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SPECTRUM AND LIGHT VARIATIONS OF THE PECULIAR A STAR HD 51418*

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ABSTRACT

HD 51418 is a previously unknown Ap star of spectral type A0p (Eu-Sr-Cr). It exhibits marked variations in the Eu II and Sr II lines, while variations in other elements also appear to be present. Light variations of 0.17 mag in *V*, 0.08 mag in *B*, and 0.07 mag in *U* have been found, the *V* amplitude being larger than for any other peculiar A star. Hβ variations have also been observed. Combined photometric and spectroscopic observations yield a period of 5.4379 days.

Subject headings: peculiar A stars — spectrum variables — stars, individual

I. INTRODUCTION

The peculiar A star HD 51418 was discovered during a search for new Ap stars in the plate files at the David Dunlap Observatory (Gulliver 1971). Five plates at 66 Å mm^{-1} dispersion taken from 1940 to 1942 showed the star to be a spectrum variable of spectral type A0p (Eu-Sr-Cr). Further plates obtained at 12 Å mm^{-1} dispersion beginning in 1970 October confirmed the spectral variations. Photometric observations were obtained during an observing session at Kitt Peak National Observatory in 1970 December. Although only four observations were obtained at that time, they were sufficient to indicate a large-amplitude variation in *V* of approximately 0.2 mag and a period of less than 10 days. More recent photometric observing sessions have confirmed and expanded these data.

II. PERIOD DETERMINATION

Photometric observations over approximately 18 months suggested a period of $5^{d}.435 \pm 0^{d}.005$. This period was improved by means of two of the 66 Å mm^{-1} spectrograms from 1940 and 1942. These revealed Eu II near maximum and, when combined with the more recent plates, gave possible periods in the above range of $5^{d}.4323$, $5^{d}.4351$, and $5^{d}.4379$. When the photometric observations were plotted with these three periods, the best fit to the observations was found to occur for the period $5^{d}.4379 \pm 0^{d}.0004$ (although the $5^{d}.4351$ period is still possible). The uncertainty in the period was obtained on the assumption that the two 66 Å mm^{-1} spectrograms lay within an interval in phase of ± 0.15 about Eu II maximum. Times of visual light (*V*) maximum are therefore given by:

$$\text{JD (Visual light maximum)} = \text{JD } 2441241.654 + 5.4379E\,, \qquad (1)$$

where the reference epoch, 1971 October 17, has been chosen to correspond with the epoch of the largest number of photometric observations.

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III. SPECTRUM VARIATIONS

Sixteen spectrograms were taken by one of us (A. F. G.) from 1970 to 1972 with the all-reflection grating spectrograph of the 74-inch (188-cm) telescope of the David Dunlap Observatory. These plates have a dispersion of 12 Å mm^{-1} and are on Kodak IIa-O emulsion. Five plates at 66 Å mm^{-1} on Ilford Astra II and Kodak 103-O emulsions were also present in the observatory plate files. These had been obtained with the one-prism Hilger spectrograph of the 74-inch telescope during an extensive radial-velocity program conducted by Young (1942).

Five of the 12 Å mm^{-1} spectra at different phases can be seen in figure 1 (plate 4). At maximum, Eu II is very strong, λ4205 of Eu II being surpassed only by the K-line of Ca II and the hydrogen lines. Other elements that are enhanced include Sr II, Cr II, and Si II. Strontium II is strengthened almost to the degree that Eu II is, whereas Cr II and Si II are considerably less enhanced. The amplitude of the variations in the strengths of the Eu II lines is also very large, while that of Sr II is somewhat less so. The spectrum as a whole is rather crowded; at 12 Å mm^{-1} there are from one to two lines per angstrom. A comparison of a preliminary line identification for HD 51418 with those for α^2 CVn by Struve and Swings (1943), Burbidge and Burbidge (1955), and Pyper (1969) reveals that the two stars are quite similar.

