A SPECTROSCOPIC AND PHOTOELECTRIC SURVEY OF THE RV TAURI STARS*

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ABSTRACT

Three spectroscopic groups (A, B, C) of RV Tauri stars are identified from a study of low-dispersion spectrograms of 48 stars that are classified as RV Tauri stars or yellow semiregular variables in the second edition of the *General Catalogue of Variable Stars*. Except for the TiO bands that may occur during deep light minima, all spectroscopic features of members of group A indicate spectral type G or K. The stars in group B show a discrepancy at all phases between the spectral type based on the Ca II lines and that based on the hydrogen lines; between secondary and primary light-maxima, strong bands of CN are present. Members of group C resemble those of group B except that bands of CN are never seen. The RV Tauri stars can usually be distinguished from the SRd variables on the basis of the strength and duration of the hydrogen emission.

Concurrent U, B, V photometry of 15 of these RV Tauri stars indicates that the members of group A are systematically redder than those of groups B and C. The latter two groups appear to be indistinguishable photometrically. The $U - B$ and $B - V$ color indices of the RV Tauri stars at most phases lie near the locus of normal, non-variable supergiants in the $U - B$, $B - V$ plane; the color indices of the semiregular variable SX Her deviate markedly from this locus. Systematic differences occur in the phase shifts between the V, $B - V$, and $U - B$ curves of group A and groups B and C. It is suggested that the yellow semiregular variables and the members of group A constitute two relatively homogeneous families of variable stars. The status of groups B and C is uncertain. Finally, a recent binary interpretation of EP Lyr, a member of group B, is discussed.

I. INTRODUCTION

The RV Tauri stars are a rare, highly luminous species of variable stars characterized by (1) light-curves having alternate deep and shallow minima; (2) periods, defined as the interval between successive deep minima, between about 50 and 150 days; and (3) spectral type F, G, or K. The last of these criteria is added to exclude various red variables that satisfy 1 and 2. Two deep or two shallow minima may occur in succession (an interchange of minima). For some RV Tauri stars such interchanges occur infrequently, while for others—e.g., R Sct (McLaughlin 1939)—the light-variation may be irregular for extended periods of time and the alternation of minima exists only as a statistical regularity. The variety of photometric characteristics is well illustrated in the exhaustive study by Gaposchkin, Brenton, and Gaposchkin (1943).

Spectroscopic surveys of the RV Tauri stars have been made by Rosino (1951) and Joy (1952). Both authors agree that the RV Tauri class is heterogeneous, but their subdivisions differ in detail. Rosino suggested that the variables possessing emission lines and having TiO bands at minimum light belong to Baade's population II. The group so defined includes both RV Tauri stars and yellow semiregular variables (hereafter denoted by "SRd"). However, Rosino himself pointed out that the SRd variables have stronger, more persistent hydrogen emission and violate the photometric criteria that

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define the RV Tauri class. He did not speculate on the nature of the variables that show neither hydrogen emission nor TiO bands. Joy did not distinguish, *ab initio*, between the RV Tauri and SRd variables. However, upon dividing his stars into high- and low-velocity groups, he found a preponderance of the RV Tauri stars in the low-velocity ($|v_{\rm rad}| < 70$ km/sec) group, while most of the SRd variables were in the high-velocity ($|v_{\rm rad}| > 70$ km/sec) group. While hydrogen emission is generally stronger in the high-velocity group, the *presence* of hydrogen emission and TiO bands (Rosino's criteria) does not seem to bear any clear relation to the kinematic properties of the stars. More recently, Kameny (1956) has shown that U, B, V photometry can distinguish between the RV Tauri and SRd variables. Thus the distinction between RV Tauri and SRd variables seems to be definite, but little can be said about the homogeneity of the RV Tauri class proper.

Concurrent series of spectroscopic and U, B, V photometric observations of a number of RV Tauri and SRd variables were obtained at the Lick Observatory in 1961 and 1962. The purpose of the investigation was several fold: to extend the spectroscopic surveys of Rosino and Joy to new and/or fainter members of the class, in order to improve the list of definite members; to strengthen the meager U, B, V data for these stars; and, finally, to re-examine the homogeneity of the RV Tauri class of variable stars on the basis of this material.

II. THE OBSERVING PROGRAM

The spectroscopic survey was made with the nebular spectrograph of the Crossley reflector. The dispersion is 430 A/mm at Hγ. For a few stars the Crossley spectrograms were augmented by 16 A/mm spectrograms obtained with the 120-inch reflector. The 48 stars listed in Table 1 were observed. Of these, 36 are classified as definite or possible RV Tauri stars in the second edition of the *General Catalogue of Variable Stars* (Kukarkin *et al.* 1958), and 2 are RV Tauri stars in globular clusters. Seven SRd variables were included in the survey for purposes of comparison with the RV Tauri stars. The spectroscopic survey includes most of the known or suspected RV Tauri stars brighter than $m_{\rm pg} = 15$ at minimum light, north of declination $-30°$, and for which finding charts have been published. Twenty-five of these stars were observed previously by Joy or Rosino. Several of the brighter stars were observed more frequently than others, while the fainter stars, those in the winter sky, and those whose spectra indicated that they were not RV Tauri stars were observed less frequently, in some cases only once.

The photoelectric survey, made with the Crossley and the 22-inch Tauchmann reflectors, was limited to the 17 stars indicated by crosses in the sixth column of Table 1. The observations were made with conventional photometers, refrigerated 1P21 photomultipliers, and the following filters: for the yellow, 4-mm Corning 3384; for the blue, 1-mm Schott BG 12 + 2-mm Schott GG 13 + 1-mm glass; for the ultraviolet, 2-mm Schott UG 2 + 2-mm Corning 7910; for the evaluation of the red leak of the ultraviolet filter, 2-mm Schott UG 2 + 2-mm Schott RG 1.

For each variable, one or two nearby field stars were chosen as local standards. Anonymous comparison stars in Table 2 are identified by finding charts in Figure 1. The variable and the comparison star were usually observed in the sequence c-v-v-c and preliminary values of V, $B-V$, and $U-B$ were derived from instrumental magnitudes and colors by comparison with U, B, V standards. Extinction coefficients were determined from measures of red-blue extinction pairs on about one-third of the nights. For other nights mean extinction coefficients were used. Upon completion of the program, mean values of V, $B-V$, and $U-B$ were computed for each comparison star. These data are given in Table 3. The residuals for a given night were subtracted from the preliminary values for each variable to obtain the final values of V, $B-V$, and $U-B$ listed in Table 4. The probable errors for the comparison stars were derived from the internal scatter and do not include possible systematic errors due to the sample of U, B, V standards used or the properties of the observing equipment.

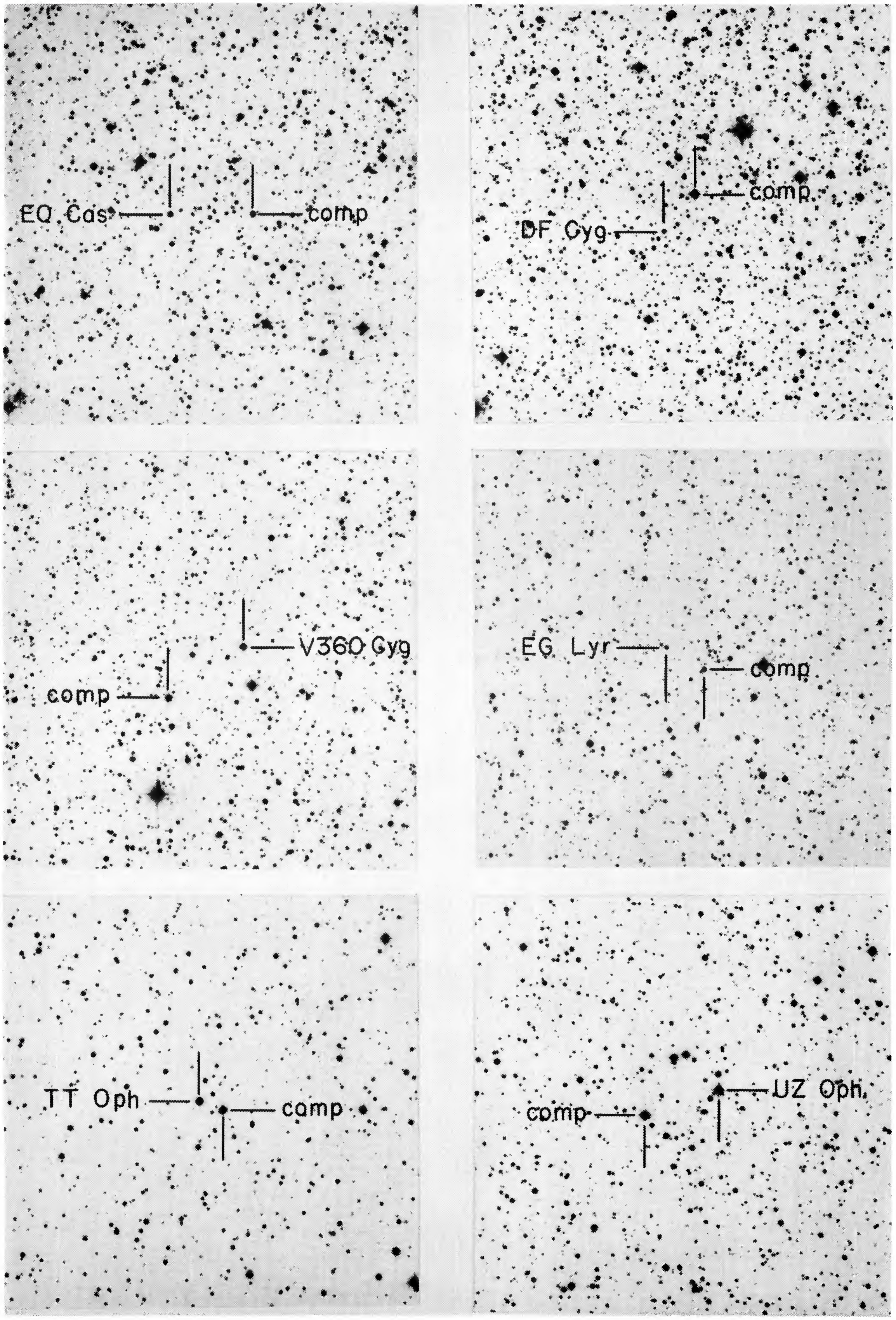

FIG. 1.—Identification charts for six anonymous comparison stars listed in Table 2. The scale is 16″.7/mm. North is up, east to the left. Copyright National Geographic Society—Palomar Observatory Sky Survey.

TABLE 1

SUMMARY OF DATA ON RV TAURI STARS

No	*Gen Cat of Var Stars* (2d Ed)				THIS STUDY			NOTE
	Star	Variable Star Class	Period (days)	Spectral Type	*U, B, V* Data	Spectral Type	RV Tauri Class or Other*	
1	SZ Aqr	RVa	108 5	K5		K0–M3e I*a*	SRd or cMe	1
2	AD Aql	RV	65 4	. . . .		Fp(R)	B?	2
3	DY Aql	RV	131 42	G5e–K0(M3)		G8e–M3 I*a*	A	3
4	AG Aur	SRd	96 0	G0e I*b*–K0ep(M3)		K2, Kp	SRd	
5	TW Cam	RVa	85 6	F8 I*b*–G8 I*b*		G0	A	
6	UY CMa	RV	113 9	G0		Fp(R)	B	
7	UZ CMa	SR	82 5	. . .		gM6	gM	
8	RX Cap	RV	67 92	G0–G3	:	F8–G0	A	
9	PY Cas	RV?	111	M5		gM5	gM	.
10	EQ Cas	RVa	58 372		×	Fp(R)	B?	2
11	BI Cep	RV	212	.		gM5e	gMe	
12	DF Cyg	RVb	49 808	cG5–cK4	×	G0–K0	A	
13	V360 Cyg	RV	70 449	F5–G0e	×	Fp–G0	C	
14	V399 Cyg	RV	120			G2–G8	A	
15	V457 Cyg	RV	79 1			G0	A	
16	CU Del	RVb	127	. . . .		. . .	gM	
17	SS Gem	RV	89 31	F8 I*b*–G5 I*b*		F8–G0	A	4
18.	SU Gem	RVb	50 12	F5–G6		F6p	A	4
19. . .	SX Her	SRd	102.9	G3e–K0(M3)	×	Gep–Gp(M2)	SRd	
20. . .	UU Her	SRd	90, 71	F2 I*b*–cF8	×	Fp	C	
21 .	AC Her	RVa	75 462	F2p I*b*–K4e(Rp)	×	Fp(R)	B	.
22. . .	BP Her	RV	168	. .		Gep–M3 I*a*	SRd	1
23. .	AB Leo	SRd	103 2	F6e–G6e		Gep–Gp	SRd	
24. .	EG Lyr	RV	136.7	. .	×	gM5	gM	
25. .	EP Lyr	RV	83.43	A I+G I	×	Fp(R)	B	5
26. .	U Mon	RVb	92.26	F8e I*b*–K0p I*b*	×	G2–G8	A	
27. . .	TT Oph	RVa	61 08	G2e–K0	×	G5–K0	A	
28 . .	TX Oph	RVa	135	F5e–G6e	×	G0–G8	A	
29. . .	UZ Oph	RVa	87 44	G2e–G8(M2)	×	G8–G(M3)	A	
30. .	V453 Oph	Cep	80		×	Fp	C	6
31	V564 Oph	RV	70.6		×	G8–K2(M2)	A	
32.	V609 Oph	RV	195	. .		gM6	gM	
33	EI Peg	RV	61 15	M4		gM5	gM	
34	TX Per	SRd	77 65	G5e–K2(M3)		Gp(M2)–K0e(M2)	SRd	
35	R Sge	RVb	70 594	G0 I*b*–G8 I*b*	×	G0–K0	A	
36	AR Sgr	RV	87 87	F5e–G6		F9	A?	
37	AZ Sgr	RV?	114	F		.	?	
38	V760 Sgr	RV	45 28			G5	A	
39	V794 Sgr	RV	160	. . . .		M3e I*a*–M4 I*a*	cM?	
40	AI Sco	RVb	71 0	G0–K2		G5	A	
41	R Sct	RVa	144	G0e I*a*–K0p I*b*	×	G8–K0(M3)	A	
42	Z Sex	RV	57	M3		gM4	gM	
43	RV Tau	RVb	78 698	G2e I*a*–K3p		G2, M2 I*a*	A	
44. .	WW Tau	SRd	113, 135	G4e–K2(M3)		G2e–Gp	SRd	
45	SV UMa	SRd	76	G1e I*b*–K3p I*a*		Gp	SRd	
46	V Vul	RVa	75 72	G4e–K3(M2)	×	G2–K0	A	
47	M2, No 11	RV	67 086	F5–G3e		Fp	C	7
48	M56, No. 6	RV	90 02	F6–G4e		Fp–Fep	C	3, 7

* Members of the spectroscopic groups described in the text are denoted by A, B, and C The symbols "gM" and "cM" refer to M-type giants and supergiants, respectively

NOTES TO TABLE 1

1. The assignment to the SRd class is based principally on the strength of the hydrogen emission.
2 The assignment to group B is based on the presence of CN at λ 3883 on a single spectrogram.
3. One of the two RV Tauri stars observed to have hydrogen emission in this survey
4. This study may be related to the members of group B (see the notes to Table 3).
5. The spectral types in the fifth column are those of Wenzel (1961*b*).
6. The period in the fourth column is that estimated from the photoelectric observations in this paper.
7. The star designation and period are taken from Sawyer (1955). The spectral types in fifth column are those of Joy (1949).

