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CHROMOSPHERICALLY ACTIVE STARS. X. SPECTROSCOPY AND PHOTOMETRY OF HD 212280

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ABSTRACT

The system HD 212280 is a chromospherically active double lined spectroscopic binary with an orbital period of 45.284 days and an eccentricity of 0.50. The spectrum is composite with spectral types of G8 IV and F5–8 V for the components. An estimated inclination of $78° \pm 8°$ results in masses of 1.7 and 1.4 $\mathscr{M}_{\odot}$ for the G subgiant and mid-F star, respectively. The distance to the system is estimated to be 112 pc. Photometric observations obtained between 1987 November and 1992 June reveal that HD 212280 is a newly identified variable star with a V amplitude of about 0.15 mag and a mean period of 29.46 days. Our V data were divided into 11 sets and in all but one case two spots were required to fit the data. Lifetimes of 650 days and a minimum of 1350 days have been determined for two of the four spots. These lifetimes are consistent with the results of Hall & Busby [Active Close Binaries, Proceedings of the NATO Advanced Studies Inst. (Kluwer, Dordrecht) (1990)]. The differential rotation coefficient of 0.05 is relatively small. Since the system has an eccentric orbit and one component is significantly evolved, its evolutionary status is of particular interest. The age of the system is about 1.9×10^9 years. The G subgiant is rotating slower than pseudosynchronously while the F-type star is rotating faster. The system and its components are compared to the circularization and synchronization time scales of Tassoul & Tassoul (ApJ, 395, 259, 1992).

1. INTRODUCTION

HD 212280=ADS 15883 [$\alpha = 22^h\ 22^m\ 32.6^s$, $\delta = 30°21'27''$ (2000)] was observed at the David Dunlap Observatory (DDO) as part of an extensive program to provide information on a large number of late-type stars for possible galactic studies. Heard (1956) published a summary of the results that included spectral classifications, photographic magnitudes, and radial velocities for over 1000 stars. In this survey HD 212280 was classified as a G0 IV star and had a photographic magnitude of 8.59. In addition, from four plates the star was found to have a velocity range of 35 km s^{-1} and double lines were seen on one plate. Bakos (1968) from three observations found $V = 7.51$ and $B - V = 0.70$. No further attention was paid to the star until Bidelman (1983) found it to have weak Ca II H and K emission. As a result, the star was placed on the observing program of the Vanderbilt/Tennessee State University automatic photoelectric telescope and Fekel *et al.* (1986) included HD 212280 in their survey of chromospherically active stars. Their high-dispersion red-wavelength spectrograms also showed double lines but the lines of the two components had very different line widths and strengths. Strassmeier *et al.* (1988) included preliminary information on the system in their catalog of chromospherically active binary stars.

The chromospherically active system is the A component of the visual binary ADS 15883. However, Aitken (1932) lists the B component as 45″ away and about 4 mag fainter and two other nearby stars are even fainter or farther away.

In this paper we present the results of extensive spectroscopic and photometric monitoring of this chromospherically active system and discuss the properties of the system. These results supersede those published previously.

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TABLE 1. Velocity observations of HD 212280.

HJD 2400000+	Phase	V_a (km s^{-1})	$(O-C)_a$ (km s^{-1})	V_b (km s^{-1})	$(O-C)_b$ (km s^{-1})	Standard
32390.838[a]	0.200	30.8	-5.9	...	...	
32749.855[a]	0.128	11.3	-24.2	...	...	
33130.816[a]	0.540	4.7	-6.4	...	...	
33883.795[a]	0.168	40.3	3.2	-39.4	-2.9	
45594.878	0.783	-20.5	-0.2	32.6	-1.1	α Ari
45595.791	0.803	-23.5	0.5	40.2	2.0	ι Psc
45939.841	0.401	23.8	0.2	-20.6	-0.7	ι Psc
46389.739	0.336	28.4	-0.2	-27.1	-1.0	ι Psc
46973.996	0.238	34.6	-0.4	-31.7	2.3	ι Psc
47453.804	0.834	-30.1	-0.0	46.4	0.8	ι Psc
47809.702[b]	0.693	-5.8	0.5	...	...	ι Psc
47810.743[b]	0.716	-8.4	1.1	...	...	ι Psc
47812.705	0.759	-16.8	-0.6	29.3	0.6	ι Psc
47813.682	0.781	-20.2	-0.3	32.4	-0.8	ι Psc
47814.705	0.804	-24.0	0.0	37.4	-0.8	ι Psc
47815.698	0.826	-27.9	0.4	44.7	1.2	ι Psc
48056.934	0.153	36.9	-0.0	-36.1	0.2	ι Psc
48060.952	0.241	34.6	-0.3	-30.7	3.1	ι Psc
48167.738[b]	0.600	4.5	-0.5	...	...	ι Psc
48425.921	0.301	30.6	-0.6	-30.2	-1.0	ι Psc
48429.899	0.389	24.1	-0.5	-22.8	-1.6	ι Psc
48505.736[b]	0.064	19.8	-0.0	...	...	ι Psc
48506.788	0.087	29.0	0.4	-25.8	0.2	ι Psc
48507.659	0.106	32.8	-0.0	-29.6	1.7	HR 7560
48508.670	0.128	36.0	0.4	-33.0	1.7	HR 7560
48604.652	0.248	34.9	0.4	-35.1	-1.8	ι Psc
48605.658	0.270	33.8	0.6	-33.2	-1.5	ι Psc
48770.976	0.921	-49.0	-0.2	69.9	1.4	HR 7560
48771.981	0.943	-50.8	0.2	72.8	1.6	HR 7560
48772.980	0.965	-48.5	0.1	...	...	HR 7560
48773.994[c]	0.988	-38.2	0.1	52.9	-2.8	HR 7560
48774.983[c]	0.009	-21.4	-0.6	33.3	-1.0	HR 7560

[a]DDO observations
[b]Blended velocity, weight = 0.5
[c]central wavelength = 6700 Å

TABLE 2. Spectroscopic orbital elements of HD 212280.