All of the 16 12 Å mm^{-1} plates were traced using the direct-intensity microphotometer of the David Dunlap Observatory. From two to four of the strongest, least-blended lines of seven elements were measured for equivalent widths. The mean equivalent width, $\langle W \rangle$, for each line averaged over the period is given in table 1. These, of course, are not the true mean equivalent widths because of the missing phases. For each line the ratio of the individual equivalent width $\langle W \rangle$ was calculated, and averaged over all the lines of the same element. The values of $W_\lambda/\langle W \rangle$ at each phase are presented in table 2. Errors in the equivalent widths W_λ of individual lines are about 20 percent, while errors in the mean equivalent widths are closer to 15 percent.

In figures 2 and 3, the ratio $W_\lambda/\langle W \rangle$ is plotted versus phase. As expected, the variations of the three rare earths in figure 2 are very similar. In each case the maximum appears to coincide with visual light maximum, although further observations near

TABLE 1

MEAN EQUIVALENT WIDTHS $\langle W \rangle$ OF SELECTED LINES IN HD 51418

Ion	Wavelength (Å)	$\langle W \rangle$ (Å)
Eu II......	3907	0.15
	3930	0.23
	4129	0.16
	4205	0.25
Gd II......	3916	0.13
	4251	0.13
Dy II......	3944	0.11
	4000	0.15
Sr II.......	4077	0.28
	4215	0.22
Si II.......	4128	0.32
	4130	0.29
Cr II.......	4038	0.14
	4170	0.15
	4261	0.19
Fe II.......	3935	0.20
	4057	0.10
	4122	0.14
	4173	0.18