While the program was in progress, it was discovered that $U - B$ was not a single-valued function of the instrumental color, C_u, near $U - B = 0.0$, and it was found that this difficulty could be eliminated by replacing the UG 2 filter with a Corning 9863 filter. The observations of U Mon after January 20, 1962, were made with the Corning filter. All the variable stars in the program, with the possible exception of UU Her, are too red to be affected by the above-mentioned difficulty with the $U - B$ transformation. However, the $U - B$ values of the comparison stars for TX Oph, UU Her, and the blue comparison star for R Sct may be too large by as much as 0.05 mag. Because the comparison stars were used only to eliminate extinction errors, these possible systematic errors are not transmitted to the variables.

TABLE 2

DATA ON COMPARISON STARS

Variable	Comparison Star	V	$B-V$	$U-B$	n*
EQ Cas	†	11 465±0 013	+1 330±0 009	+1 097±0 040	8
DF Cyg	†	10 214±0 009	+0 565±0 004	+0 048±0 004	10
V360 Cyg	†	11 326±0 011	+0 555±0 006	+0 035±0 004	14
SX Her	+24°2972	8 917±0 007	+1 305±0 004	+1 387±0 006	22
UU Her	+38°2798‡	8 866±0 005	+0 417±0 004	−0 056±0 004	18
UU Her	+38°2791§	8 740±0 009	+0 196±0 009	+0 166±0 009	7
AC Her	+21°3465	7 405±0 004	+1 069±0 003	+0 828±0 003	26
EG Lyr	†	11 929±0 015	+1 060±0 007	+0 714±0 016	8
EP Lyr	+27°3336	9 555±0 005	+0 440±0 004	−0 014±0 004	24
U Mon	− 9°2069	6 625±0 005	−0 118±0 004	−0 573±0 015	22
U Mon	− 9°2086	6 579±0 007	+1 622±0 005	+1 998±0 010	23
TT Oph	†	10 894±0 009	+0 528±0 005	+0 044±0 009	10
TX Oph	+ 5°3312	10 247±0 013	+0 372±0 005	+0 194±0 011	7
UZ Oph	†	10 858±0 012	+1 125±0 008	+0 897±0 016	9
V453 Oph	− 2°4358	10 544±0 006	+0 660±0 005	+0 215±0.008	18
V564 Oph	+ 7°3495	9 678±0 008	+1 379±0 006	+1 507±0 012	11
R Sge	+16°4192	8 887±0 007	+0 884±0 004	+0 402±0 007	12
R Sct	− 6°4897	7 052±0 006	+0 095±0 004	+0 124±0 004	21
R Sct	− 6°4922	5 946±0 005	+1 632±0 005	+1 713±0 005	28
V Vul	+25°4301	8 580±0 010	+1 060±0 008	+0 832±0 008	11

* The number of observations
† See Fig 1 for identification
‡ TZ Her
§ UY Her

III. SPECTROSCOPIC RESULTS

Spectrograms of the variable stars were compared with MK standard spectra of luminosity classes II, I*b*, and I*a* on a Hartmann spectrocomparator. It should be stated at the outset, however, that MK classification is generally not possible at a dispersion of 400 A/mm. For F-type spectra we have used the growth of the K line of Ca II and the decline of the Balmer lines with advancing type as spectral-type criteria. In G- and K-type spectra the G band and the CN band head at λ 3883 increase in strength from G0 to about G8 and weaken in types later than K0. The structure of the G band can be seen to change progressively from a sharp, symmetrical feature in the early G's to a more diffuse feature at K0. This change in structure is accompanied by a drop in the continuum shortward of the G band that increases with advancing type. The line λ 4226 of Ca I is not seen in types earlier than K0 in I*b* supergiants; thereafter it grows smoothly with advancing type. Most metallic blends increase in strength with increasing luminosity in the G's and K's, while λ 4226 of Ca I decreases with increasing luminosity in the K's and M's. At best, the distinctions between luminosity classes II, I*b*, and I*a* are difficult to determine from 400 A/mm spectrograms of F-, G-, and K-type standards. If peculiarities occur, as is frequently the case for the RV Tauri and SRd variables, both the spectral type and the luminosity class may be highly indeterminate. Therefore, the spectral classifications presented in Table 3 must be regarded as of low precision. Nevertheless, it is possible to identify the following three spectroscopic groups among the RV Tauri stars:

A) *GK-type variables.*—All spectral features indicate type G or K, although irregularities in the strength of the CN bands, the λ 4175 blend, or the G band may occur, and the TiO bands may appear at light minima. Spectra of representative members of this group are shown in Figure 2, *a*, together with 9 Peg (G5 I*b*). Spectra of R Sct at successive secondary and primary light-minima are shown in Figure 2, *b*, to illustrate that the TiO bands at minimum light are well marked on Crossley spectrograms. During primary minimum [see R Sct (2) in Fig. 2, *b*] the TiO bands in R Sct are about as strong as those in the M4 supergiant U Lac; however, λ 4226 is prominent in U Lac and is not visible in R Sct. Note [see R Sct (1) in Fig. 2, *b*] that TiO may also be present at the preceding secondary minimum and that at both phases the metallic-line spectrum matches that of the G8 I*a* supergiant AX Sgr.

B) *Fp(R) variables.*—The spectra are markedly peculiar at all phases, and a unique spectral type cannot be assigned. Hydrogen-line types range from about F5 to G0 or later. The Ca II lines invariably correspond to an earlier type. Hydrogen emission may be responsible for part of the discrepancy on spectrograms taken during rising light but cannot be responsible at other phases when hydrogen emission is neither expected nor seen on 16 A/mm spectrograms (in the case of AC Her and EP Lyr). The most conspicuous spectral variations with phase occur in the CN and CH bands. The strength of the carbon features in AC Her, the brightest member of this group, was first reported by Rosino (1951), who classified AC Her as Rp. Spectrograms of several representatives of this group are shown in Figure 3. Near primary light-minima the CN band head at λ 3883 may reach a strength as great as in any supergiant, e.g., 9 Peg (see Fig. 3, *a*), while at other times it is not present at all (see Fig. 3, *b*). Given well-exposed spectrograms in the region λλ 3800–4000, it is impossible to confuse such stars with members of group A, even at very low dispersion.

C) *Fp variables.*—The hydrogen and Ca II lines resemble those of group B (see Fig. 4, *a*) but the bands of CN and CH are weak or absent at all phases. Both of the globular-cluster variables observed in this survey appear to belong to this group, though the phase coverage, particularly for variable No. 11 in M2, is too poor to state that CN is never present. Since the distinction between group B and group C depends entirely on the detection of CN absorption at certain phases, infrequently observed variables of type B may be spuriously attributed to group C.

The absorption spectra of the SRd variables are peculiar. The continuum is usually very smooth, and blends such as those at λ 4175 and λ 4200 as well as the CN bands may be weak or absent, indicating a type no later than G0 or G2, but the structure of the G-band region and the absence of hydrogen absorption usually indicate a later type. We have denoted such spectra simply as "Gp" or "Kp." The most distinctive characteristic of the SRd spectra is the strong Balmer emission when the stars are bright (as in Fig. 4, *b*). In only two RV Tauri stars (DY Aql and variable No. 6 in M56) have hydrogen-emission lines been detected on our spectrograms. In both cases the emission lines are very weak compared with those commonly seen in SRd variables. Thus the strength of the hydrogen emission appears to provide a useful spectroscopic criterion for the distinction between RV Tauri and SRd variables if a dispersion of the order of 400 A/mm is employed.

A number of RV Tauri stars cannot be placed unambiguously in group A, B, or C for reasons other than those discussed above. For example, TW Cam, RX Cap, V457 Cyg, and AR Sgr have approximately normal spectra with types near F8 or G0. We have tentatively identified them as early-type members of group A. The variables SS Gem, SU Gem, and TT Oph may be related to group B for the reasons given in the notes to Table 3. The variables SZ Aqr and V794 Sgr are difficult to classify. Hydrogen emission and TiO were present simultaneously in SZ Aqr for a period of 2 months in 1961, but λ 4226 of Ca I is not visible. Therefore, the star is probably not a long-period variable and is unlike typical RV Tauri stars. It may be a peculiar SRd variable, as suggested by Rosino (1951), or it may be an M-type supergiant with abnormally strong hydrogen emission. The galactic latitude ($b^{\mathrm{I}} = -62°$) argues against the latter possibility. One spectrogram of V794 Sgr is similar to those of SZ Aqr.

Eight of the program stars are M-type giants, one of them (BI Cep) an Me. Since there is no compelling reason to believe that the RV Tauri class merges smoothly with any of the various families of M-type variables, we suggest that the latter eight stars are not RV Tauri stars. It should be noted that, after excluding the M-type giants and the SRd variables, there are few RV Tauri stars with periods as long as 100 days.

The RV Tauri subtypes or other classifications either confirmed or assigned on the basis of the present spectroscopic survey are given in the eighth column of Table 1.

IV. PHOTOMETRIC RESULTS

The data in Table 4 have been plotted as filled circles in Figures 5–8. In cases where the number of observations is small, isolated observations have been shifted forward or backward one cycle. Such shifted observations are denoted by open circles. Uncertain observations are indicated by small symbols.

A majority of the stars for which light-curves are shown exhibit the alternation of minima characteristic of the RV Tauri class. Among these there are two predominant light-curve shapes. For V360 Cyg, TT Oph, and UZ Oph, the V light-maxima are symmetrical, and successive maxima are of equal height. The more frequent case is a light-curve in which the primary minimum is followed by a bright (primary) maximum. The light-curve shapes bear no obvious relation to the spectroscopic groups of the previous section.

The variable V453 Oph is a new addition to the RV Tauri class. It was previously classified as a cepheid with a period of 0.97 day. Because of the short period, it was included in surveys of RR Lyrae stars by Joy (1950), who found that it had a high radial velocity (-95 km/sec), and by Preston (1959), who reported that it is a weak-lined star ($\Delta S = 4$). A series of 20 A/mm spectrograms obtained by Preston (1960) with the Mount Wilson 100-inch coudé spectrograph in 1960 showed that broad, centrally reversed hydrogen-emission lines occurred for at least 7 days when the star was brightening at the rate of 0.1 mag/day. Our photoelectric data leave little doubt that V453 Oph is an RV Tauri star with a period of approximately 80 days.

In addition to the general tendency for the RV Tauri stars to have successive minima of different depths, the following photometric regularities may be noted: (1) The members of group A are systematically redder than those of groups B and C. This difference will be discussed in the following section. (2) For 7 of the 9 stars for which adequate data exist, the V light-amplitude and the $B - V$ color amplitude are correlated, and, at a given light-amplitude, the variables of group A tend to have larger color amplitudes than those of groups B and C. Curiously, the two brightest RV Tauri stars in the sky—R Sct and U Mon—do not obey this correlation. (3) The $B - V$ and $U - B$ color index-curves precede the V light-curve. This phenomenon is conspicuous in the photoelectric observations of Kameny (1956). Real differences in phase shift between the V and $B - V$ curves as a function of phase itself exist between the spectroscopic subgroups. For group A these shifts are very nearly independent of phase, while for groups B and C the shifts are much larger at secondary maxima and minima than at primary maxima and minima. These conclusions are summarized in Table 5, where $\Delta\phi_1 = \phi(V) - \phi(B - V)$. Mean values for group A and groups B and C are given at the bottom of Table 5. At primary minimum the shifts are smaller for groups B and C than for group A, while the reverse