$$P = 45.2839 \pm 0.0032 \text{ (m.e.) days}$$
$$T = 2448412.292 \pm 0.088 \text{ HJD}$$
$$\gamma = 3.99 \pm 0.27 \text{ km s}^{-1}$$
$$K_A = 44.08 \pm 0.35 \text{ km s}^{-1}$$
$$K_B = 53.90 \pm 1.12 \text{ km s}^{-1}$$
$$e = 0.499 \pm 0.006$$
$$\omega_A = 240.2^\circ \pm 1.1^\circ$$
$$\omega_B = 60.2^\circ \pm 1.1^\circ$$
$$a_A \sin i = 2.378 \pm 0.027 \times 10^7 \text{ km}$$
$$a_B \sin i = 2.908 \pm 0.065 \times 10^7 \text{ km}$$
$$M_A \sin^3 i = 1.583 \pm 0.056 \; M_\odot$$
$$M_B \sin^3 i = 1.295 \pm 0.037 \; M_\odot$$
$$M_A/M_B = 1.223 \pm 0.025$$

Standard error of an observation of unit weight = 0.44 km s^{-1}

2. SPECTROSCOPIC OBSERVATIONS AND REDUCTIONS

From 1983 September to 1992 June, 28 high-dispersion spectroscopic observations were obtained at the Kitt Peak National Observatory (KPNO) with the coudé feed telescope, coudé spectrograph, and a Texas Instruments charge-coupled device (CCD). Two of the observations were centered at 6695 Å while all of the rest were centered at a wavelength of 6430 Å. The spectrograms cover a wavelength range of about 80 Å and have a resolution of about 0.2 Å. Most of the spectra have signal-to-noise ratios of 100:1 or better.

The radial velocities were determined relative to several International Astronomical Union (IAU) radial-velocity standard stars (Pearce 1957). However, the IAU radial-velocity system is currently undergoing revision. At present the most consistent and accurate velocities are those of Scarfe *et al.* (1990). From their work we assumed velocities of -14.5 km s^{-1} for α Ari, 5.6 km s^{-1} for ι Psc, and 0.0 km s^{-1} for HR 7560. Fekel *et al.* (1986) published the radial velocities of the first two observations. The velocities listed in the present paper are slightly different because different velocities were assumed for the standard stars.

Details of the velocity-reduction procedure have been given by Fekel *et al.* (1978). For the primary 5 or 6 lines typically were used for the velocity determinations. Because the lines of the secondary are weak and significantly broadened by rotation, various lines of the primary often distort the profiles so that only 1 or 2 lines of the secondary were used for its velocity determinations.

3. ORBIT

Twenty-eight velocities of the primary component and 23 velocities of the secondary were measured. Table 1 lists the observation dates and observed velocities as well as velocity residuals in the final solution. Also listed are the orbital phases where zero phase is the time of periastron. An initial value of the orbital period was determined from the radial velocities of the primary with the period-finding program of Deeming (Bopp *et al.* 1970). Preliminary orbital elements were determined with a slightly modified version of the Wilsing–Russell method (Wolfe *et al.* 1967). Separate orbital solutions were obtained for the primary and secondary with a differential corrections computer program of Barker *et al.* (1967). The orbital elements from the two solutions were similar and so a single orbital-element solution was determined (Table 2) with all velocities of the secondary given a weight of 0.1 relative to those of the primary. In four cases the lines of the primary and secondary were significantly blended. The velocity measurement of such line profiles primarily reflects the velocity of the primary and the four velocities were given a weight of 0.5 in the orbital solution. For one observation obtained of the lithium region, no unblended lines of the secondary were available for measurement despite the large velocity difference of the components. The velocities obtained at the DDO did not significantly improve the orbital solution and so were given zero weight. However, they are consistent with our solution (Fig. 1). The observed radial velocities and the computed radial-velocity curves are plotted in Fig. 1. The final orbital elements are given in Table 2.

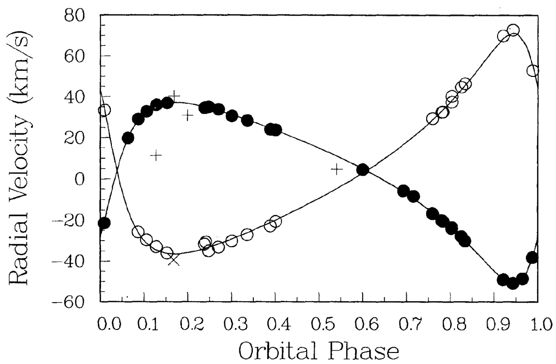

FIG. 1. Radial velocities of HD 212280 compared with the computed radial-velocity curves. For the G8 IV star, filled circles represent the KPNO velocities and pluses, the DDO velocities. For the F star, open circles are for the KPNO velocities and the × is the DDO velocity.

4. PHOTOMETRY AND SPOT SOLUTIONS

Over 300 photometric observations of HD 212280 were made in the Johnson system between JD 2,447,115 and JD 2,448,797 with the Vanderbilt/Tennessee State 0.4 m robotic telescope on Mt. Hopkins (Henry 1991). Each observation consisted of a group of three differential measurements in B and V made in quick succession between HD 212280 and the comparison star HD 211460 ($V=6.69$, $B-V=0.95$, G5 IV). Each group mean has been corrected for differential extinction and transformed to the UBV system. Additionally, HD 211006 ($V=5.89$, $B-V=1.15$, K2 III) was observed each night as a check on the constancy of the comparison star. No variations greater than one percent were observed between the comparison and check stars over the 4.6 year observing interval.

Inspection of the resulting light curve (a portion of which is shown in Fig. 2) revealed that HD 212280 is a new variable star with an amplitude of about 0.15 mag in V and a period of approximately 30 days. Periodogram analysis of the entire V data set gave a preliminary photometric period of 29.06 ± 0.1 days, quite different from the 45.284 day orbital period. Since we assume the light variation is caused by rotation of a spotted primary star, HD 212280 becomes one of a small group of nonsynchronously rotating chromospherically active binaries (Hall & Henry 1990; Fekel & Eitter 1989).