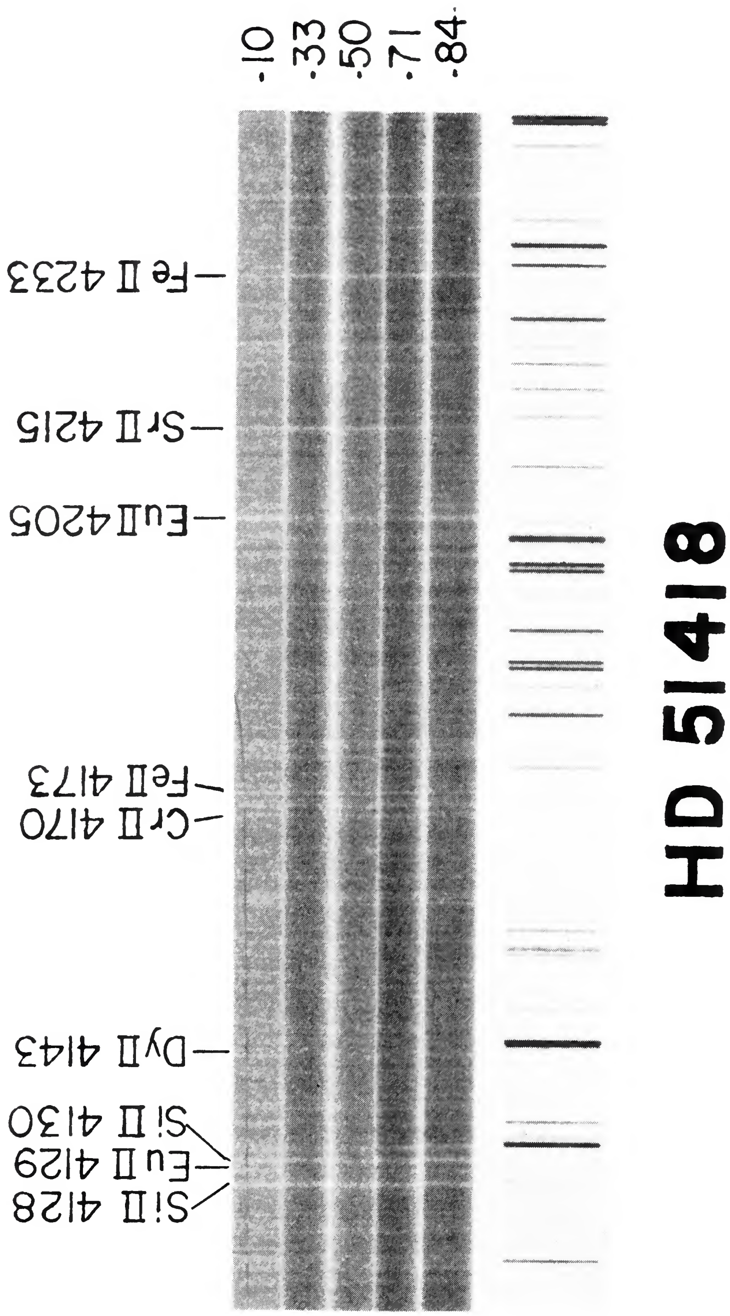

FIG. 1.—Reproduction of portions of 12 Å mm⁻¹ spectra of HD 51418 at various phases (indicated at right). Note strong variations in the Eu II lines and other rare earths, and, out of phase with these, in the Sr II line.

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TABLE 2

INTENSITY VARIATIONS IN THE SPECTRUM OF HD 51418

JD (2440000 +)	PHASE	$W_\lambda/\langle W\rangle$						
		Eu II	Gd II	Dy II	Sr II	Si II	Cr II	Fe II
870.9	0.82	0.98	0.94	0.81	0.84	0.99	0.98	0.91
877.9	0.10	1.57	1.51	1.68	0.99	1.14	1.26	1.31
883.9	0.22	1.12	1.09	1.17	1.12	1.07	0.97	1.15
949.8	0.33	0.87	0.88	0.80	1.41	1.14	1.17	0.95
953.7	0.05	1.51	1.59	1.31	0.97	1.07	1.10	1.24
967.7	0.62	0.89	0.93	0.75	0.97	0.91	0.90	0.86
967.8	0.63	0.90	0.73	1.04	1.01	0.95	0.99	1.06
1044.5	0.75	1.03	1.10	0.98	0.91	0.92	1.01	1.06
1058.6	0.33	0.87	0.86	0.94	1.22	1.17	0.93	0.95
1064.6	0.43	0.81	...	0.70	1.26	1.03	0.89	0.97
1255.9	0.61	0.97	1.00	0.91	0.98	1.00	0.97	1.07
1260.7	0.50	0.71	0.64	0.63	0.80	0.78	0.86	0.70
1278.9	0.84	1.17	1.01	1.17	0.80	1.01	0.94	0.90
1299.9	0.71	0.83	1.01	1.10	0.97	0.98	1.11	0.90
1387.6	0.84	1.08	1.10	1.14	0.87	1.14	1.13	1.17
1396.7	0.51	0.71	0.67	0.81	0.91	0.72	0.81	0.81

rare-earth maximum would be desirable. The coincidence of rare-earth and visual-light maxima in stars of this type has been described by Preston (1971). In contrast to the rare earths, Sr II reaches a maximum at a phase of about 0.35. Variations in other elements, however, are not as well established. Variations in Si II, if present, are at or below the level of the errors. The lines of Cr II and Fe II appear to vary in phase with the rare earths, although the amplitude of the former is near the error level. The Fe II fluctuations are more definite although not large.

A variation of Cr II in phase with the rare earths is unusual (e.g., Hack and Struve 1970; Pyper 1969; Preston 1967). In the light of this, the Cr II variations were examined more closely. A plot of the ratio of the central depths of the Cr II lines to the height of the continuum revealed a curve similar to that in figure 3. This indicates that it cannot be the line profiles that are in error, and suggests that the choice of a continuum is not the problem either. This latter conclusion follows from the expectation that the error in the choice of a continuum would be such that, at rare-earth maximum, the continuum would be chosen too low. However, this would result in a variation of central depth over continuum out of phase with the rare earths. Examination of the order in which the plates were traced and measured also did not reveal any systematic trends. It is possible that undetected blends due to the rare earths could be responsible, although for this to occur in all three lines of Cr II would be surprising.