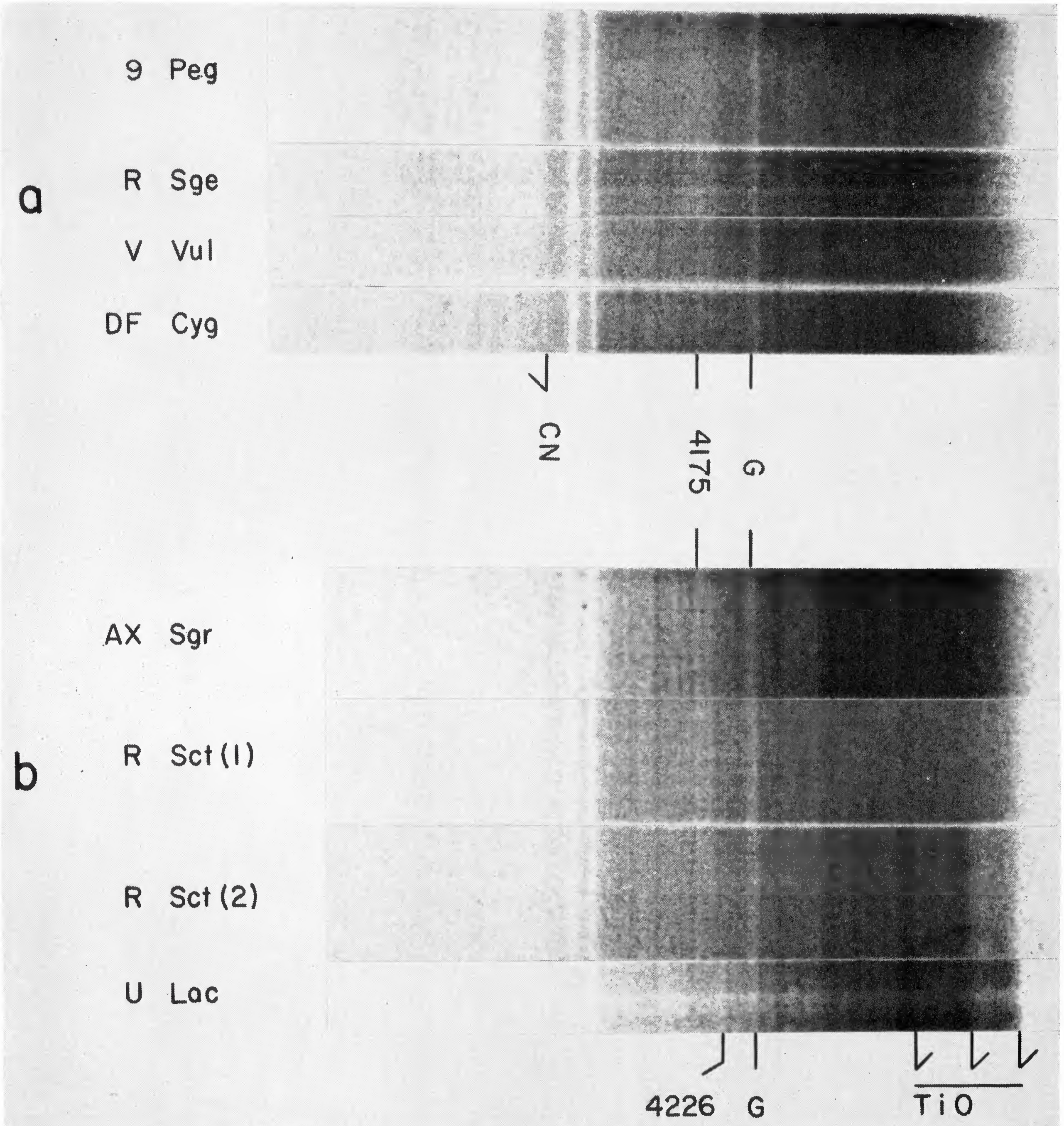

FIG. 2.—*a:* Spectra of RV Tauri stars of group A with 9 Peg (G5 I*b*). *b:* Spectra of R Sct at consecutive secondary (*1*) and primary (*2*) light-minima with AX Sgr (G8 I*a*) and the M4 supergiant U Lac. At primary minimum the TiO bands in R Sct are as strong as those in U Lac, but λ 4226, well-marked in U Lac, is not visible in R Sct; TiO may also be present at the secondary minimum. Note that at both phases the metallic-line spectrum of R Sct is well matched by that of AX Sgr.

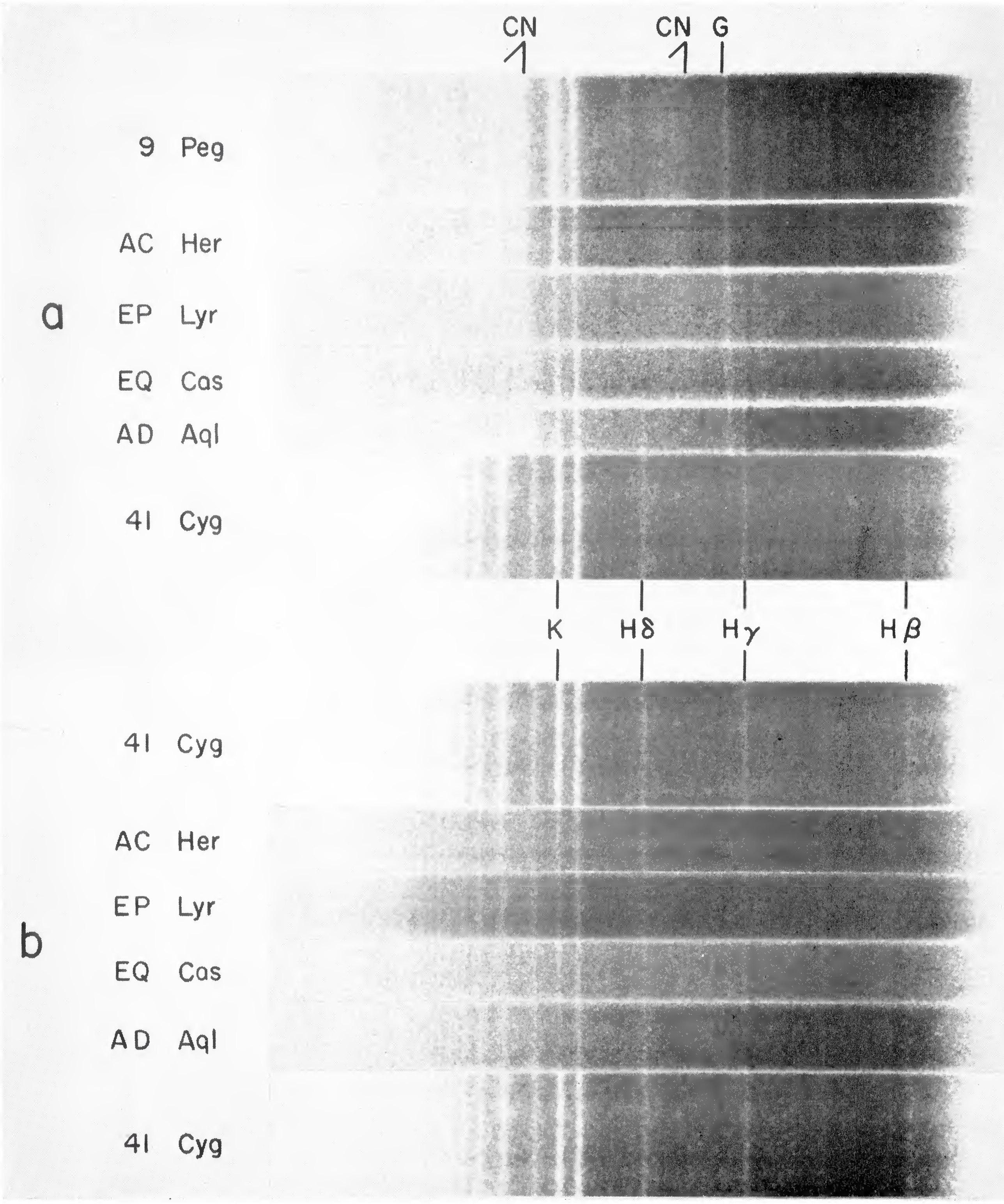

FIG. 3.—*a:* Spectra of members of group B at phases when the CN bands are strong. *b:* Spectra of members of group B when CN is not visible. Note the weakness of the K line relative to 41 Cyg (F5 II) in both panels. Emission lines λ 4047 and λ 4358 of Hg I due to city lights appear on several spectrograms.

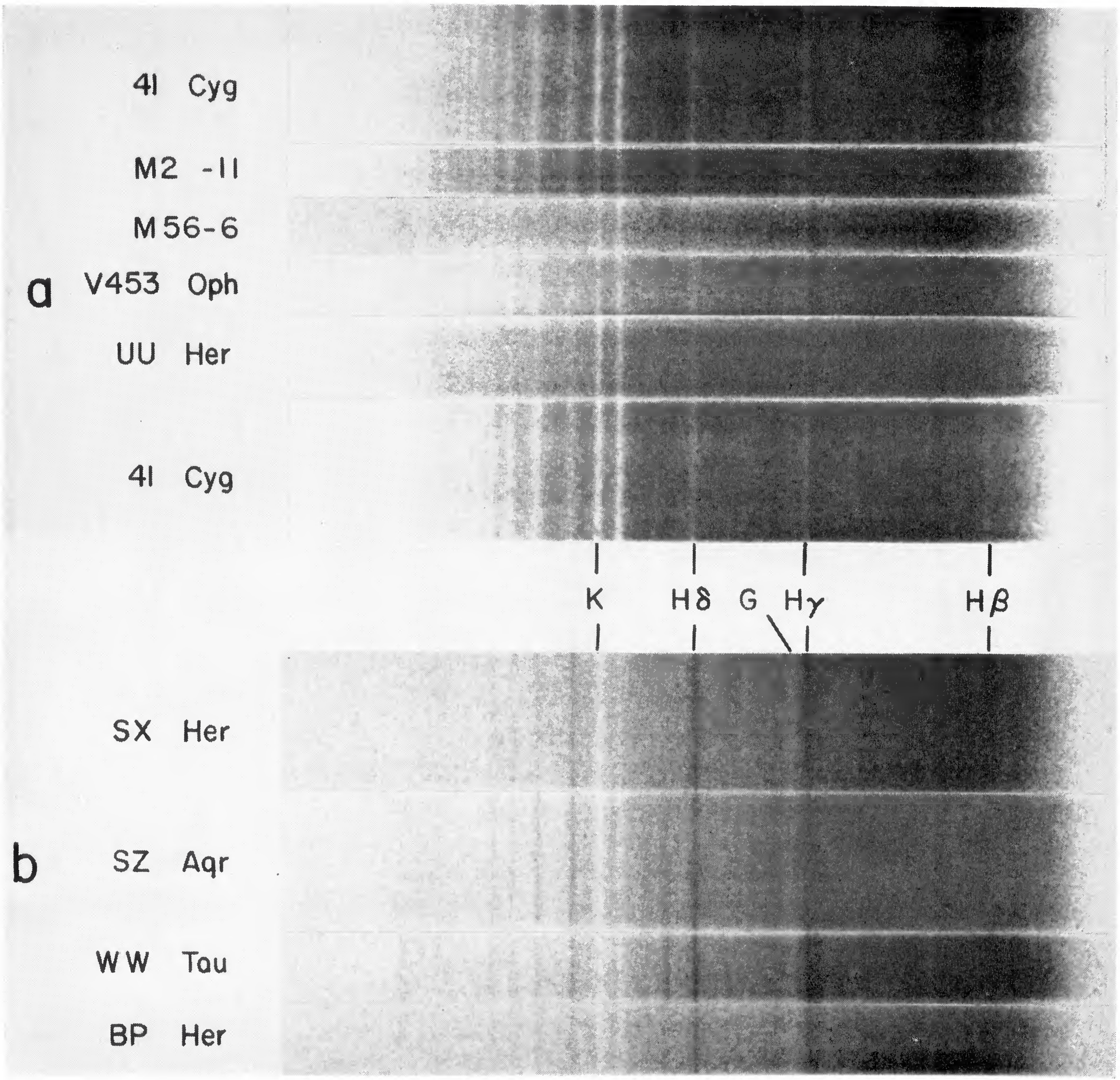

FIG. 4.—*a:* Spectra of members of group C. The spectra resemble those of group B in Fig. 3, *b*. *b:* Spectra of SRd variables when hydrogen emission is present. Note the weakness in the SRd spectra of all metallic blends prominent in the spectra of Fig. 2 and the diffuse character of the G band. Emission lines λ 4047 and λ 4358 of Hg I due to city lights appear on several spectrograms.

TABLE 3

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Star	JD 2437000+	Spectral Type	Spectral Type From: H	CaII	CN_{uv}	Notes
SZ Aqr	500	K0	-	-	-	16
	521	M3Ia	-	-	-	13
	552	M3eIa	-	-	-	13
	556	M3eIa	-	-	-	13
	575	Mep	-	-	-	11
	581	M2e	-	-	-	-
	586	Mep	-	-	-	15
AD Aql	528	Fp	F5	F1	G5Ib	-
	547	Fp	F6	A3	-	3
	556	Fp	F7	A5	-	4
	575	Fp	F6	A5	-	3, 9
	581	Fp	F5	A3	-	3
	586	Fp	F:	A:	-	1, 4
DY Aql	471	M3Ia	-	-	-	13
	520	M2Ia	-	-	-	13
	556	G8e	-	-	-	14
	557	K0e	-	-	-	14
	578	K(M2)	-	-	-	-
AG Aur	699	K2	-	-	-	-
	763	Kp	-	-	-	15
TW Cam	694	G0:	-	-	-	-
	699	G0	-	-	-	-
	737	G0	-	-	-	-
UY CMa	694	Fp	F8	A9	G1Ib	-
	699	Fp	G0	F0	G2Ib	-
	719	G0p	-	-	-	11
	758	Fp	F7	A8	-	-
UZ CMa	695	M6II	-	-	-	13
RX Cap	500	G0	-	-	-	5
	528	G0	-	-	-	10
	553	G0	-	-	-	-
	575	F8	-	-	-	4
PY Cas	491	M4II	-	-	-	13
	552	M5II	-	-	-	13
EQ Cas	495	Fp	-	A7	-	2, 3, 7
	504	Fp	-	F6	G2Ib	7
	524	Fp	-	A6	-	3, 7
	556	Fp	-	F0	-	3, 4, 7
	578	Fp	G0	F0	G0Ib	-
BI Cep	556	M5eII	-	-	-	13
DF Cyg	495	K0	-	-	-	-
	524	K0	-	-	-	-
	547	K0:	-	-	-	1
	556	G0	-	-	-	2

TABLE 3 (Continued)

Star	JD 2437000+	Spectral Type	Spectral Type From: H	CaII	CN_{uv}	Notes
DF Cyg	557	G5	-	-	-	-
	575	G2	-	-	-	-
V360 Cyg	491	Fp	G0	F6	-	3, 10
	520	G0	-	-	-	10
	556	Fp	-	F5	-	2, 3, 7
	575	Fp	-	F2	-	3, 7
V399 Cyg	494	G5	-	-	-	-
	528	G2	-	-	-	15
	552	G8	-	-	-	-
	575	G2	-	-	-	11
	586	G8	-	-	-	1
V457 Cyg	763	G0	-	-	-	-
	815	G0	-		-	-
CU Del	820	M3II	-	-	-	13
SS Gem	694	G0	-	-	-	6, 11
	699	G0	-	-	-	11
	763	F8:	-	-	-	2
SU Gem	694	F6	-	-	-	11
	699	Fp	F7	F4	-	-
	758	F7p	-	-	-	4
SX Her	464	Gp(M2)	-	-	-	5, 15
	474	Gp	-	-	-	5, 15
	504	Gep	-	-	-	5, 15
	547	Gp	-	-	-	5, 15
	573	Gp(M2)	-	-	-	5, 15
	581	Gp	-	-	-	5, 15
	586	Gep	-	-	-	5, 15
UU Her	464	Fp	F8	F2	-	-
	515	Fp	F7	F2	-	-
	547	Fp	F6	F1	-	10
	573	Fp	F8	F5	-	10
AC Her	464	Fp	G0	F5	G5Ib	-
	474	Fp	G0	F2	G2Ib	2
	521	Fp	F8	F4	G2Ib	-
	552	Fp	-	F3	-	3, 7
	573	Fp	F7	F0	-	3
	586	Fp	-	-	-	2
BP Her	491	Gep	-	-	-	5, 15
	524	Gep	-	-	-	5, 15
	553	M2	-	-	-	15
	557	M3	-	-	-	12, 15
	578	Gep	-	-	-	5, 15
AB Leo	694	Gep	-	-	-	5, 15
	699	Gep	-	-	-	5, 15
	737	Gp	-	-	-	1, 5, 15
	763	Gp	-	-	-	5, 15