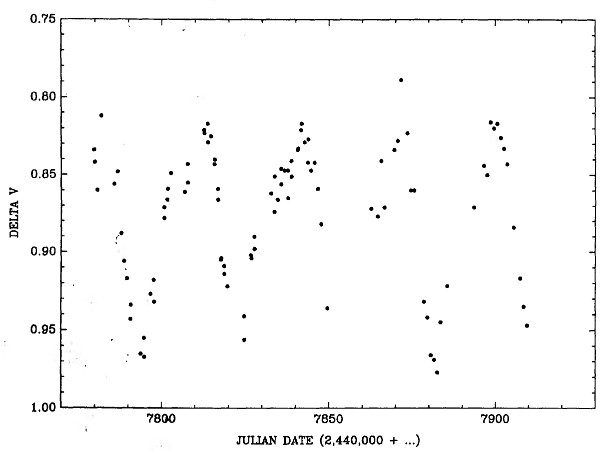

FIG. 2. A portion of the V light curve of HD 212280 observed with the 0.4 m robotic telescope of Vanderbilt and Tennessee State University. HD 212280 is a new variable star with an amplitude of about 0.15 mag in V and a photometric period of approximately 29.5 days.

The times of observation for the V data were converted into phases with the preliminary photometric period of 29.06 days and the arbitrary epoch JD 2 447 431. Those observations then were analyzed with the two-spot model of Hall *et al.* (1990) that is described in further detail by Henry *et al.* (1993). In this model, the light variations of the active star are described in terms of the light loss caused by one or two dark spots as they transit across the stellar disk. Although Pettersen *et al.* (1992) proposed that the photometric rotational modulation of light from BY Draconis type stars may be the result of a bright facular network, we have presumed that the cool, dark spots on chromospherically active stars like HD 212280 are magnetically active regions. This presumption is based in large part on the anticorrelation between brightness and Ca II H and K emission, over the rotation cycle, in lower main-sequence stars (Dorren & Guinan 1982; Lockwood *et al.* 1984; Radick *et al.* 1990) as well as in evolved chromospherically active stars (Baliunas & Dupree 1982; Baliunas 1988). Such an anticorrelation indicates that dark spots are spatially associated with regions of enhanced chromospheric emission just as observed in active regions on the Sun. The "zebra" model of Pettersen *et al.* (1992) would predict little or no correlation between brightness and H and K emission.

In our two spot model, if spot 1 culminates at phase θ_1, then the functional form of the light loss for that spot is taken to have the simple form of the lower half of a cosine curve within ±0.25 phase units of θ_1. When the spot is out of sight it causes no loss of light. If two spots are present, their effects are simply added together to give the light loss at phase θ,

$$m_{\rm calc}=m_0+A_1\cos(\theta-\theta_1)+A_2\cos(\theta-\theta_2),$$

where m_0 is the magnitude of the hemisphere on which neither spot 1 nor spot 2 appears, and θ is understood to apply only within 0.25 phase units of θ_i. We did not choose m_0 to coincide with the maximum brightness level ever observed in HD 212280 or some other level brighter than the local light curve maximum, because it is very difficult if not impossible to specify the magnitude of the truly unspotted hemisphere. The combined effect of many factors such as circumpolar spots, spots uniformly distributed in longitude, and changes in photospheric brightness over the course of decade-long magnetic cycles can act to determine the true unspotted level. The use of an erroneous value of m_0 for the unspotted magnitude in all light-curve solutions could lead to erroneously estimated spot sizes. Choosing m_0 to be the local maximum, as we have done, does guarantee that the amplitudes A_1 and A_2 provide a correct measure of the *minimum* spot sizes. The longitudes of the spots

TABLE 3. Parameters of the two spot fits HD 212280.

Data Set	Mean Epoch	n	JD (min) (2440000+)	Amplitude (mag)	Spot	Max. (mag)	Mean (mag)	RMS (mag)
1	1988.82	51	7470.8 ±0.1	0.114 ±0.004	A	7.482	7.546	0.008
			7480.6 ±0.1	0.091 ±0.005	B			
2	1988.97	29	7500.4 ±0.3	0.095 ±0.008	A	7.490	7.545	0.011
			7510.0 ±0.3	0.085 ±0.007	B			
3	1989.40	33	7674.9 ±0.3	0.076 ±0.007	A	7.544	7.568	0.014
			-	- -	-			
4	1989.73	29	7793.6 ±0.2	0.132 ±0.008	A	7.521	7.573	0.010
			7803.2 ±0.7	0.035 ±0.008	C			
5	1989.83	43	7822.7 ±0.1	0.124 ±0.006	A	7.517	7.566	0.010
			7834.1 ±0.6	0.034 ±0.005	C			
6	1989.98	30	7881.4 ±0.2	0.136 ±0.007	A	7.513	7.571	0.013
			7891.8 ±0.6	0.050 ±0.009	C			
7	1990.45	11	8056.3 ±0.3	0.076 ±0.006	A	7.530	7.560	0.005
			8041.9 ±0.5	0.022 ±0.011	C			
8	1990.90	32	8228.4 ±0.2	0.100 ±0.006	A	7.536	7.572	0.010
			8218.4 ±1.0	0.017 ±0.005	C			
9	1991.34	20	8377.5 ±0.3	0.117 ±0.015	A	7.501	7.550	0.013
			8369.2 ±1.2	0.043 ±0.012	C			
10	1991.44	28	8403.5 ±0.3	0.081 ±0.006	A	7.507	7.553	0.009
			8410.8 ±0.4	0.066 ±0.007	D			
11	1992.38	10	8758.1 ±0.3	0.072 ±0.012	A	7.543	7.576	0.005
			8741.6 ±1.0	0.034 ±0.008	D			

are given by θ_1 and θ_2. We do not attempt to derive spot latitudes with this model.

Since the light-curve shape of HD 212280 changes with time, in a way that cannot be known at the outset, the V observations were binned into several separate data sets, each to be analyzed separately with the two-spot model in order to follow the evolution of the spots. To minimize changes in the light-curve shape within a given data set and to maximize the time resolution of spot evolution, the length of each data set was kept as short as possible but still contained enough data to adequately define each light curve. The density of our data was such that, fortunately, only one or two cycles were required to define the phase curve at each epoch. Therefore, by choosing the Julian date limits for each data set to include one or, at most, two rotation cycles, we defined 11 data sets that satisfied our criteria of short time span and adequate phase coverage.