Radial-velocity measurements of four of the 12 Å mm^{-1} plates indicate that the star does not have a variable velocity. These measurements gave a mean velocity of -26.4 ± 0.6 (p.e.) km s^{-1}. The five prism plates at 66 Å mm^{-1} were found by Young (1942) to have a mean velocity of -23.5 ± 1.0 (p.e.) km s^{-1}. The radial-velocity measurements of the 12 Å mm^{-1} plates were based upon lines of Fe I, Fe II, and Ti II. If the oblique-rotator model is assumed, the small deviations in radial velocity indicate that any spectrum variations in Fe II should be small, supporting the result mentioned above.

IV. PHOTOMETRIC VARIATIONS

The photometric observations reported were obtained by one of us (J. E. W.) with the No. 4 16-inch (41-cm) Boller and Chivens reflector at Kitt Peak National Observatory. The data were obtained in three observing sessions: 1970 November 26 to

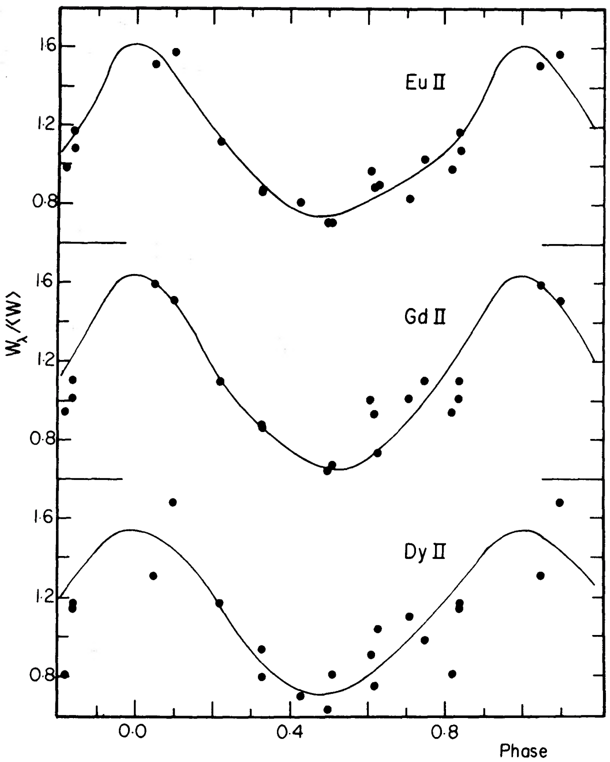

FIG. 2.—Equivalent-width variations for Eu II, Gd II, and Dy II. For each element, the plotted point represents the mean of all the lines of that element. For each line, the equivalent width, W_λ, is expressed as a fraction of the mean equivalent width, $\langle W\rangle$.