TABLE 3 (Continued)

Star	JD 2437000+	Spectral Type	Spectral Type From: H	CaII	CN_{uv}	Notes
EG Lyr	471	M5II	-	-	-	13
	547	M5II	-	-	-	13
EP Lyr	464	Fp	F8	A8	-	3
	524	Fp	F8	A8	-	4
	547	Fp	F6	A7	-	3
	573	Fp	F7	F2	G5Ib	-
	581	Fp	F7	F1	G5Ib	-
	586	Fp	F9	F2	G5Ib	-
U Mon	699	G8	-	-	-	-
	737	G2	-	-	-	-
	750	G5	-	-	-	-
	758	G2	-	-	-	-
	761	G2	-	-	-	-
TT Oph	464	G5	-	-	-	11
	515	G8	-	-	-	-
	526	Gp	-	-	-	7, 11
	546	K0	-	-	-	-
	573	G8	-	-	-	-
TX Oph	464	G8	-	-	-	-
	515	G0	-	-	-	-
	526	G0	-	-	-	11
	546	G0p	-	-	-	11
1	573	Gp	-	-	-	4, 7, 10, 1
UZ Oph	464	G8	-	-	-	-
	520	G8	-	-	-	-
	546	G:	-	-	-	1
	573	G(M3)	-	-	-	-
V453 Oph	449*	F6p	-	-	-	9
	452*	Fp	F8	F4	-	-
	454*	Fp	F7	F5	-	-
	457*	Fp	F8	F3	-	9
	465*	Fp	F7	F0	-	10
	581	Fp	F9	F7	-	9
	763	Fp	F6	F0	-	-
V564 Oph	464	K1	-	-	-	14
	514	K2(M2)	-	-	-	1
	526	K2(M2)	-	-	-	-
	547	K0	-	-	-	-
	573	G8p	-	-	-	15
V609 Oph	763	M6II	-	-	-	13
EI Peg	474	M5II	-	-	-	13
	520	M5II	-	-	-	13
	547	M5II	-	-	-	13
	586	M5II	-	-	-	13

* JD 2436000+

TABLE 3 (Continued)

Star	JD 2437000+	Spectral Type	Spectral Type From: H	CaII	CN_{uv}	Notes
TX Per	699	K0e(M2)	-	-	-	-
	719	G5e(M3)	-	-	-	-
	737	Gp(M2)	-	-	-	-
R Sge	471	G2	-	-	-	2
	514	K0	-	-	-	-
	547	K0	-	-	-	-
	578	G0	-	-	-	-
AR Sge	464	F9	-	-	-	-
	521	F9p	-	-	-	7
	547	F9	-	-	-	-
AZ Sgr	500	Fp	G0	F7	-	-
	514	G0	-	-	-	-
	556	A7	-	-	-	16
	557	A7	-	-	-	16
V760 Sgr	495	G5	-	-	-	1
	552	G5	-	-	-	-
V794 Sgr	495	M3eIa	-	-	-	13
	528	M3Ia	-	-	-	13
	553	M4Ia	-	-	-	13
AI Sco	514	G5	-	-	-	-
	526	G5	-	-	-	-
R Sct	474	K0	-	-	-	-
	504	G8	-	-	-	-
	520	K0	-	-	-	-
	547	K0(M3)	-	-	-	-
	552	K0(M3)	-	-	-	-
	573	G8	-	-	-	-
	586	K0	-	-	-	-
Z Sex	699	M4II	-	-	-	13
RV Tau	689	M2Ia	-	-	-	13, 15
	699	G2	-	-	-	-
WW Tau	694	G2e	-	-	-	-
	695	Gep	-	-	-	5, 15
	699	Gep	-	-	-	5, 15
	719	Gp	-	-	-	-
	737	G2e	-	-	-	-
	761	-	-	-	-	1, 8
SV UMa	699	Gp	-	-	-	11, 15
	763	Gp	-	-	-	5, 11, 15
V Vul	464	G8	-	-	-	-
	504	G2	-	-	-	5
	524	G2	-	-	-	2
	547	K0	-	-	-	-
	578	G2	-	-	-	-

TABLE 3 (Concluded)

Star	JD 2437000+	Spectral Type	Spectral Type From: H	CaII	CN_{uv}	Notes
M 56	526	Fp	F8	F2	-	10
Var. 6	552	Fp	G0	F2	-	9
	557	Fp	F8	F5	-	9
	578	Fp	-	F0	-	7, 9
	815	Fep	-	F3	-	-
	820	Fp	-	F4	-	7
M 2	526	Fp	F7	F0	-	-
Var. 11	553	Fp	G0	F5	-	10

Notes to Table 3:

1. Spectrogram underexposed.
2. Spectrogram overexposed.
3. CN not present.
4. CN band head at λ 3883 may be present.
5. CN weak for the assigned type.
6. CN strong for the assigned type.
7. Hydrogen lines not visible.
8. Hydrogen emission not visible.
9. G band not visible.
10. G band weak for type based on hydrogen lines.
11. CaII lines weak for the assigned type.
12. λ 4226 of CaI not visible.
13. The luminosity based on strength of λ 4226 of CaI.
14. Ti0 may be present.
15. Continuum very smooth.
16. Wrong star observed?

TABLE 4

PHOTOMETRIC OBSERVATIONS

EQ Cas

JD 2437000+	V	B-V	U-B
495.96	11.50	+0.92	+0.18:
542.88	12.32	+1.30:	-
544.01	12.56	+1.40	+1.46:
552.87	11.56	+0.96	+0.56:
556.88	11.38	+0.94	+1.27
573.87	11.76	+1.08	+0.82:
588.82	11.64	+1.14	+0.88
606.74	12.36	+1.20	+0.54:
621.75	11.31	+1.12	+0.96

DF Cyg

JD 2437000+	V	B-V	U-B
488.91	10.82	+1.48	+1.68
489.89	10.84	+1.48	+1.62
495.90	11.60	+1.46	+1.43
496.88	11.54	+1.28	+1.01
500.90	10.87	+1.04	+1.01
511.85	10.45	+1.28	+1.33
524.81	10.91	+1.12	+0.91
542.77	11.16	+1.52	+2.00:
543.89	11.37	+1.54	+1.65
552.82	10.84	+1.07	+1.04
556.79	10.29	+1.02	+0.96
573.80	11.44	+1.42	+1.46
589.78	11.25	+1.55	+1.83:
606.68	10.62	+1.20	+1.14:
621.21	12.19	+1.46	-

V360 Cyg

JD 2437000+	V	B-V	U-B
488.97	11.40	+1.02	+0.69
489.93	11.44	+1.02	+0.75
495.94	11.70	+0.84:	+0.48
496.92	11.53	+0.85	+0.46
500.96	11.32	+0.72	+0.28
502.93	11.22	+0.70	+0.26
511.95	10.90	+0.87	+0.52
530.91	11.95	+1.05	+0.90:
532.83	11.80	+1.06	+0.46
541.96	11.06	+0.82	+0.24
543.85	10.96	+0.82	+0.33
549.95	10.91	+0.88	+0.50
571.82	11.14	+0.66	+0.22
581.75	10.90	+0.94	+0.66
589.74	11.15	+1.01	+0.84

V360 Cyg - concluded

JD 2437000+	V	B-V	U-B
602.75	11.95	+1.03	+0.62:
606.70	11.64	+0.84	+0.37
616.68	10.98	+0 82	+0.44
621.68	10.92	+0.90	+0.60

SX Her

JD 2437000+	V	B-V	U-B
441.90	8.46	+1.72	+1.64
443.75	8.50	+1.74	+1.77:
455.79	8.82	+1.72	+1.56
460.72	8.72	+1.66	+1.56
462.76	8.72	+1.66	+1.60
466.84	8.62	+1.64	+1.56
471.84	8.50	+1.64	+1.61
478.78	8.48	+1.69	+1.45:
480.82	8.44	+1.66	+1.56
484.81	8.38	+1.62	+1.53
488.73	8.38	+1.66	+1.51
489.72	8.36	+1.67	+1.47
490.75	8.36	+1.64	+1.48
494.74	8.26	+1.54	+1.36
496.82	8.03	+1.49	+1.18
501.76	8.02	+1.42	+0.91
502.72	7.96	+1.40	+0.94
507.73	7.94	+1.42	+1.02
511.75	7.93	+1.47	+1.21
514.72	7.96	+1.50	+1.26
524.77	8.12	+1.60	+1.48
532.77	8.22	+1.66	+1.66
541.76	8.40	+1.72	+1.70
542.74	8.38	+1.74	+1.66
552.70	8.65	+1.62	+1.42
562.68	8.93	+1.62	+1.33
581.63	8.24	+1.54	+1.30
589.62	8.10	+1.48	+1.26

UU Her

JD 2437000+	V	B-V	U-B
441.92	9.28	+0.60	+0.34
443.80	9.26	+0.56	+0.34
455.83	8.86	+0.38	+0.32
460.74	8.96	+0.46	+0.32
462.79	8.86	+0.47	+0.34
466.86	8.94	+0.56	+0.34

TABLE 4 – Continued

UU Her - concluded

JD 2437000+	V	B-V	U-B
478.81	9.25	+0.66	+0.42
480.91	9.24	+0.69	+0.38
488.74	9.27	+0.56	+0.34:
490.77	9.21	+0.52	+0.32
494.75	8.99	+0.42	+0.28
500.74	8.70	+0.36	+0.30
507.75	8.74	+0.44	+0.30
514.74	8.95	+0.55	+0.38
524.78	9.18	+0.70	+0.45
532.78	9.36	+0.66	+0.37
541.77	9.10	+0.44	+0.25
543.76	9.01	+0.44	+0.24
552.72	8.79	+0.48	+0.30
556.72	8.84	+0.55	+0.35
562.69	8 92	+0.58	+0.35
573.72	9.12	+0.63	+0.35

AC Her

JD 2437000+	V	B-V	U-B
443.85	7.38	+0.82	+0.54
455.88	7.66	+0.97	+0.94
460.81	8.14	+1.09	+0.87
462.95	8.32	+1.10	+0.82
466.93	8.40	+1.01	+0.65
471.87	7.94	+0.76	+0.38
478.90	7.14	+0.60	+0.36
480.95	7.08	+0.62	+0.33
484.88	7.14	+0.68	+0.41
489.82	7.30	+0.73	+0.44
490.86	7.32	+0.75	+0.46
494.86	7.50	+0.78	+0.51
495.82	7.56	+0.78	+0.51
496.83	7.61	+0.78	+0.51
501.87	7.84	+0.78	+0.42:
502.82	7.66	+0.73	+0.40
507.85	7.70	+0.58	+0.26
511.80	7.34	+0.52	+0.24
524.79	7.40	+0.88	+0.82
530.82	7.61	+0.97	+0.87
541.82	8.32	+0.97	+0.67
542.75	8.26	+0.96	+0.65
550.76	7.50	+0.65	+0.34
556.75	7.19	+0.69	+0.40
562.71	7.31	+0.74	+0.48
571.76	7.51	+0.69	+0.39
580.68	7.66	+0.62	+0.32
588.64	7.52	+0.64	+0.28
595.64	7.40	+0.84	+0.51
602.63	7.46	+0.94	+0.82

AC Her - concluded

JD 2437000+	V	B-V	U-B
606.60	7.58	+1.00	+0.92
616.60	8.38	+1.09	+0.90
622.61	8.08	+0.77	+0.36
625.61	7.52	+0.69	+0.33

EG Lyr

JD 2437000+	V	B-V	U-B
488.85	12.06	+1.56	+0.77
489.84	11.78	+1.70	+0.93
495.88	12.10	+1.70	+1.16
496.87	12.08	+1.86:	-
500.85	12.22	+1.68	+1.27
511.92	12.47	+1.76	-
526.90	12.57	+1.76	+0.89
530.84	12.40	+1.69	-
543.83	12.50	+1.78	+1.10:
552.75	12.38	+1.78	+1.30:
573.76	12.86	+1.72	+0.74
588.66	12.72	+1.63	+1.00:
589.66	12.71	+1.72	+0.82

EP Lyr

JD 2437000+	V	B-V	U-B
466.95	10.34	+0.64	+0.40
478.95	10.32	+0.62	+0.30:
484.92	10.26	+0.76	+0.53
488.88	10.22	+0.88	+0.74
489.85	10.25	+0.88	+0.67
490.89	10.26	+0.87	+0.75
494.90	10.32	+0.87	+0.76
495.83	10.36	+0.89	+0.79
496.83	10.38	+0.89	+0.82
500.88	10.64	+0.96	+0.74
507.86	10.90:	+1.00:	-
511.83	10.80	+0.84	+0.58
524.80	10.01	+0.62	+0.42
526.88	10.01	+0.67	+0.36
532.80	10.09	+0.73	+0.40
541.85	10.22	+0.71	+0.40
542.75	10.28	+0.69	+0.38
550.82	10.30	+0.64	+0.32
556.77	10.20	+0.53	+0.32
562.72	9.98	+0.62	+0.40
571.78	10.28	+0.84	+0.64
580.70	10.50	+0.84	+0.82
588.67	10.80	+0.99	+0.66
595.65	10.72	+0.82	+0.48
602.64	10.06	+0.56	+0.35

TABLE 4 – Continued

EP Lyr - concluded

JD 2437000+	V	B-V	U-B
606.61	10.16	+0.56	+0.38
616.61	10.14	+0.76	+0.42
621.65	10.48:	+0.72	+0.30
622.62	10.16	+0.71	+0.38