The parameters resulting from the 11 spot fits are presented in Table 3. Columns 2 and 3 give the midepoch of each data set and the number of observations contained in each set, respectively. Column 4 gives the time of maximum light loss due to each spot, converted to Julian date from the photometric phase determined in the model. The spot amplitudes are listed in column 5, while column 6 provides a letter identification for each spot (as explained below). The last three columns tabulate the maximum brightness of the star, (m_0), for each fit, the average brightness, computed by averaging the resulting fit over the rotation cycle, and the rms deviation of the data from the two-spot fit, respectively. The magnitudes listed in columns 7 and 8 have been converted from differential to apparent magnitudes with $V=6.69$ for the comparison star. The rms deviations are within the same range as the scatter in the check minus comparison star magnitudes, indicating we have modeled the light variations to the precision of our data. Every data set with the exception of data set 3 required two spots to fit the data to this precision. Figure 3 shows an example of one of these two-spot fits.

A migration curve for the spots in Table 3 can be created by plotting the resulting phases of each spot against Julian date (Fig. 4). A long-lived spot rotating at exactly the preliminary 29.06 day photometric period would not change in phase from data set to data set and thus would trace out a horizontal series of points (within the observational errors) on the migration curve for as long as that spot persisted. We assume, therefore, that a set of points that can be approximated by a straight line segment in the migration curve is the result of a single spot rotating with a period that can be determined from the slope of the line. Four spots can be identified in this manner on the migra-

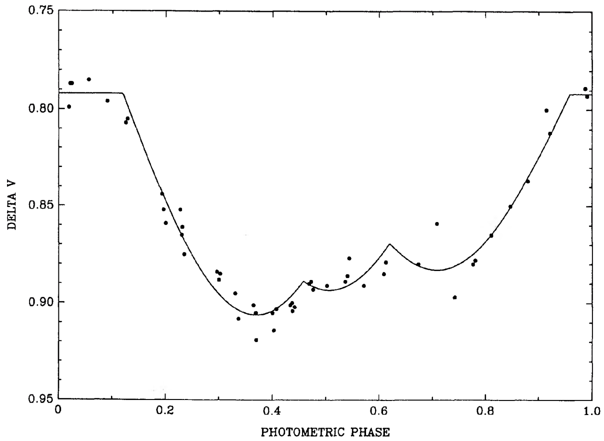

FIG. 3. The two-spot fit for HD 212280 data set 1. Spot A is located at phase 0.37 and has an amplitude of 0.11 mag. Spot B is located at phase 0.71 with an amplitude of 0.09 mag.

tion curve; all have positive slopes, indicating that they are rotating with periods somewhat longer than the 29.06 day preliminary period. Only spots A and C lived long enough to have their rotation periods reliably determined. These periods are 29.21 ± 0.03 days and 29.70 ± 0.05 days, respectively.

A companion to the migration curve in Fig. 4 is the amplitude curve plotted in Fig. 5. Here, the amplitudes of the various spots in Table 3 are plotted against Julian date. Points representing multiple sightings of the same spot are interconnected and given the same identifications as in the migration curve. Since the third data set was fit with only one spot (A), we show the decay of spot B to zero amplitude with a solid line. Spot C, however, apparently disappeared and spot D appeared sometime between data sets 9 and 10. Therefore, the decay of spot C is shown with a dashed line since it was not explicitly observed. From the two figures, we can see that spot A persisted throughout the entire interval of observation; consequently spot A has a minimum lifetime of 1350 days. The formation and decay of spot C took place entirely within the observing interval; its lifetime is approximately 650 days. Because spot B decayed near the beginning of our observing period and spot D began shortly before the end of our observing period, little of significance can be said about their lifetimes.

The range of slopes in the migration curve of Fig. 4 implies the existence of spots at different latitudes on a differentially rotating star. This range of observed rotation periods can be used to estimate the differential rotation coefficient k for the primary star with the method of Hall and Busby (1990). The result is $k=0.05 \pm 0.01$. If we make a reasonable estimate of the Roche-lobe-filling fraction, this is consistent with the relation between k and rotation period found by Hall [1991, Eq. (2)].

The greatest amplitudes observed for spots A and C are 0.14 and 0.05 mag, respectively. These amplitudes must be increased to approximately 0.20 and 0.07 mag, respectively, due to light dilution effects of the secondary star.

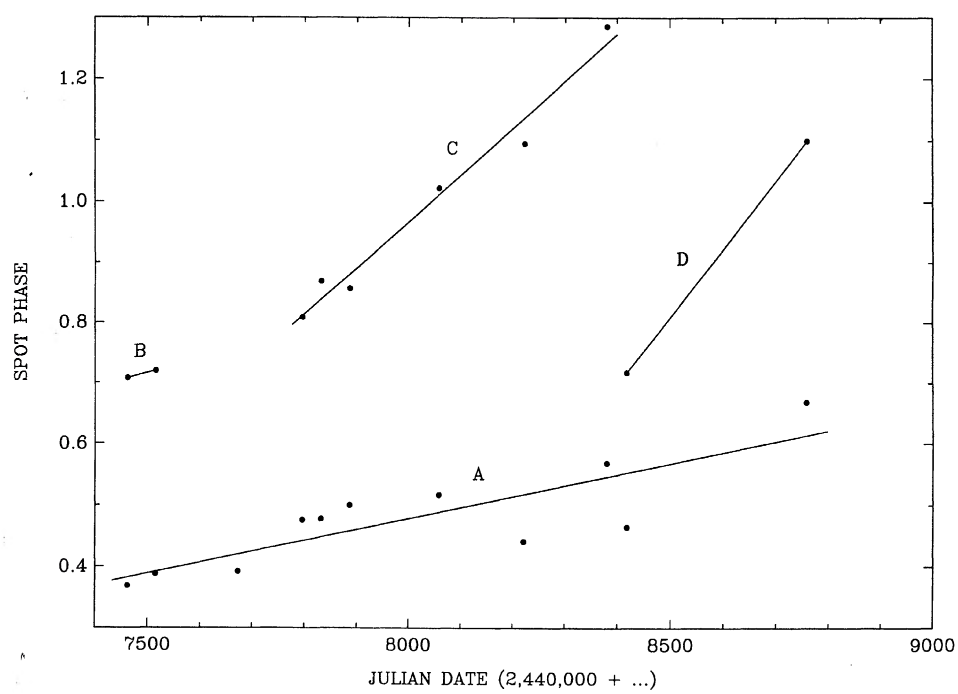

FIG. 4. Spot migration curve identifying four separate spots that existed on HD 212280 between 1988 and 1992, plotted from the data in Table 3. The various slopes of the line segments reveal the rotation periods of the spots and the differential rotation of HD 212280. The lengths of the line segments in time correspond to the lifetimes of the spots.

