable. Photometry obtained over several months (Paper I) showed no sign of variability; presumably its long orbital period, resulting in a low rotation velocity, is the cause. AS Dra, the BY Dra variable HD 283882 (Bopp, Noah, and Klimke 1980), and HD 223778 (which resembles a BY Dra star in terms of spectral type, orbital period, and Ca II emission) all show UV emission line surface fluxes that are comparable to those seen in the active (but single) dwarfs ξ Boo A or ϵ Eri, but considerably lower than the fluxes seen in the flare/BY Dra star EQ Vir (Linsky *et al.* 1982). Significantly, the 4 day rotation period of EQ Vir is shorter than the observed photometric (rotational) periods of AS Dra, HD 223778 or HD 283882.

Both HD 185151 (Bopp *et al.* 1982) and HD 26337 are RS CVn systems. From our limited data, we can only note that the line surface fluxes are comparable to those reported by Hartmann, Dupree, and Raymond (1982) for the RS CVn systems HR 4665 (= DK Dra) and σ Gem. In view of the strength of the Mg II emission we observe in HD 26337, and its short orbital period, future SWP exposures are recommended.

The most interesting (and active) object that we observed with *IUE* was BD +26°730. The strength of the Ca II and Balmer emission seen in BD +26°730 suggests that chromospheric/transition-region emission in the UV should be correspondingly strong. The *IUE* observations in 1981 January showed strong Mg II, C IV, and N V emission that is characteristic of very active dMe/BY Dra stars (Fig. 13). The emission lines observed and their fluxes at the Earth are tabulated in Table 7. For comparison with other active-chromosphere dwarfs, the emission line flux at the stellar surface is given in column (4) of Table 7. This surface flux is computed using the parallax of 0''.060 given in Gliese's (1969) catalog, and an assumed radius of 0.8 R_{\odot} . The parallax given by Gliese is not in fact a measured

TABLE 6
SURFACE FLUXES

Star	O I λ 1305	C IV λ 1550	Si II λ 1812bl	Mg II λ 2800 bl
HD 26337	...	...	...	3.3 (6)
HD 184467	...	...	...	1.9 (5)
HD 185151	3.6 (4)	< 2.5 (4)	< 1.4 (4)	1.1 (6)
HD 223778	< 9.8 (3)	3.3 (4)	1.6: (4)	1.1 (6)
HD 283882	< 2.0 (5)	< 6.7 (4)	< 2.4 (5)	1.7 (6)
AS Dra	2.2 (5)	< 6.4 (4)	3.2 (5)	3.2 (6)

trigonometric parallax, but is instead spectroscopic, based on inferred Hyades membership. This admittedly has its uncertainties, but use of the relationship between $(V-R)$ color and visual surface flux (Barnes, Evans, and Moffett 1978) is made difficult since no $(V-R)$ color has yet been published for the star, and the amount of contribution from the stellar secondary to V and $(V-R)$ is unknown. However, if we assume no secondary contribution and choose $(V-R)=1.00$ (appropriate for dK5), then the surface fluxes derived from the two methods agree to within 30%, which probably represents the precision of these values.

Even with uncertainties as large as 30%, it is clear that the UV line surface fluxes for BD +26°730 are extremely high. If we compare our results with the published values for other flare/BY Dra stars given by Linsky *et al.* (1982) or Butler *et al.* (1981), we find BD +26°730 to be the most surface-active dK-M star yet observed in the UV. (Since simultaneous ground-based photometry of BD +26°730 did not take place during the *IUE* exposures, we cannot rule out the possibility of enhancement of the UV lines due to a stellar flare.) Ratios of observed surface flux to corresponding quiet-Sun values are given in the last column of Table 7.

V. SUMMARY AND CONCLUSIONS

We have presented "first epoch" photometric and spectroscopic observations of 15 BY Dra, RS CVn, and FK Com stars. These stars and about two dozen additional active-chromosphere objects are presently being monitored photometrically at Kitt Peak. It is hoped that this observational program will provide the information necessary to determine, for example, the time scale for significant evolution or disappearance of a stellar active region, and how this behavior might vary for different values of spectral type or rotation speed.

It is already clear that changes in the size and location of starspots can take place on time scales as short as 10 days (see also Bartolini *et al.* 1983). We noted in Paper I that the BY Dra star HD 175742 was constant in brightness in 1980 mid-October, but resumed its variability by the end of that month (Henry 1981). Similar behavior has been demonstrated to occur in the RS CVn system HD 1833 and the BY Dra star HD 143313 in this paper. There are *sudden* intervals when photometric variability is not seen; these intervals are apparently *not*

TABLE 7
UV EMISSION-LINE FLUXES IN BD +26°730 (ergs cm⁻² s⁻¹)

Line (1)	λ (Å) (2)	Observed Flux (3)	Surface Flux ^a (4)	Surface Flux Quiet Sun (5)
N V.....	1239	18.7 (-14)	1.6 (5)	188
O I.....	1305	16.2 (-14)	1.4 (5)	35
C II.....	1335	30.8 (-14)	2.6 (5)	57
C IV.....	1550	47.3 (-14)	4.0 (5)	70
He II.....	1640	11.9 (-14)	1.0 (5)	78
C I.....	1657	17.9 (-14)	1.1 (5)	21
Si II.....	1808, 1817	26.1 (-14)	2.2 (5)	14
Mg II.....	2795, 2803	3.8 (-12)	3.2 (6)	2.6

^aDerived using parallax of 0".060, $R = 0.8 R_{\odot}$.