U Mon

JD 2437000+	V	B-V	U-B
589.02	5.86	+0.85	+0.59
590.01	5.80	+0.86	+0.50
603.91	5.77	+1.10	+0.88
616.95	6.35	+1.18	+0.92
619.91	6.62	+1.14	+0.85
622.92	6.82	+1.03	+0.72
626.90	7.02	+0.94	+0.66
631.86	6.53	+0.95	+0.63
637.90	6.00	+0.92	+0.62
641.99	5.63	+0.94	+0.70
655.83	5.71	+1.03	+0.95
656.91	5.71	+1.07	+0.92
660.84	5.85	+1.08	+0.98
663.79	5.96	+1.14	+0.92
664.85	6.01	+1.10	+0.94
672.85	6.17	+1.00	+0.76
675.83	6.04	+0.90	+0.65
678.81	5.89	+0.82	+0.51
679.81	5.84	+0.81	+0.51
689.79	5.68	+1.03	+0.80
692.81	5.70	+1.09	+0.90
694.81	5.76	+1.12	+0.98
696.77	5.78	+1.15	+0.94
699.79	5.87	+1.17	+1.06
700.78	5.91	+1.13	+1.08
717.74	6.60	+1.06	+0.84
722.70	6.26	+0.99	+0.56
727.72	5.82	+0.83	+0.62
732.71	5.63	+0.86	+0.63
736.64	5.56	+0.93	+0.68
742.68	5.56	+1.04	+0.88
748.73	5.72	+1.12	+1.00
754.64	5.96	+1.18	+1.07
759.68	6.18:	+1.20:	+1.06:
764.71	6.50	+1.13	+0.86
765.69	6.52	+1.09	+0.84
766.64	6.54	+1.07	+0.86
770.68	6.26	+0.98	+0.70
775.64	5.86	+0.89	+0.57
776.67	5.80	+0.86	+0.54
787.66	5.82	+1.12	+0.83

TT Oph

JD 2437000+	V	B-V	U-B
488.75	10.72	+1.38	+1.50
489.74	10.84	+1.34	-
495.73	10.68	+1.10	+0.87
496.73	10.48	+0.97	+0.22
500.76	9.88	+0.84	+0.42
501.80	9.77	+0.84	+0.37
502.74	9.58	+0.85	+0.44
511.73	9.58	+1.07	+0.98
524.74	10.20	+1.04	+0.74
530.74	9.76	+0.92	+0.27
539.70	9.54	+1.05	+1.13
541.70	9.67	+1.16	+1.32
543.69	9.79	+1.24	+1.44
550.68	10.66	+1.34	+1.35:
551.69	10.76	+1.34	+1.12
556.67	10.62	+1.10	+0.90:
573.66	9.54	+1.10	+0.56

TX Oph

JD 2437000+	V	B-V	U-B
489.76	10.45	+1.11	+0.77
495.75	10.08	+1.00	+0.74
496.75	10.02	+0 97	+0.72
501.82	9.90	+1.00	+0.69
507.78	9.97	+0.92	-
511.77	9.93	+0.95	+0.75
524.75	10.02	+0.99	+0.76
530.76	10.02	+0.92	+0.82
542.68	10.08	+0.91	+0.62
551.72	9.82	+0.86	+0.56
556.69	9.93	+0.85	+0.58
573.69	10.10	+1.05	+0.76

UZ Oph

JD 2437000+	V	B-V	U-B
488.78	11.50	+1.10	-
489.78	11.42	+1.10	+0.71
495.76	10.78	+0.98	+0.81
496.76	10.68	+0.98	+0.77
500.80	10.34	+0.98	+0.71
511.77	10.34	+1.18	+1.14
524.73	11.07	+1.22	+1.14:
526.79	11.16	+1.26	+1.17
532.74	11.22	+1.13	+0.98
541.73	10.29	+0.90	+0.52
543.70	10.25	+0.90	+0.56
552.68	10.23	+1.16	+1.08
573.70	11.40	+1.05	+1.04

TABLE 4 – Continued

V453 Oph

JD 2437000+	V	B-V	U-B
441.95	10.40	+0.83	+0.44
443.82	10.44	+0.77	+0.58
455.86	10.64	+0.87	+0.46
460.78	10.76	+0.88	+0.44
462.87	10.84	+0.81	+0.50
466.89	10.96	+0.76	+0.42:
478.85	10.66:	+0.94:	-
480.86	10.70	+0.90	+0.53
488.79	10.64	+0.96	+0.79
489.79	10.66	+0.96	+0.74
490.81	10.68	+0.96	+0.79
494.82	10.76	+1.02	+0.80
495.80	10.84	+1.07	+0.86
496.80	10.97	+1.05	+0.82
500.78	11.34	+1.16	+0.67
511.80	11.00	+0.89	+0.52
524.76	10.40	+0.84	+0.54
532.75	10.54	+0 84	+0.44
542.70	10.72	+0.78	+0.47
550.70	10.74	+0.75	+0.40
564.72	10.60	+0.92	+0.58:
589.64	11.53	+1.02	+0.50

V564 Oph

JD 2437000+	V	B-V	U-B
488.81	9.73	+1.60	+1.63
489.80	9.72	+1.61	+1.71:
495.78	9.74	+1.55	+1.53
496.78	9.74	+1.56	+1.48
500.83	9.88	+1.62	+1.77
507.81	10.16	+1.70:	-
511.83	10.23	+1.72	+1.88
524.71	10.42	+1.59	+1.46
526.81	10.41	+1.72	+1.96
530.78	10.32	+1.64:	+1.59:
542.72	9.93	+1.58	+1.40:
543.72	9.92	+1.66	+1.66
550.72	9.87	+1.69	+1.62:
556.71	10.04	+1.69	+1.78
564.75	9.84	+1.63	-
580.66	9.89	+1.60	+1.55:
581.65	9.86	+1.62	+1.60

R Sge

JD 2437000+	V	B-V	U-B
488.92	9.06	+1.06	+0.90
489.91	9.14	+1.12	+0.82

R Sge - concluded

JD 2437000+	V	B-V	U-B
495.91	9.22	+1.00	+0.80
496.90	9.18	+0.97	+0.83
501.90	9.09	+0.81	+0.62
502.88	9.08	+0.75	+0.61
507.90	9.02	+0.92	-
511.88	9.08	+1.08	+0.97
524.80	9.50	+1.42	+1.63
532.83	10.04	+1.27	+1.34
541.90	8.92	+0.90	+0.68
543.81	8.85	+0.92	+0.79
550.86	8.88	+1.06	+0.96
552.79	8.92	+1.11	+1.09
564.78	9.28	+0.95	+0.79
581.70	8.95	+1.08	+1.00
589.70	9.25	+1.28	+1.34
606.66	9.88	+1.14	+0.88
616.64	8.71	+0.90	+0.77

R Sct

JD 2437000+	V	B-V	U-B
455.90	5.14	+1.46	+1.52
460.83	5.24	+1.53	+1.66
462.90	5.26	+1.54	+1.74
466.91	5.35	+1.57	+1.82
478.88	5.64	+1.54	+1.85
480.93	5.62	+1.50	+1.73
484.85	5.54	+1.43	+1.57
490.84	5.36	+1.36	+1.32
494.85	5.25	+1.29	+1.15
495.81	5.22	+1.26	+1.13
496.81	5.26	+1.30	+1.07
501.84	5.14	+1.27	+1.01
502.80	5.11	+1.24	+1.02
507.83	5.08	+1.29	+1.10
511.78	5.06	+1.36	+1.18
524.69	5.18	+1.50	+1.62
530.69	5.44	+1.52	+1.78
541.80	6.21	+1.51	+1.74
542.67	6.26	+1.46	+1.74
550.75	6.25	+1.32	+1.24
552.70	6.04	+1.25	+1.24
556.66	5.52	+1.20	+1.10
562.65	4.96	+1.20	+1.05
564.69	4.90	+1.19	+1.09
569.63	4.73	+1.23	+1.22
571.66	4.85	+1.30	+1.28
573.64	4.89	+1.34	+1.36
580.62	4.97	+1.42	+1.58
581.61	5.03	+1.41	+1.72

TABLE 4 – Concluded

R Sct - concluded

JD 2437000+	V	B-V	U-B
583.61	5.09	+1.39	+1.66
588.60	5.17	+1.44	+1.70
589.60	5.16	+1.48	+1.72
595.62	5.31	+1.42	+1.72
602.61	5.52	+1.42	+1.59
606.59	5.63	+1.44	+1.52
616.59	5.66	+1.22	+1.14:
622.60	5.32	+1.14	+0.97:
625.60	5.21:	+1.14:	+0.94:

V Vul

JD 2437000+	V	B-V	U-B
488.94	8.06	+1.01	+0.86
489.92	8.10	+1.04	+0.89
495.92	8.28	+1.11	+0.92

V Vul - concluded

JD 2437000+	V	B-V	U-B
496.90	8.35	+1.10	+0.96
501.93	8.51	+1.16	+0.97
502.90	8.54	+1.16	+0.99
504.92	8.60	+1.14	+0.94
507.92	8.64	+1.12	+0.84
511.90	8.54	+0.99	+0.75
530.89	8.41	+1.40	+1.56
541.92	9.20	+1.47	+1.55
542.83	9.29	+1.48	+1.54:
549.81	9.35	+1.18	+1.13
550.80	9.23	+1.22	+1.06
564.80	8.16	+1.12	+0.93
581.71	8.56	+1.10	+0.82
589.71	8.22	+0.84	+0.60
606.67	8.46	+1.34	+1.28
616.66	8.93	+1.42	+1.34
621.67	9.05	+1.31	+1.19

is true at secondary maximum and minimum. Only at primary maximum do the differences in mean phase shifts between the two groups fail to exceed the sum of the average deviations. The quantity $\Delta\phi_2 = \phi(B - V) - \phi(U - B)$ is also given in Table 5. This phase shift is small or non-existent except near primary minimum for groups B and C, where it is pronounced.

The RV Tauri stars are conveniently compared with each other and with non-variable supergiants in the $U - B$, $B - V$ plane. Typical RV Tauri stars execute elongated, inclined loops in this plane, such as those for AC Her and R Sct shown in Figure 9. Since methods for defining a mean color index for pulsating stars (Kraft 1961; Preston 1961) cannot be applied to the RV Tauri stars in a straightforward manner, we have simply intercompared the stars at the stationary points of the color index-curves. The co-ordinates of these points are given in Table 6. Most of these stars are more than 1 kiloparsec

TABLE 5

PHASE SHIFTS $\Delta\phi_1 = \phi(V) - \phi(B - V)$ AND $\Delta\phi_2 = \phi(B - V) - \phi(U - B)$ FOR STATIONARY POINTS OF LIGHT AND COLOR INDEX-CURVES

STAR	MIN I		MAX I		MIN II		MAX II		GROUP
	$\Delta\phi_1$	$\Delta\phi_2$	$\Delta\phi_1$	$\Delta\phi_2$	$\Delta\phi_1$	$\Delta\phi_2$	$\Delta\phi_1$	$\Delta\phi_2$	
DF Cyg	0 04	+0 04	0 08	0 02	. ..	. ..	..	..	A
V360 Cyg	06	..	10	04	0 09	0 00	13	00	C
AC Her	05	+ 09	05	03	17	00	16	− 04	B
EP Lyr	04	+ 08	02:	00	14	− 04	10	+ 04	B
U Mon	15	00	14	04	08	+ 04	09	00	A
TT Oph	07	+ 07	11	03	11	+ 02	11	00	A
UZ Oph	..	...	10		11	+ 02	05	+ 02	A
V453 Oph	01	+ 08	..	..	16	..	20	..	C
R Sge	12	00	07	01	08	+ 01	09	00	A
R Sct	09	− 01	0 07	0 00	06	− 01	07	00	A
V Vul	0 12	+0 01			0 08	0 00			A
Group A .	0 10±0 03	0 02±0 03	0 10±0 02	0 02±0 01	0 09±0 02	+0 01±0 01	0 08±0 02	0 00±0 00	
Groups B, C	0 04±0 02	0 08±0 00	0 06±0 03	0 02±0 01	0 14±0 02	−0 01±0 01	0 15±0 03	0 00±0 03	

TABLE 6

CO-ORDINATES OF STATIONARY POINTS OF COLOR INDEX-CURVES

STAR	MIN I		MAX I		MIN II		MAX II		E_{B-V}
	$B-V$	$U-B$	$B-V$	$U-B$	$B-V$	$U-B$	$B-V$	$U-B$	
DF Cyg	1 55	1 72	1 00	0 97	1 35:	1 40:	1 10:	0 85:	0 1:
V360 Cyg	1 07	0 88:	0 80:	0 22:	1 02:	0 75	0 69	0 25	1:
UU Her	0 68	0 42	0 36	0 28	0 70	0 45	0 41	0 28	1
AC Her	1 10	0 94	0 60	0 31	0 78	0 50	0 58	0 26	1
EP Lyr	0 98	0 72	0 56	0 38	0 74	0 42	0 54	0 30	3
U Mon	{1 18	0 98:	0 92	0 62	1 12	0 98	0 80	0 50	1
	{1 20	1 12:	0 82	0 57	1 20	1 07	0 86	0 54	.
TT Oph	1 36	1 46	0 84	0 27	1 15:	1 05:	0 90	0 22	2
TX Oph			0 93	0 70	1 00:	0 80:	0 86	0 56	2
UZ Oph	. .	. .	0 97	0 71	1 26	1 19	0 90	0 53	2
V453 Oph	1 15:	0 85:	.	.	0 88:	0 55:	0 76	0.41	4
V564 Oph	1 70:	1 90:	1 6::	1 6::	1 70:	1 80:	1 55	1 50	25
R Sge	1 42	1 63	0 90	0 68	1 12	1 09	0 75	0 61	1
R Sct	{1 53	1 82	1 18	1 05	1 60	1 89	1 26	1 00	.
	{. .	. ..			1 46	1 73	. ..	. .	2
V Vul	1 50	1 50	. .	. ..	1 16	1 00	0 85:	0 60:	3
SX Her	1 74	1 68	1 40	0 92		.	.	.	0 1