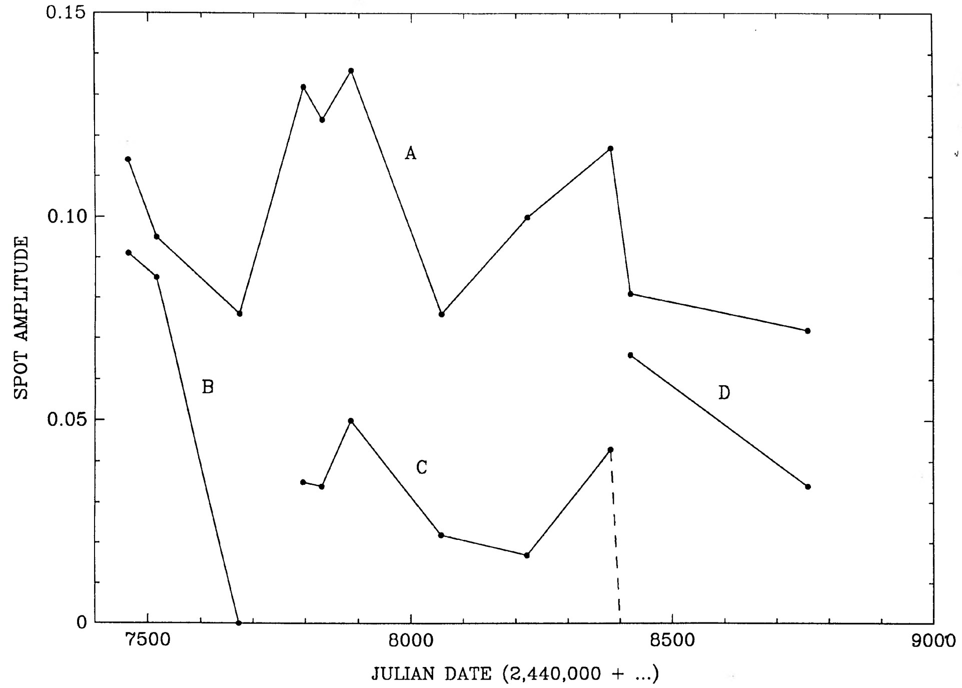

FIG. 5. Spot amplitude in V vs time for the spots on HD 212280 identified in Table 3. Spot A has persisted throughout our interval of observation with an amplitude of approximately 0.1 mag while spot C formed and dissipated within the observing time interval. Spot B decayed shortly after we began observing HD 212280 and spot D formed only recently.

Here we have assumed a difference between the two components of 0.9 mag in V (see Sec. 5). The amplitudes can then be translated into approximate spot radii by the method of Hall and Busby (1990) that assumes the spots cross the center of the stellar disk. The resulting radii at maximum size for spots A and C are 23° and 14°, respectively. We can compare the observed lifetimes of these two spots with the time scale of their disruption due to shear induced by differential rotation as calculated in the model of Hall & Busby (1990). With a differential rotation coefficient of $k=0.05$, spot A with a radius of 23° should be disrupted by shear within 900 to 1600 days depending on its latitude. Spot C with a radius of only 14° could survive disruption forces for 1500 days or longer. The observed minimum lifetime of 1350 days for spot A and the lifetime of 650 days for spot C are consistent with the findings of Hall & Busby (1990) that spots larger than about 20° have lifetimes limited by differential rotation while spots smaller than 20° generally dissipate faster than shear alone would disrupt them.

5. FUNDAMENTAL PROPERTIES

The spectral type of G0 IV listed by Heard (1956) and the $B-V=0.70$ of Bakos (1968) result from the composite nature of the spectrum. Because the lines of two components were seen on blue-wavelength photographic plates but the secondary is difficult to detect and measure at red wavelengths, the secondary should have a significantly earlier spectral class than the primary. Despite the slight line broadening, the star with the strong lines is clearly substantially later in spectral class than G0.

The spectral types were determined with the technique of spectrum addition (Strassmeier & Fekel 1990). Of the various combinations tried, the best fit to the line depths was for the combination of HR 7560 (F8 V) and η Cep (K0 IV). Several sensitive line ratios, however, suggest that a G8 IV spectral-type is more appropriate and a fit with HR 7560 and β Aql (G8 IV) is nearly as good (Fig. 6). Both η Cep and β Aql are slightly metal poor compared to the Sun, with [Fe/H] of -0.17 and -0.08 (Frisk 1983), respectively. Because its lines are weak and significantly broadened, it is a bit more difficult to constrain the spectral type of the secondary. Thus, the secondary might be as early as a mid-F star if the system is somewhat metal rich. We estimate the spectral types as F5–F8 V+G8 IV although a spectral class of F5 is probably more consistent with the information discussed below.