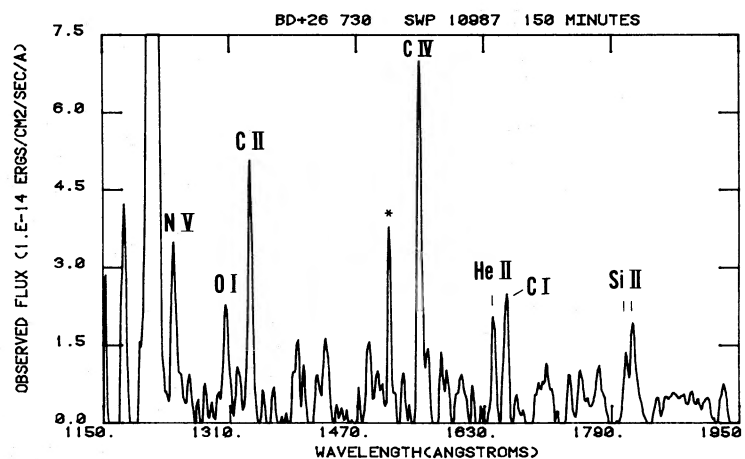


FIG. 13.—*IUE* SWP spectrum of BD +26°730 (1981 Jan) calibrated in apparent flux units at the Earth. A radiation noise spectra is marked by an asterisk.

times when the star is free of spots, since the stars do not approach maximum brightness. Rather, there must be some sudden spot migration, resulting in a uniform longitudinal distribution or else a grouping of spots near the rotation pole.

Despite the fact that large polar spot groups are unprecedented in the solar case, evidence in support of their frequent occurrence on BY Dra and RS CVn stars continues to accumulate. In addition to the photometric indications in this paper, Oskanyan *et al.* (1977) also discuss abrupt changes in the light curve of BY Dra itself, and invoke polar spots to explain this. Application of Doppler imaging techniques to V711 Tau (Vogt and Penrod 1982) have established the existence of polar spot groups on the active stellar component. It will be important to see if monitoring of surface features via Doppler imaging confirms the phenomenon of rapid poleward migration that is suggested by the photometry.

We also note that the HD 26337 system should be considered an ideal target for Doppler imaging. Our photometric observations and those of Fekel *et al.* (1982) establish the star as very chromospherically active. The G5 IV spectral type is very close to that of the active component in the V711 Tau system, and implies a radius $\sim 3 R_{\odot}$. The observed $v \sin i$ of 35–40 km s⁻¹ and the 2 day rotation period then suggest that HD 26337 is viewed close to the pole, with $i \sim 30^{\circ}$. Such a configuration is optimal for determining unique two-dimensional maps of starspots (sizes, shapes, and locations) via Doppler imaging (Vogt 1982). Lastly, HD 26337 is bright ($V \sim 7.1$) and the secondary star is much fainter than the primary (no secondary spectrum was evident on Fekel's high signal to noise Reticon scans), permitting useful line profile information to be obtained even at conjunction.

We have established the photometric period of the FK Com star HD 199178 at 3.337 days. Coupled with the $v \sin i$ of 80 km s⁻¹, this gives a lower limit on the stellar radius of $\sim 5 R_{\odot}$, consistent with the giant classification. The light curve is variable on time scales as short as a few weeks, and there are intervals (e.g., 1976) when the star is constant in brightness. This sort of photometric behavior is quite typical of surface-active stars, and similar behavior has been recently reported in FK Com itself by Dorren, Guinan, and McCook (1982). The absence of any velocity variation greater than 3–5

km s⁻¹ in both HD 199178 (Bopp 1982) and FK Com (McCarthy and Ramsey, private communication) argues strongly that these objects are not binaries, and that the photometric and spectroscopic behavior is the result of dynamo driven magnetic fields in an active chromosphere/corona.

Our *IUE* data on the late-type binary systems support the general trend toward *increasing* UV surface flux with *decreasing* orbital period (Dupree 1981). It is likely that rotation is really the critical parameter in determining the activity level, however, since all these stars show identical orbital and photometric periods.

The BY Dra star BD +26°730 shows extremely strong Ca II H and K and UV emission, the strongest yet observed among dK/M stars. Significantly, the 1.8 day rotation period (assuming synchronous rotation) is quite short for a BY Dra star (BY Dra and EQ Vir both have rotation periods near 4 days), providing further support for the rotation/activity correlation.

The very long photometric period of BD +26°730, noted by Hartmann *et al.* (1981), presents us with an opportunity to study optical and UV activity as the star reaches light minimum around 1990. The preliminary orbital analysis presented by Hartmann *et al.* suggests that BD +26°730 is viewed very near the pole ($i \sim 10^{\circ}$); the stellar secondary is of very low mass, and does not contribute any appreciable light in the visible or UV. Any variability exhibited by this star should then be the result of formation or decay of polar spot groups, rather than being produced by varying aspect as the star rotates. Continued observation of BD +26°730 as it heads toward light minimum may permit us to test theoretical predictions of dynamo cycle periods. Present models are in disagreement, with Belvedere, Chiuderi, and Paterno (1982) predicting an increasing dynamo cycle period within a spectral type range from F5 to M0 while Robinson and Durney (1982) suggest the opposite.

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