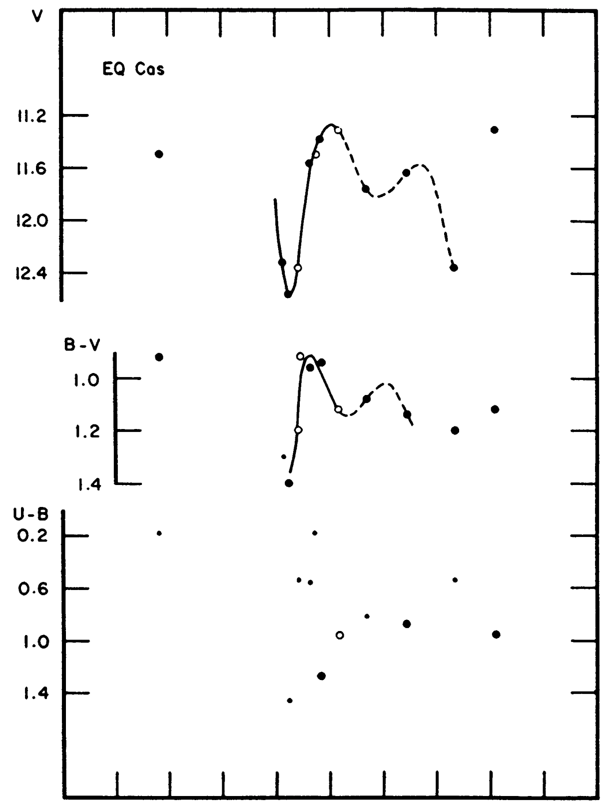


FIG. 5*a*

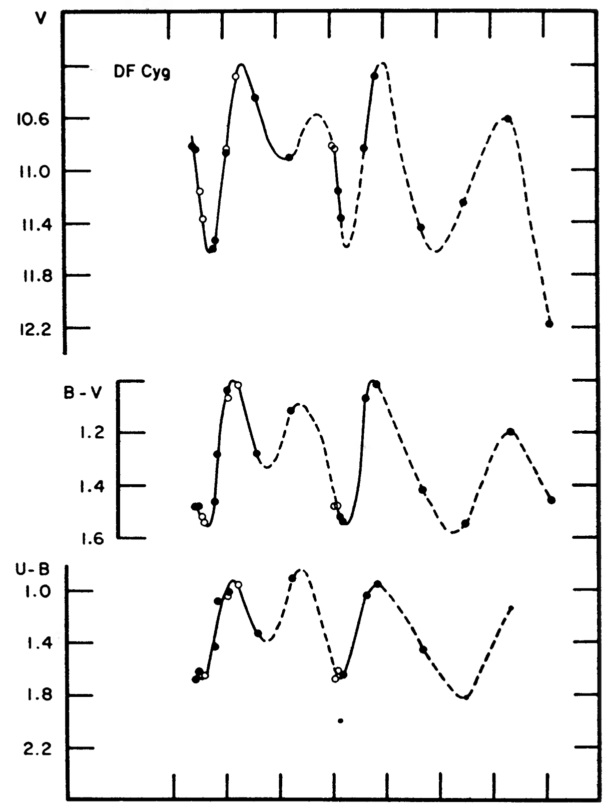
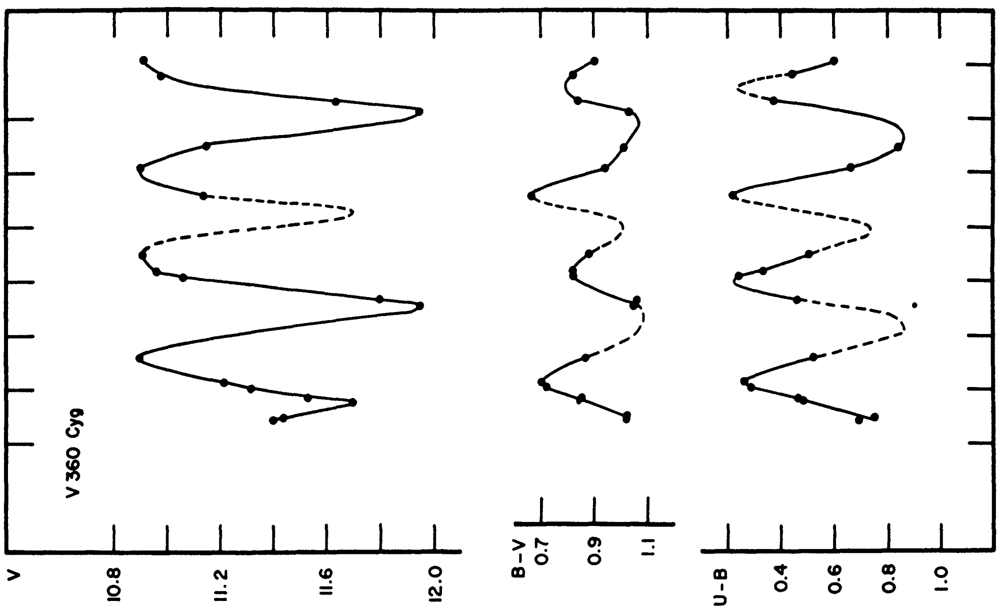


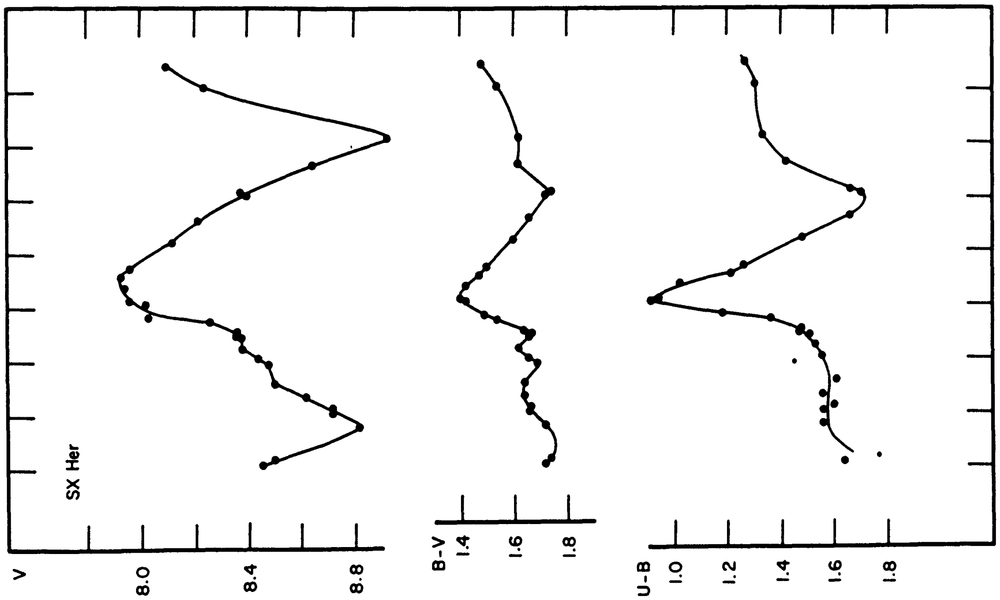
FIG. 5*b*

FIG. 5.—The V, $B - V$, and $U - B$ variations of three RV Tauri stars and the SRd variable SX Her. Open circles denote observations shifted forward or backward one cycle. Small symbols indicate uncertain observations. Highly uncertain portions of the freehand curves are dashed.



V 360 Cyg
V
10.8
11.2
11.6
12.0
B−V
0.7
0.9
1.1
U−B
0.4
0.6
0.8
1.0
JD 2437000+
500
540
580
620

FIG. 5c



SX Her
V
8.0
8.4
8.8
B−V
1.4
1.6
1.8
U−B
1.0
1.2
1.4
1.6
1.8
JD 2437000+ 460
500
540
580

FIG. 5d

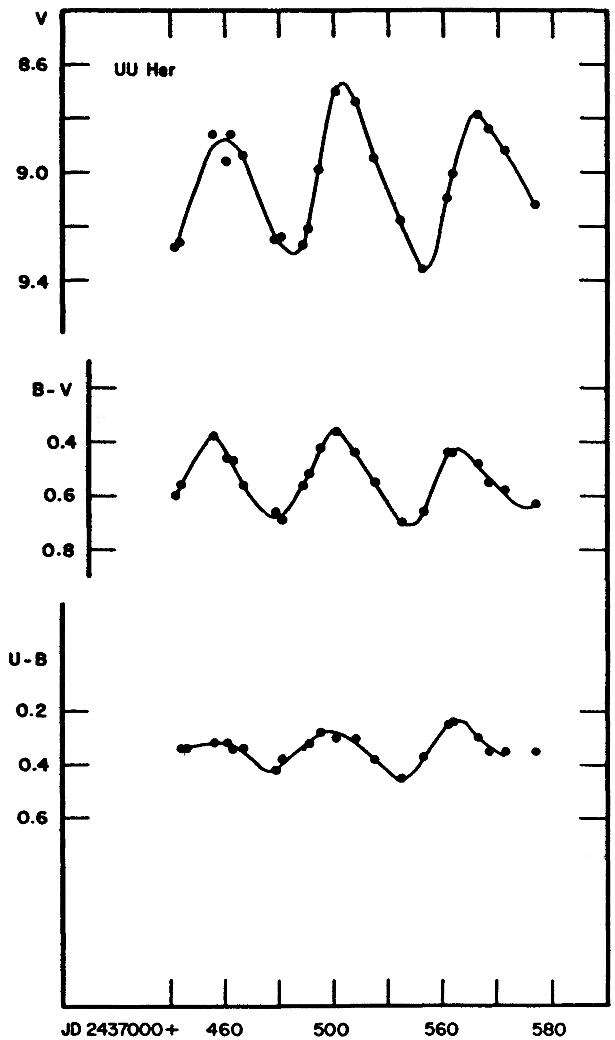


Fig. 6a

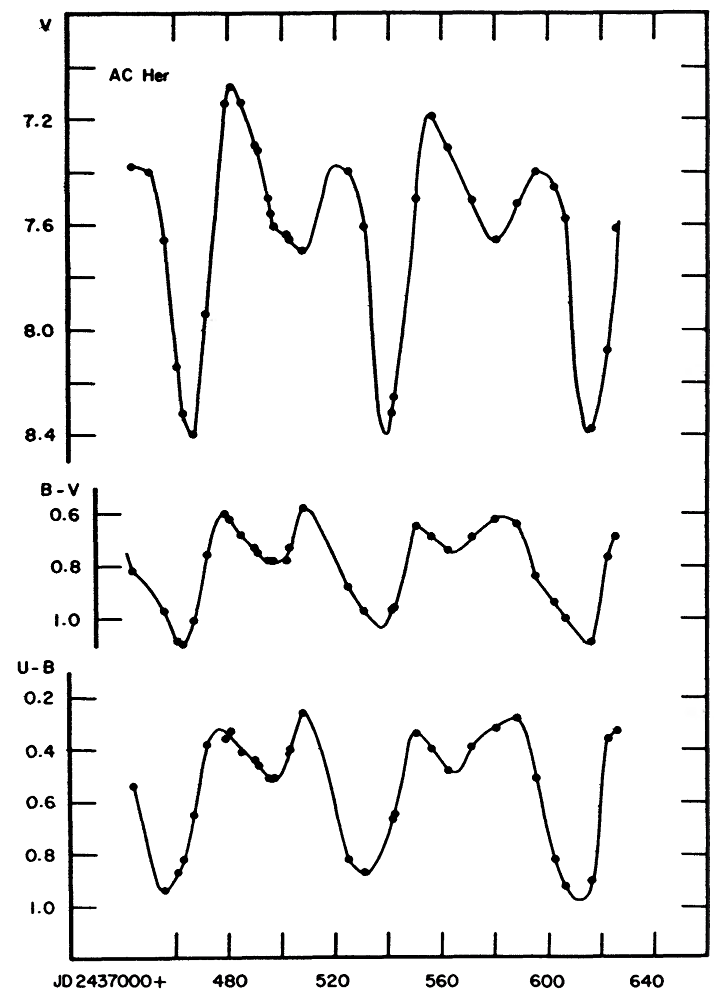


Fig. 6b

Fig. 6.—The V, $B - V$, and $U - B$ variations of four TV Tauri stars. Small symbols indicate uncertain observations. Highly uncertain portions of the freehand curves are dashed.