The derived continuum magnitude difference of 1.25 mag at 6430 Å is approximately a ΔR magnitude. As expected, the cooler, more massive, and more evolved star is brighter at red wavelengths. However, this magnitude difference is a maximum value since, as Griffin & Griffin (1986) have noted, the greater line blanketing of the cooler star decreases its contribution to the light-intensity ratio. With the assumed colors from FitzGerald (1970) the com-

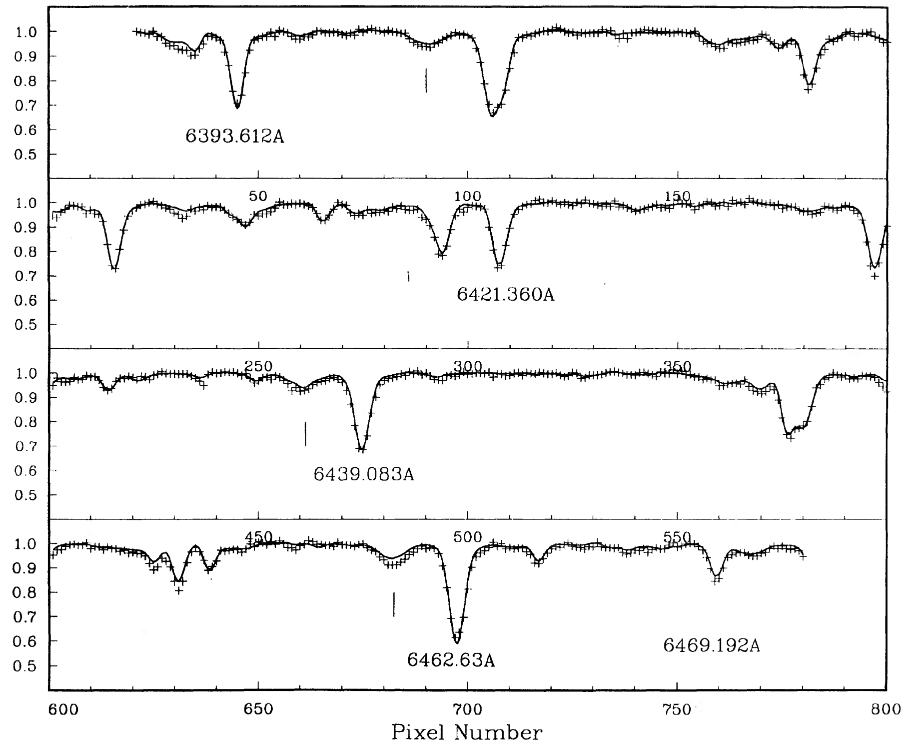

FIG. 6. The spectrum (pluses) of HD 212280, plotted as pixel number versus relative intensity, from about 6393 to 6469 Å. The solid line is the fit with the summed spectra of HR 7560 and β Aql. The wavelengths of several lines are identified. Tick marks indicate lines of the hotter component.

bined $B-V$ color of 0.70 mag (Bakos 1968) is reproduced by an F7 V+G8 IV pair of stars with $\Delta V=0.8$ mag or an F5 V+G8 IV pair of stars with $\Delta V=1.0$ mag. Thus, the composite $B-V$ color is quite consistent with our spectral types estimated from spectrum addition.

The $B-V$ colors of the individual components, 0.45 to 0.50 for F5 V to F7 V and 0.82 for G8 IV (FitzGerald 1970), appear to be quite similar to some of the classical eclipsing RS CVn systems (Popper 1988, 1990). Many of these systems have mass ratios close to unity (Popper 1988, 1990) due to the more evolved star having undergone mild mass loss as it ascends the giant branch (Popper & Ulrich 1977). Thus, it is a bit surprising that the mass ratio of HD 212280 is 1.22 ± 0.03, rather different from unity. However, if the cool star is at the base of the giant branch, as suggested by its spectral type, it should have experienced relatively little mass loss.

The minimum masses of the stars are relatively large, 1.58 ± 0.06 $\mathscr{M}_\odot$ and 1.30 ± 0.04 $\mathscr{M}_\odot$, and make HD 212280 one of the more massive RS CVn systems. The large minimum masses suggest that eclipses are a possibility. However, the long period of 45.284 days makes the possibility small despite the rather large orbital eccentricity of 0.5. Our photometry shows no evidence of eclipses. Nevertheless, the probable inclination of the system is quite high since an inclination of 70° results in a mass of 1.57 $\mathscr{M}_\odot$, somewhat large for an F5 V to F7 V star (Allen 1973). From the lack of eclipses and the assumption of reasonable masses for a mid-F star, we estimate the inclination as $78°\pm8°$. Thus, the masses of the two stars are 1.7 and 1.4 $\mathscr{M}_\odot$.

If an absolute visual magnitude of 3.8 is assumed for the F star, the distance to the system is 100 pc. An assumed magnitude of 3.4 increases the distance to 125 pc.

Fekel *et al.* (1986) determined $v \sin i$ values of 21 ± 3 km s^{-1} and 8 ± 2 km s^{-1} for the F and G stars, respectively. The rotation periods of spots A and C result in a mean period of 29.46 days for the G star. Thus, its minimum radius is 4.7 ± 1.1 $R_\odot$. With our estimated inclination the actual radius is 4.8 $R_\odot$. Such a radius is quite consistent with the 1.7 $\mathscr{M}_\odot$ $Z=0.02$ evolutionary track of Schaller *et al.* (1992) and places it at the base of the first-ascent giant branch with an age of about 1.9×10^9 years [Schaller *et al.* (1992) acknowledge that the ages given by Maeder & Meynet (1988) for masses in the range 1.2 $\mathscr{M}_\odot$ to 2.0 $\mathscr{M}_\odot$ were significantly too long]. The models of Claret & Giménez (1992) give a similar age of 2×10^9 years. An interpolated track from Schaller *et al.* (1992) for the 1.4 $\mathscr{M}_\odot$ star indicates that it has evolved through about two-thirds of its main-sequence lifetime, has a radius of about 1.7 $R_\odot$, and has a V mag that is about 0.8 mag fainter than the G subgiant. Such a theoretical magnitude difference is consistent with our observational estimate.