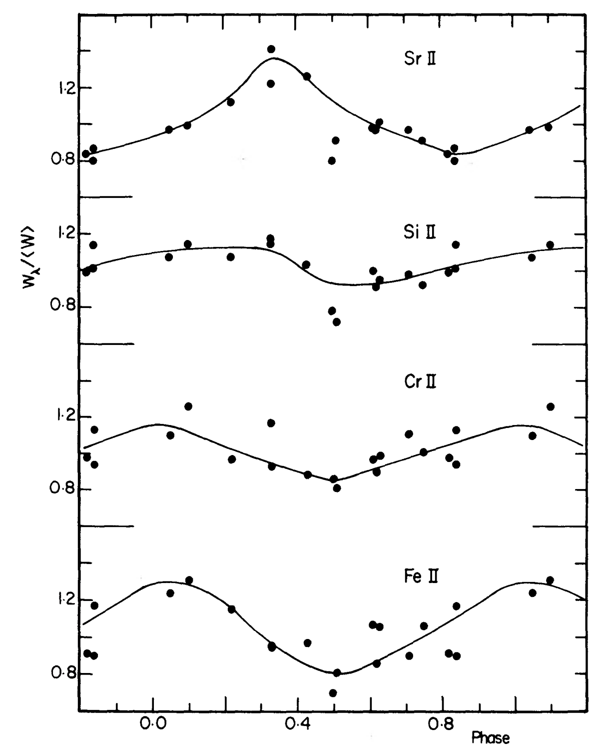

FIG. 3.—Equivalent-width variations for Sr II, Si II, Cr II, and Fe II

TABLE 3

COORDINATES, SPECTRAL TYPES, AND MAGNITUDES OF HD 51418 AND COMPARISON STARS

PARAMETER	STAR		
	60 Aur	16 Lyn	HD 51418
HR No.	2541	2585	...
HD No.	50037	50973	51418
R.A. (1950)	$06^h49^m.8$	$06^h54^m.0$	$06^h55^m.8$
Decl. (1950)	+38°30′	+45°10′	+42°23′
Spectral Type	F5 V	A2 Vn	A0p
V	6.34	4.91	6.60*
B − *V*	+0.46	+0.02	+0.13*
U − *B*	+0.05	+0.05	−0.13*

* At maximum light.

December 9; 1971 October 11 to October 31; and 1972 May 5 to May 26. A refrigerated 1P21 photomultiplier with standard *UBV* filters was used in conjunction with a charge-integration data system. Readings were obtained from a digital voltmeter.

Differential magnitudes were obtained, using as comparison stars HD 50037 (60 Aur) and HD 50973 (16 Lyn). The positions, magnitudes, and spectral types are given in table 3. Although the separations of the comparison stars from HD 51418 are rather large, the differential measures should be accurate to a few thousandths of a magnitude.

a) *UBV Observations*

The *V*, *B*, and *U* light curves for HD 51418 appear in figures 4*a*, 4*b*, and 4*c*, respectively, and the data from which these curves were derived are listed in table 4. The differential magnitudes, ΔV, ΔB, and ΔU, are for HD 51418 − HD 50037. The second comparison star, HD 50973, was found to be slightly variable.

The light variation has an amplitude of 0.17 mag in *V*, 0.08 mag in *B*, and 0.07 mag in *U*. The color variations ($B - V$) and ($U - B$) are approximately in antiphase with the *V* light curve and have amplitudes of 0.09 mag in ($B - V$) and 0.01 mag in ($U - B$). The light curves are symmetric, almost sinusoidal at maximum light, and slightly flattened at minimum, with no evidence of a secondary maximum. The light curves are quite similar in shape to those of α^2 CVn as discussed by Pyper (1969). The phase shift in the *B* and *U* curves, which corresponds to *B* and *U* leading *V* by 0.06 in phase, is significant. Similar phase shifts have been observed in other Ap stars (Winzer, unpublished data).

The scatter in the observations defining the *B* light curve is more than twice the expected observational precision; this would appear to be a real effect. Observations obtained over a 2-hour period with the 24-inch reflector at the David Dunlap Observatory Observatory near phase 0.49 showed no significant variation, indicating that this scatter is not due to low-amplitude pulsations such as have been found by Rakos (1962) for a few Ap stars. The observations, however, are consistent with some form of flare activity which would be most apparent in the hydrogen lines and would therefore have the largest effect on the *B* magnitudes. Spectroscopic observations of some changes in the hydrogen lines seem to support this idea.

b) Hβ *Observations*

In order to search for variations in the hydrogen lines, Hβ observations were carried out during the 1972 May observing session. Values of the Hβ index as deter-