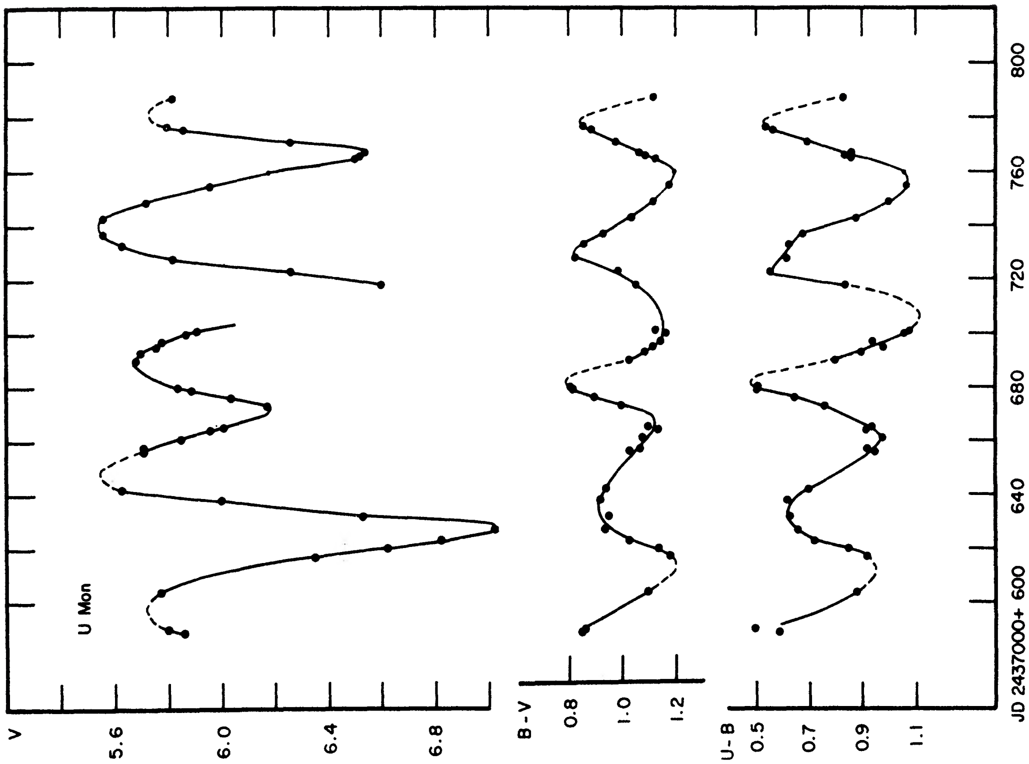

U Mon
V
5.6
6.0
6.4
6.8
B - V
0.8
1.0
1.2
U - B
0.5
0.7
0.9
1.1
JD 2437000+ 600
640
680
720
760
800

FIG. 6d

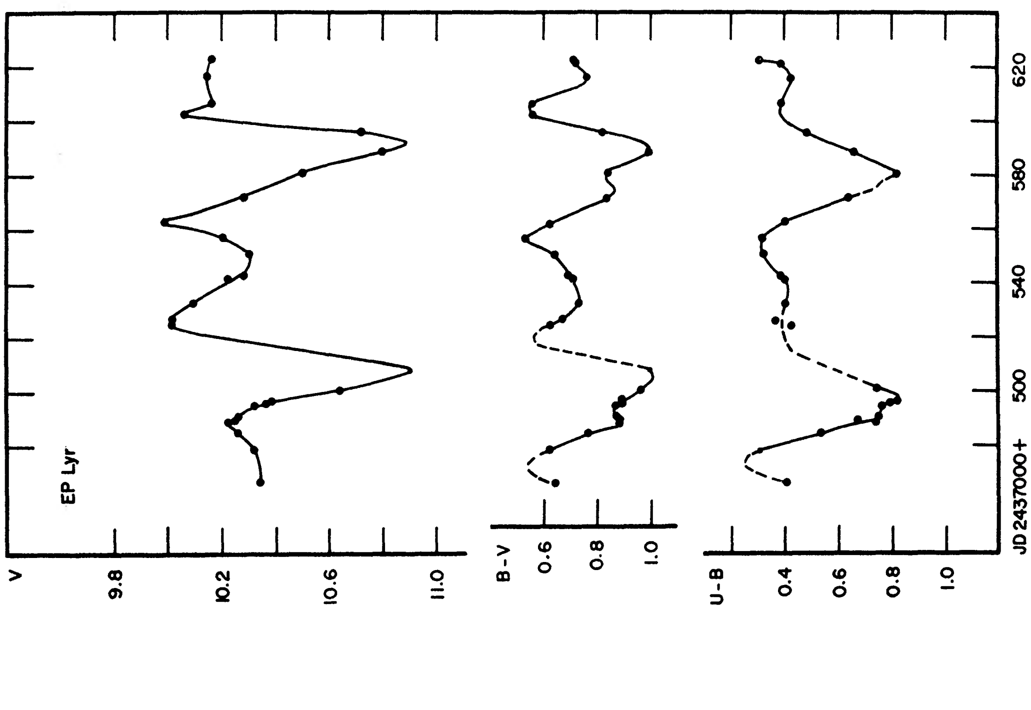

EP Lyr
V
9.8
10.2
10.6
11.0
B - V
0.6
0.8
1.0
U - B
0.4
0.6
0.8
1.0
JD 2437000+
500
540
580
620

FIG. 6c

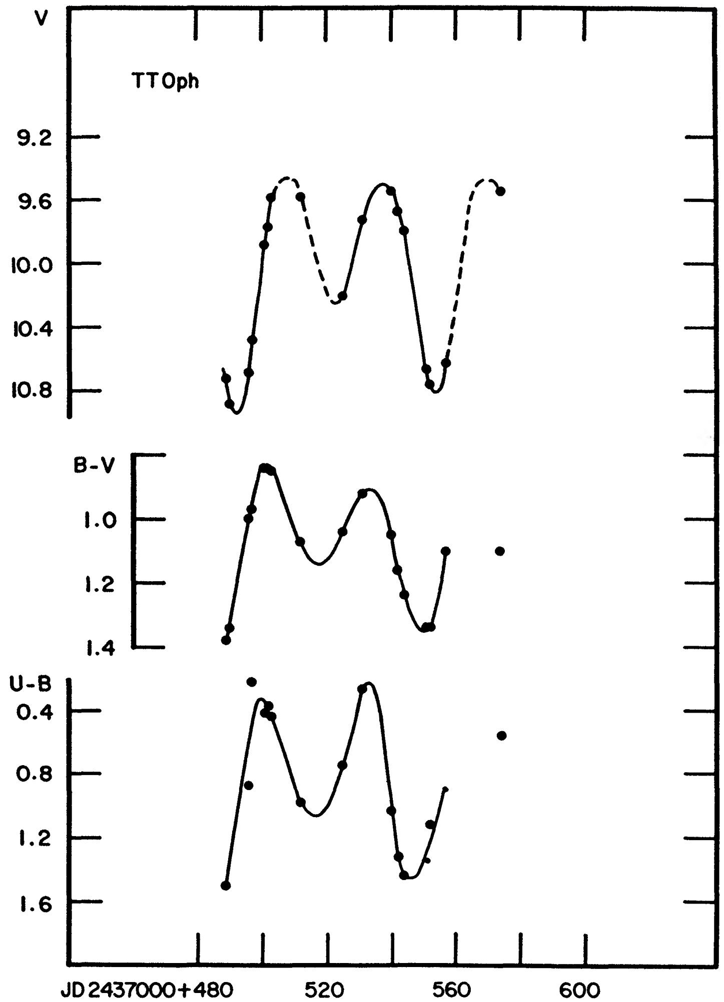


FIG. 7a

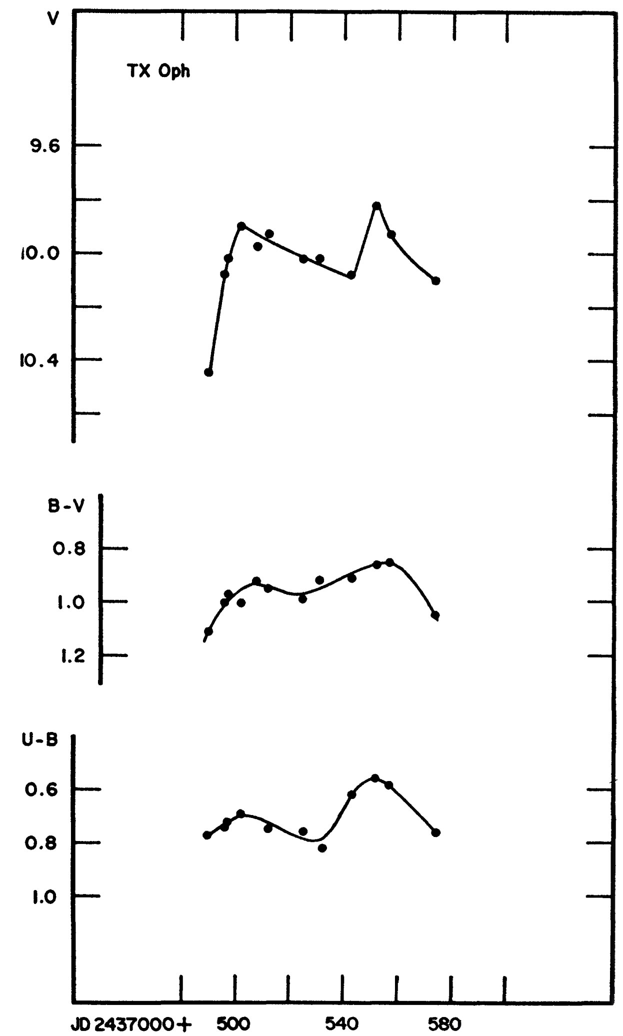


FIG. 7b

FIG. 7 —The V, $B-V$, and $U-B$ variations of four RV Tauri stars. Small symbols indicate uncertain observations. Highly uncertain portions of the freehand curves are dashed.

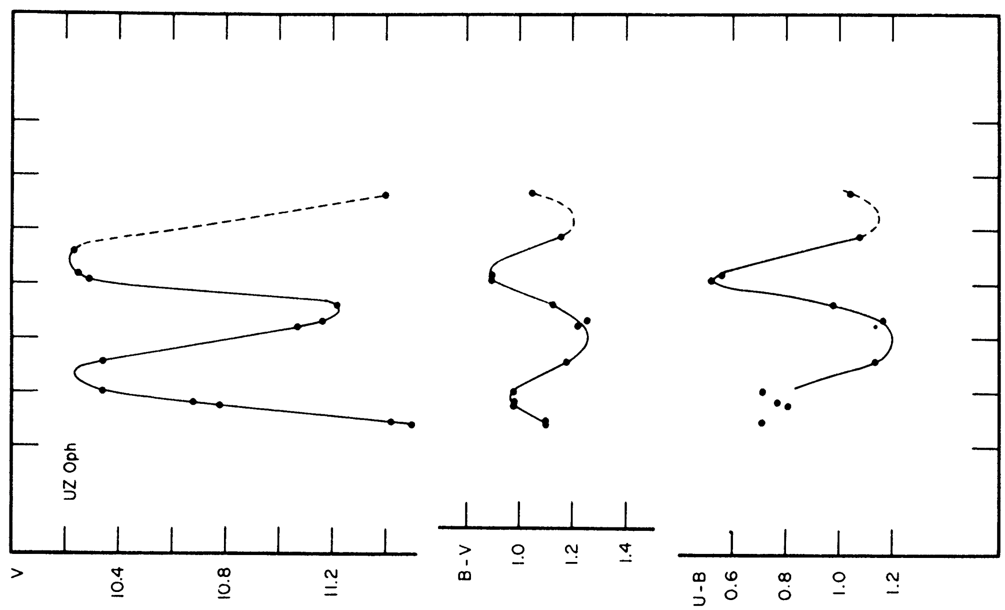

UZ Oph
V
10.4
10.8
11.2
B - V
1.0
1.2
1.4
U - B
0.6
0.8
1.0
1.2
JD 2437000 +
500
540
580

Fig. 7c

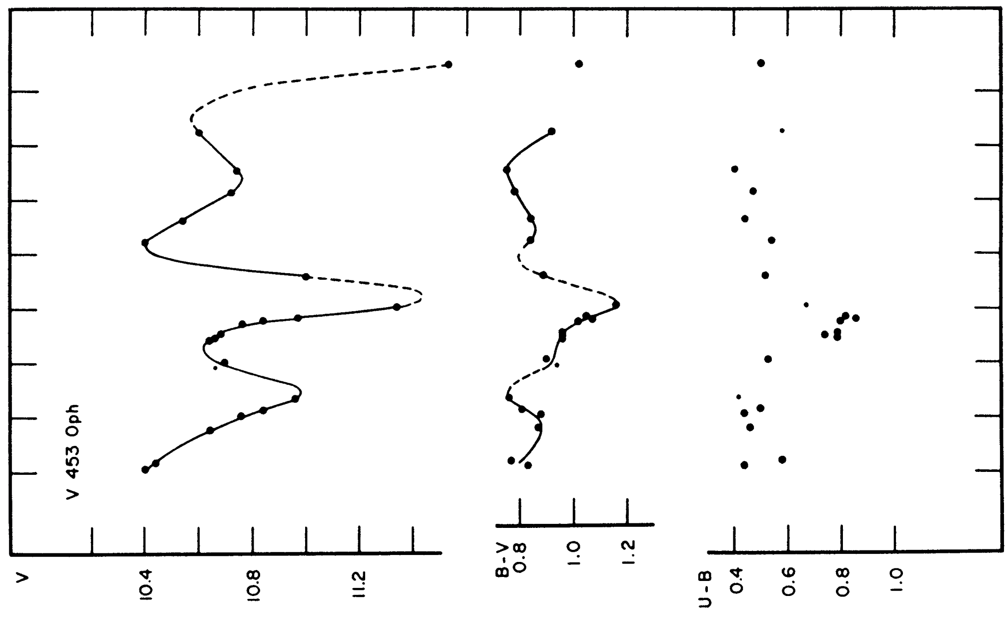

V 453 Oph
V
10.4
10.8
11.2
B - V
0.8
1.0
1.2
U - B
0.4
0.6
0.8
1.0
JD 2437000 + 460
500
540
580

Fig. 7d

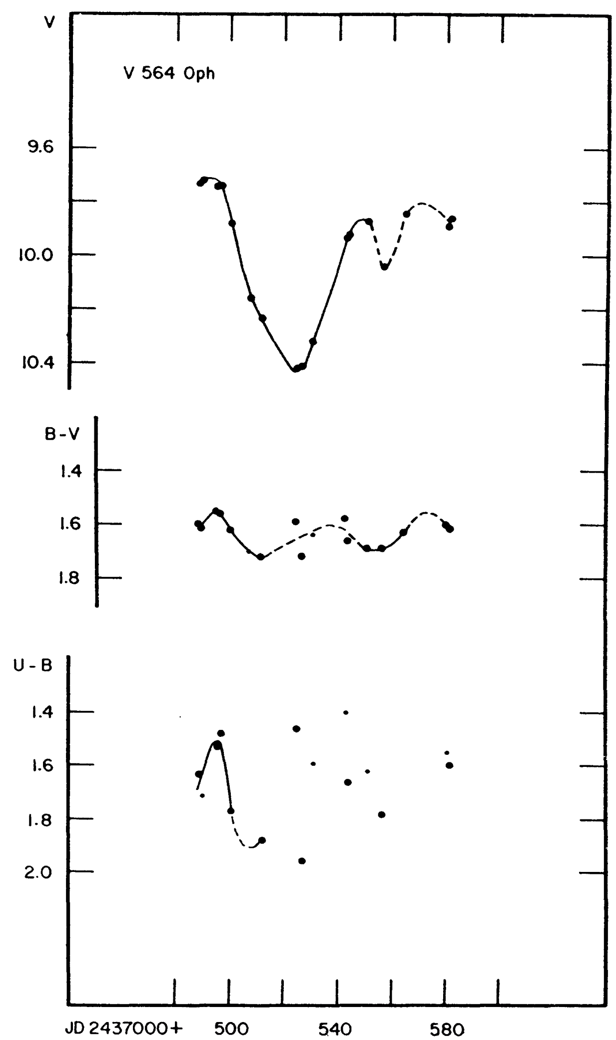


FIG. 8a

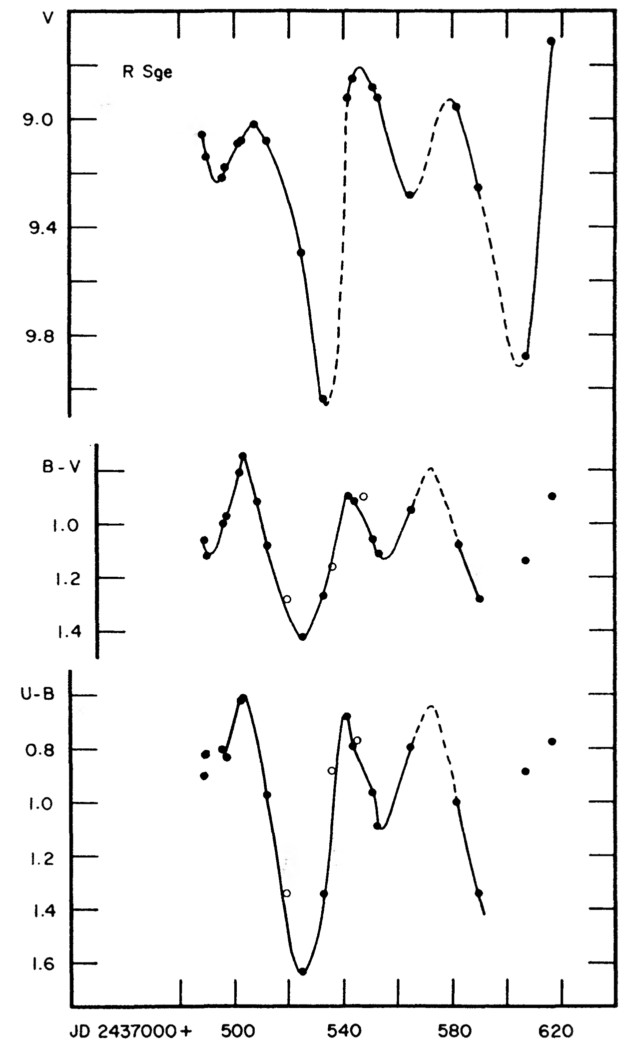


FIG. 8b

FIG. 8.—The V, $B - V$, and $U - B$ variations of four RV Tauri stars. Open circles denote observations shifted forward or backward one cycle. Small symbols indicate uncertain observations. Highly uncertain portions of the freehand curves are dashed.