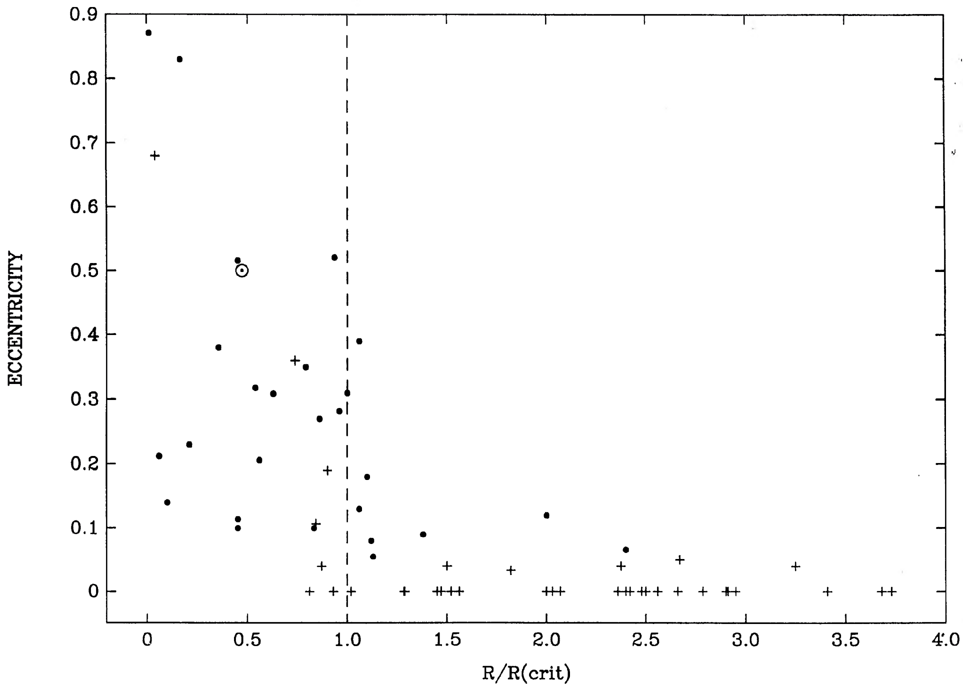

FIG. 7. The circled point shows the location of HD 212280 compared with the data previously plotted by Hall & Henry (1990). Crosses and pluses indicate stars with masses and radii that are well-determined and estimated, respectively. In agreement with the circularization theory of Tassoul (1988), the dashed line separates binaries with circular orbits (on the right) from binaries with eccentric orbits (on the left).

6. DISCUSSION

HD 212280 is of particular interest because of its substantially differing orbital and rotation periods as well as its decidedly noncircular orbit. As such it is a rather unusual chromospherically active system. The majority of known chromospherically active stars are synchronously rotating (Hall & Henry 1990; Fekel & Eitter 1989). However, stars in eccentric orbits, because of the variable tidal interaction, are expected to have a rotation period shorter than the orbital period. Hut (1981) derived equations to determine this pseudosynchronous rotation period. Hall (1986) showed that a number of chromospherically active stars with eccentric orbits are pseudosynchronously rotating. For HD 212280, with $e=0.5$, the pseudosynchronous rotation period is 16.3 days. With an assumed radius of 1.5–2 $R_{\odot}$, the estimated rotation period for the F star is 3.5–5 days while from our photometry the average rotation period of the G star is 29.46 days. Thus, the F star is rotating faster than pseudosynchronous while the G subgiant is rotating more slowly.

Several competing theories now exist for the circularization of binary star orbits. In all these theories, the circularization time scale depends strongly on the ratio a/R where a is the semimajor axis of the binary and R is the radius of the larger star. The dependence ranges from $a/R^{6.125}$ to $a/R^{10.5}$ (Tassoul 1988). Goldman & Mazeh (1991) and Tassoul & Tassoul (1992) have discussed their very different theories and compared the predicted time scales for circularization with several observational samples. Most of the comparisons are for samples of late-type main-sequence stars where circularization time scales are several billion years for binary orbits with periods of 10 days (Mathieu & Mazeh 1988). However, after a star evolves off the main sequence and substantially increases its radius, circularization occurs on a much more rapid time scale, even for stars of longer period. For a series of masses between 1 and 3 $\mathscr{M}_{\odot}$ and periods between 0.3 and 300 days, Hall & Henry (1990) used the circularization time-scale equation of Tassoul (1988) to determine the radius of the larger star when the binary should be circularized. They then compared these results with systems that contain at least one evolved (subgiant or giant) chromospherically active star and found good agreement with the theory of Tassoul (1988). With a mass of 1.7 $\mathscr{M}_{\odot}$ and an orbital period of 45.284 days, the G-type subgiant in HD 212280 would need to reach a critical radius of 10.2 $R_{\odot}$ before the orbit would be circularized. The position of HD 212280 in Fig. 2 of Hall & Henry (1990) is shown in our Fig. 7. As with the other evolved systems in their sample, HD 212280 is consistent with Tassoul's theory.

The synchronization situation is more difficult to quantify with certainty. All theories of circularization and synchronization agree that the larger star in a binary will synchronize before the orbit circularizes (Hall & Henry 1990) but because the orbit of HD 212280 has *not* yet circularized, this condition is not useful in providing an *a priori* expectation concerning synchronization. Tassoul (1987) showed that a tendency toward pseudosynchronization should occur for $a/R<20$ even for very massive early-type (=radiative) stars and noted that the synchronization time is about 10^7 yr even for $a/R=35$. The G subgiant is sufficiently massive that it must have been radiative while on the main sequence and at that time rotating much faster than pseudosynchronously. Because it is rotating more *slowly* than pseudosynchronously now and currently has $a/R=16$, it must have become pseudosynchronized at some intermediate epoch as predicted by Tassoul's (1987) theory. The present slower than pseudosynchronous rotation might be understood qualitatively by noting that the G-type star is now at the base of its first ascent giant branch, i.e., having just completed its phase of most rapid expansion. In the future, as it moves up the giant branch with a slower rate of radial expansion, pseudosynchronization may be re-established.

The F star is agonizingly close to the main-sequence boundary between radiative and convective stars, although probably on the convective side, and is rotating about four times faster than the pseudosynchronous speed. However, *both* the radiative and the convective synchronization time scales computed with Eq. (49) of Tassoul & Tassoul (1992) indicate that this star *should be* pseudosynchronized. For the radiative case, $t_{\rm syn}=0.65\text{–}1.5\times10^8$ yr, for the convective case, $t_{\rm syn}=2\text{–}5\times10^5$ yr, where the range in both cases corresponds to a radius range of 1.5–2.0 $R_\odot$. Recall that the age of the system, estimated from the present position of the G star in the appropriate (1.7 $\mathscr{M}_\odot$) theoretical evolutionary model of Schaller *et al.* (1992), is 1.9×10^9 yr, and that this age estimate is relatively secure to the extent that the G star is presently in a stage of rapid evolution. The discrepancy appears to be a factor of at least 12 (radiative assumption) and possibly as large as a factor of 3800 (convective assumption). Even if the assumed mass of the G subgiant is increased to 1.8 $\mathscr{M}_\odot$ to account for observational error, the age of the system only decreases to 1.6×10^9 yr. One possible source of confusion is whether in an eccentric orbit the term a in Eq. (49) of Tassoul & Tassoul (1992) should be the semimajor axis of the orbit, which we have taken it to be, or alternatively, should be the star-to-star separation at periastron $a(1-e)$. In the alternative, the discrepancy in $t_{\rm syn}$ would be even greater, by an additional factor of 20.