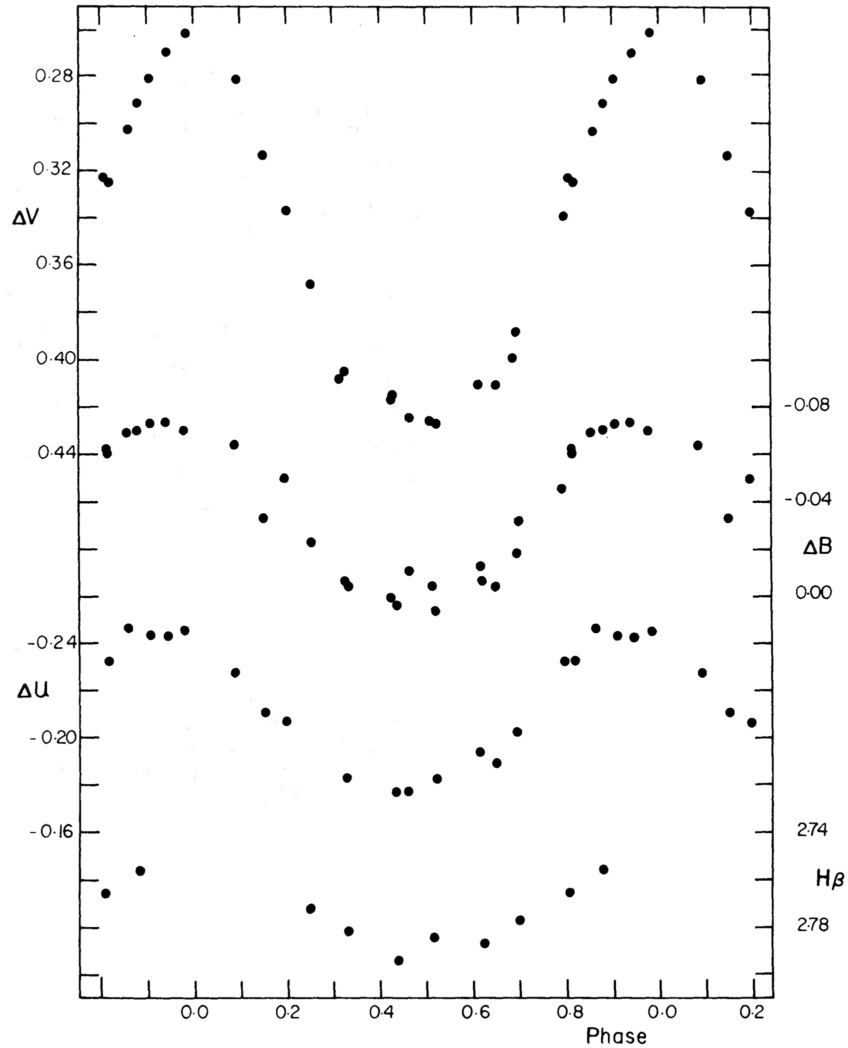

FIG. 4.—Light curves of HD 51418 plotted for a period of 5.4379 days with *V* light maximum at JD 2441241.654. (*a*) Variation in *V*. (*b*) Variation in *B*. (*c*) Variation in *U*. These are differential magnitudes, HD 51418 − HD 50037. (*d*) Variation in the Hβ system defined by Crawford and Mander (1966).

mined on eight nights are listed in table 4. The observations on the first five nights consist of single determinations. On the last three nights the star was monitored for approximately 1 hour with a time resolution of 2 minutes; the Hβ index for these nights represents an average value. The values of Hβ in table 4 have been transformed to the Hβ system defined by Crawford and Mander (1966).

There appear to be two different types of variation present. First, the Hβ index varies with phase. This variation is shown in figure 4*d*. Second, the star shows some indication of short-period variations. On the last night of monitoring, fluctuations as great as 0.03 mag in Hβ on time scales as short as 5 minutes were noted. These are shown in figure 5. These variations seem similar to the activity reported by Wood (1967) for HD 215441; however, further observations should be obtained before any definite conclusions are drawn.