We cannot, however, claim to have found a solid conflict between observation and theory. This is because the situation with HD 212280 happens to violate one of the simplifying assumptions made when the synchronization theory was developed (Tassoul & Tassoul 1990). They had assumed that the initial rotation rate would be only a little faster or a little slower than the pseudosynchronous period and then made the reasonable assumption that the synchronization time, $t_{\rm syn}$, is one order of magnitude longer than the spin-down time, $t_{\rm sd}$. For stars starting very far from pseudosynchronization (such as HD 212280, which has the F star rotating 4 times faster after almost 2 billion years and probably even faster at an earlier epoch) they explain that $t_{\rm syn}$ may be much longer than $t_{\rm sd}$ but that the exact relation between the two, in such a nonlinear situation, could not be ascertained.

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REFERENCES

Aitken, R. G. 1932, The New General Catologue of Double Stars (McGraw-Hill, New York)
Allen, C. W. 1973, Astrophysical Quantities, 3rd Ed. (Athlone, London)
Bakos, G. A. 1968, AJ, 73, 187
Baliunas, S. L. 1988, in Solar Radiative Output Variation, edited by P. Foukal (Cambridge Research and Instrumentation, Cambridge), p. 230
Baliunas, S. L., & Dupree, A. K. 1982, ApJ, 252, 668
Barker, E. S., Evans, D. S., & Laing, J. D. 1967, R. Obs. Bull., 130
Bidelman, W. P. 1983, AJ, 88, 1182
Bopp, B. W., Evans, D. S., & Laing, J. D. 1970, MNRAS, 147, 355 (with an Appendix by T. J. Deeming)
Claret, A., & Giménez, A. 1992, A&AS, 96, 255
Dorren, J. D., & Guinan, E. F. 1982, AJ, 87, 1546
Fekel, F. C., Bopp, B. W., & Lacy, C. H. 1978, AJ, 83, 1445
Fekel, F. C., & Eitter, J. J. 1989, AJ, 97, 1139
Fekel, F. C., Moffett, T. J., & Henry, G. W. 1986, ApJS, 60, 551
FitzGerald, M. P. 1970, A&A, 4, 234
Frisk, U. 1983, Ph.D. thesis, Stockholm University
Goldman, I., & Mazeh, T. 1991, ApJ, 376, 260
Griffin, R., & Griffin, R. 1986, Ap&A, 7, 45
Hall, D. S. 1986, ApJ, 309, L83
Hall, D. S. 1991, in The Sun and Cool Stars: Activity, Magnetism, and Dynamos, edited by I. Tuominen, D. Moss, and G. Rudiger (Springer, Berlin), p. 353
Hall, D. S., & Busby, M. R. 1990, in Active Close Binaries, Proceedings of the NATO Advanced Study Institute, edited by C. Ibanoglu (Kluwer, Dordrecht) p. 377
Hall, D. S., & Henry, G. W. 1990, in Active Close Binaries, Proceedings of the NATO Advanced Study Institute, edited by C. Ibanoglu (Kluwer, Dordrecht), p. 287
Hall, D. S., Henry, G. W., & Sowell, J. R. 1990, AJ, 99, 396
Heard, J. F. 1956, Publ. DDO, 2, 107
Henry, G. W., Eaton, J. A., Hamer, J. Nagarajan, R., & Hall, D. S. 1993, in preparation
Henry, G. W., Nagarajan, R., & Busby, M. R. 1991, IAPPP Comm. No. 45, 11
Hut, P. 1981, A&A, 99, 126
Lockwood, G. W., Thompson, D. T., Radick, R. R., Osborn, W. H., Baggett, W. E., Duncan, D. K., & Hartmann, L. W. 1984, PASP, 96, 714
Maeder, A., & Meynet, G. 1988, A&AS, 76, 411
Mathieu, R. D., & Mazeh, T. 1988, ApJ, 326, 256
Pearce, J. A. 1957, Trans. IAU, 9, 441
Pettersen, B. R., Hawley, S. L., & Fisher, G. H. 1992, in Cool Stars, Stellar Systems, and the Sun, edited by M. S. Giampapa and J. A. Bookbinder (Astronomical Society of the Pacific, San Francisco), p. 285
Popper, D. M. 1988, AJ, 96, 1040
Popper, D. M. 1990, AJ, 100, 247
Popper, D. M., & Ulrich, R. K. 1977, ApJ, 212, L131
Radick, R. R., Lockwood, G. W., & Baliunas, S. L. 1990, Science, 247, 39
Scarfe, C. D., Batten, A. H., & Fletcher, J. M. 1990, Publ. DAO, 18, 21
Schaller, G., Schaerer, D., Meynet, G., & Maeder, A. 1992, A&AS, 96, 269
Strassmeier, K. G., & Fekel, F. C. 1990, A&A, 230, 389

Strassmeier, K. G., Hall, D. S., Zeilik, M., Nelson, E., Eker, Z., & Fekel, F. C. 1988, A&AS, 72, 291
Tassoul, J.-L. 1987, ApJ, 322, 856
Tassoul, J.-L. 1988, ApJ, 324, L71
Tassoul, J.-L., & Tassoul, M. 1990, ApJ, 359, 155
Tassoul, J.-L., & Tassoul, M. 1992, ApJ, 395, 259
Wolfe, R. H., Horak, H. G., & Storer, N. W. 1967, in Modern Astrophysics, edited by M. Hack (Gordon and Breach, New York), p. 251