TABLE 4

Photometric Observations of HD 51418

JD (2440000 +)	Phase	ΔV	ΔB	ΔU	Hβ
921.875	0.203	+0.336	-0.050	-0.208	
925.924	0.948	0.271	-0.074	0.242	
928.877	0.491	0.448	+0.022	0.162	
930.882	0.860	0.320	-0.069	0.247	
1236.995	0.151	0.314	-0.033	0.211	
1237.953	0.328	0.405	-0.006	0.182	
1238.990	0.519	0.427	+0.006	0.182	
1239.940	0.694	0.388	-0.019	0.203	
1243.936	0.429	0.416	+0.001	0.178	
1244.932	0.612	0.411	-0.013	0.195	
1245.932	0.796	0.340	-0.045	0.232	
1246.942	0.982	0.262	-0.070	0.245	
1251.965	0.906	0.282	-0.073	0.243	
1252.983	0.093	0.282	-0.063	0.227	
1254.993	0.463	0.423	-0.010	0.178	
1255.974	0.644	0.410	-0.005	0.189	
1256.925	0.819	0.325	-0.060	0.232	
1444.636	0.327	0.408	-0.003	0.170	2.782
1445.656	0.514	0.426	-0.004	0.184	2.784
1446.655	0.698	0.399	-0.034	0.215	2.776
1447.662	0.883	0.291	-0.070	0.236	2.757
1449.660	0.251	0.367	-0.021	0.200	2.772
1450.666	0.436	0.417	+0.004	0.180	2.794
1451.669	0.621	0.411	-0.006	0.203	2.788
1452.674	0.805	+0.323	-0.063	-0.246	2.767

V. SUMMARY

The observational results that have been presented here indicate that the new Ap star HD 51418 is one of the more interesting members of the Ap star group. The star has been classified as a member of the Eu-Sr-Cr subgroup with large variations in the Eu II and Sr II line intensities. HD 51418 resembles the well-known Ap star α^2 CVn

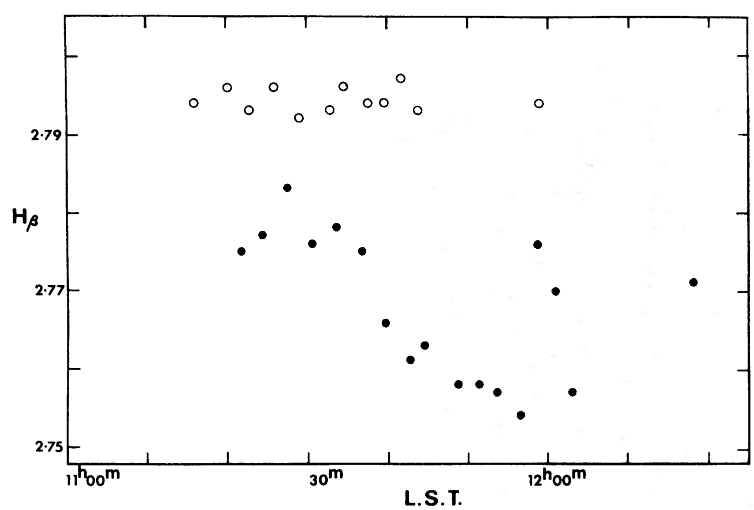

FIG. 5.—Hβ variation of HD 51418 observed from Kitt Peak on 1972 May 14 (*filled circles*). These represent the results of 1 hour of monitoring with a time resolution of approximately 2 minutes and a precision of approximately ±0.005 mag. The observations of 1972 May 12 (*open circles*) are presented for comparison.

in richness of spectral detail, yet it possesses light variations of more than twice the amplitude. The variation in the visual, ΔV of 0.17 mag, is larger than for any other Ap star. In addition, Hβ observations show systematic variations with phase as well as sporadic short-period activity. The nature of these variations are as yet poorly understood. The intriguing problem of the interpretation of the observed phase shifts also remains unsolved.

Further study of this star would be desirable. Higher-resolution spectroscopy is required in order to improve line identifications and line-intensity variations. Zeeman observations should also definitely be obtained. Additional narrow-band photometry as well as scanner observations are necessary since these should provide a better understanding of such problems as short-period variations and variations in the absolute energy distribution.

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