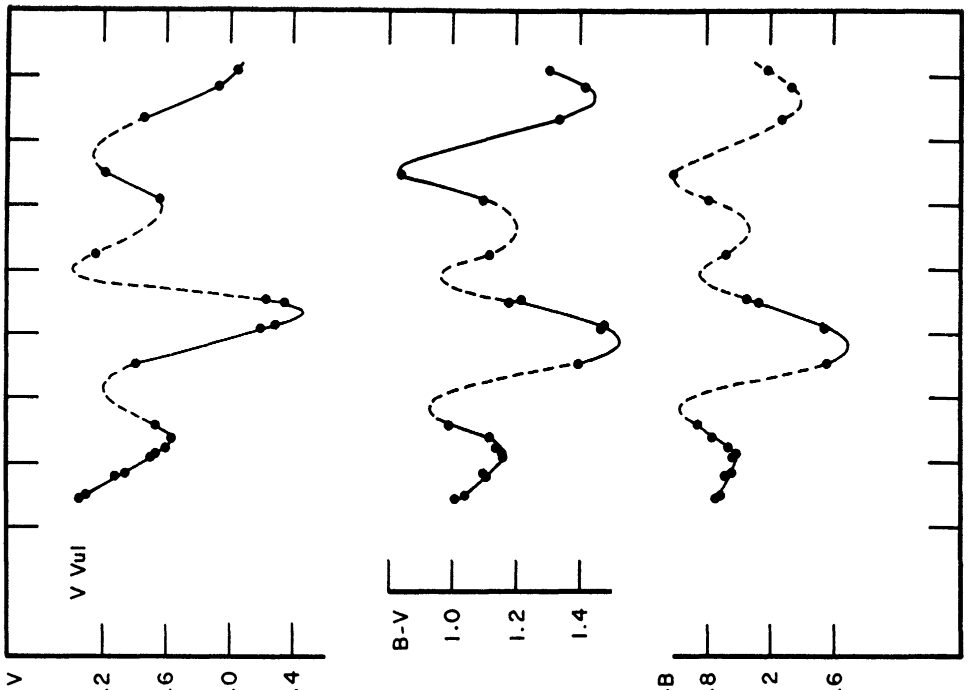

V
8.2
8.6
9.0
9.4
V Vul
B-V
1.0
1.2
1.4
U-B
0.8
1.2
1.6
JD 2437000+ 480
520
560
600

Fig. 8d

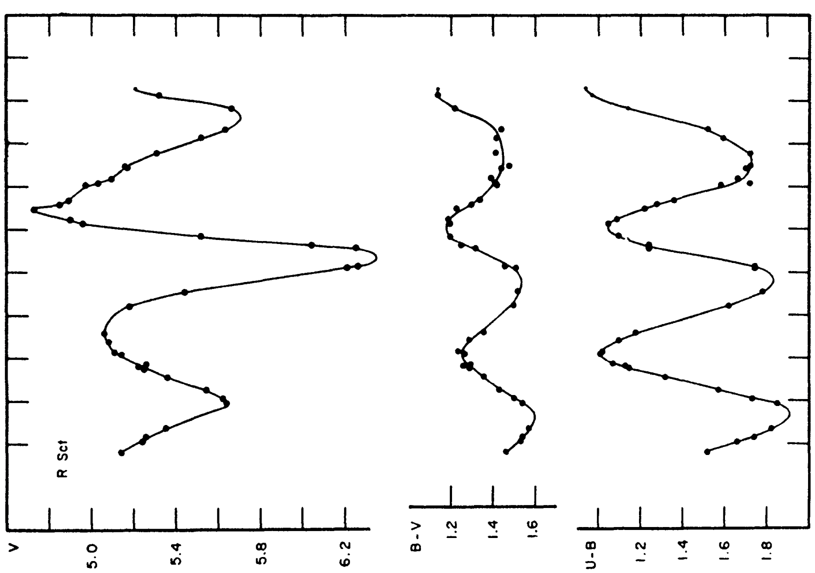

V
5.0
5.4
5.8
6.2
R Sct
B-V
1.2
1.4
1.6
U-B
1.2
1.4
1.6
1.8
JD 2437000+
480
520
560
600

Fig. 8c

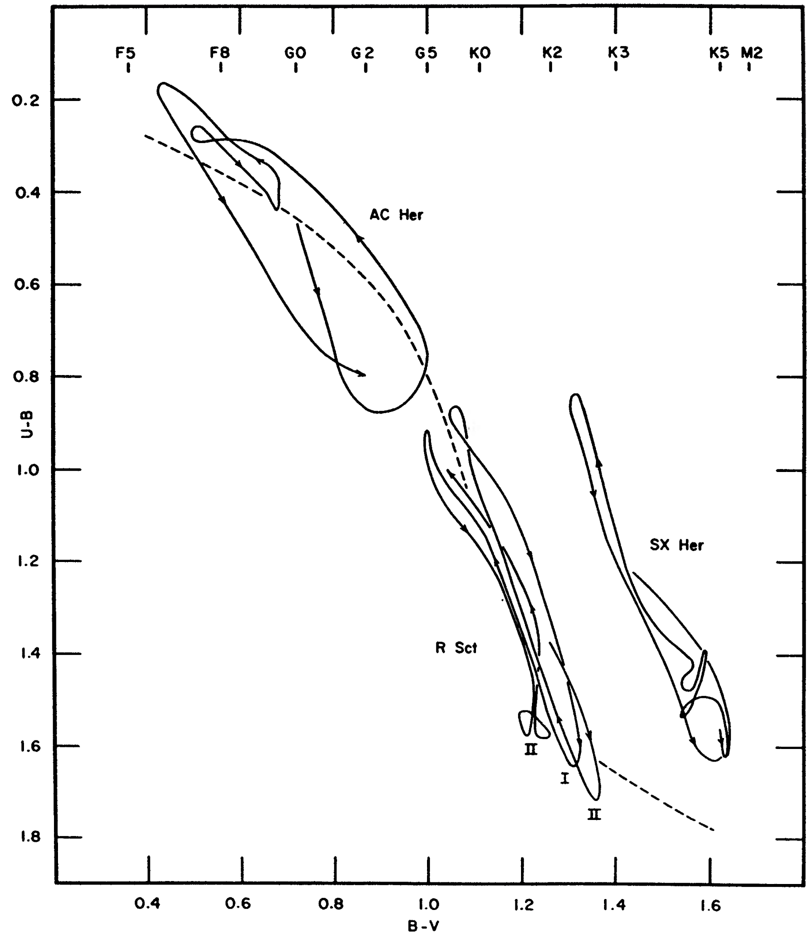


FIG. 9.—Color loops for AC Her, R Sct, and SX Her in the $U - B$, $B - V$ plane. The dashed curve is the smoothed locus for I*b* supergiants (Kraft and Hiltner 1961). Equivalent I*b* spectral types are indicated across the top. The symbols *I* and *II* refer to primary and secondary color minima of R Sct, respectively.

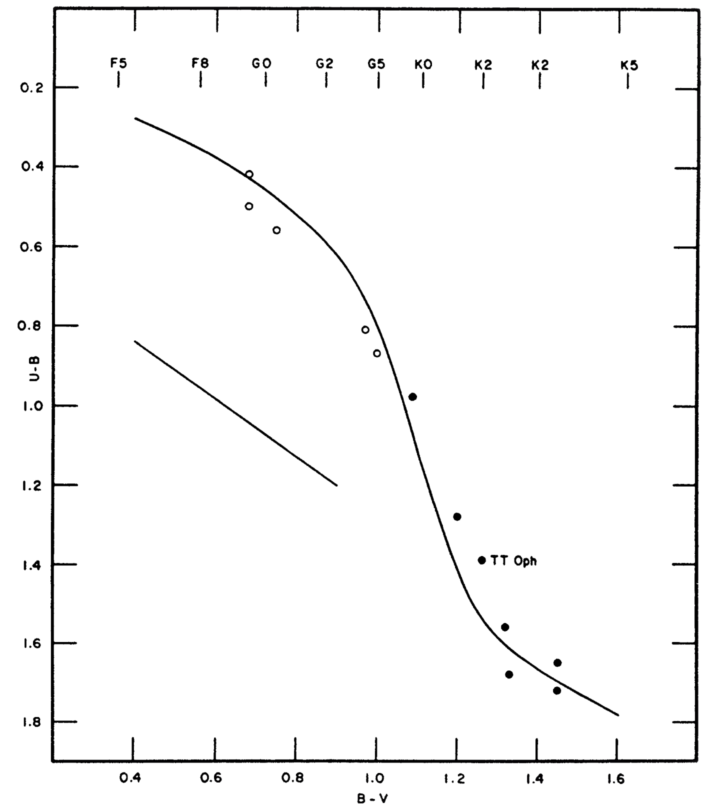


FIG. 10.—Color indices, corrected for interstellar reddening, of RV Tauri stars at primary color minimum. *Coding: filled circles*, group A; *open circles*, groups B and C. The solid curve and the indicated spectral types are as in Fig. 9. The straight-line segment is a reddening line.

distant, so that interstellar reddening is generally not negligible. The last column of Table 6 contains crude estimates of E_{B-V} obtained from the color excesses of nearby B-type stars published by Hiltner (1956) and by Stebbins, Huffer, and Whitford (1940) on the assumption that $M_V = -3$ for all RV Tauri stars. In regions where known B-type stars either are foreground objects on this assumption or are not available (e.g., in high galactic latitudes), a limiting value of the color excess was estimated from $E_{B-V} = 0.08$ csc b. The color excess E_{U-B} was obtained from $E_{U-B} = 0.72\ E_{B-V}$. The color indices at primary light-minimum and primary light-maximum, corrected for interstellar reddening by this rough procedure, are shown in Figures 10 and 11, where filled and open circles denote members of group A and groups B and C, respectively. At color minimum, all the

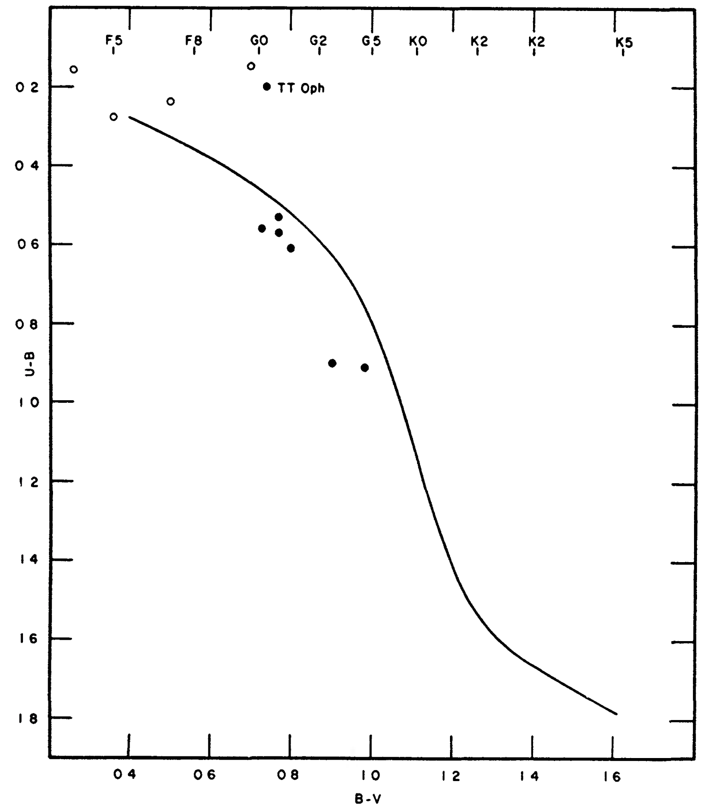


FIG. 11.—Color indices, corrected for interstellar reddening, of RV Tauri stars at primary color maximum *Coding: filled circles*, group A; *open circles*, groups B and C.

RV Tauri stars lie surprisingly near the Kraft-Hiltner (1961) locus for Ib supergiants and are well separated from the yellow semiregular variable SX Her. There is no overlap of group A with groups B and C, but, in spite of the spectroscopic dissimilarities, the colors of the three spectroscopic groups appear to form a continuous sequence. At primary color maximum, the deviations from the supergiant locus are larger than at the color minima, but the spectroscopic groups (A versus B and C) remain separated photometrically. The position of TT Oph in Figure 11 tends to support the suggestion that it may be related to group B as noted in Section III, b.

R Sct lies near the supergiant locus not only at stationary points but at all phases, as the color loop in Figure 9 indicates. During 1961 a systematic decrease in $U - B$ and $B - V$ curves was superimposed on the cyclic variations producing displacements of the lower extremities of the color loops. From Figures 8, c, and 9 it can be seen that the

$B - V$ and $U - B$ indices at primary minimum (I) interpolate smoothly between the indices at adjacent secondary minima (II). Thus it is not obvious that the color indices are affected markedly by the TiO present at primary minimum, as suggested by Kameny (1956).

For AC Her the I*b* spectral types inferred from the color indices differ markedly from the Ca II types at all phases. They are in better agreement with types inferred from the CN bands. In addition to the Crossley spectrograms listed in Table 3, thirteen 16 A/mm spectrograms (120-inch coudé) of AC Her were obtained in 1961. This higher-dispersion material confirms what is suggested by the Crossley spectra, namely, that CN absorption is weak or absent between the primary and secondary maxima of the $B - V$ curve. This phase interval corresponds to the smaller of the two loops described by AC Her during one complete cycle (see Fig. 9). This small loop lies entirely within the I*b* spectral type interval F6–G0 within which the bands of CN are normally weak or absent in non-variable supergiants. Near primary minimum when the CN bands are strong in AC Her, the color indices indicate a type near G5. In I*b* supergiants the strength of the CN bands reaches a maximum near G5 (compare CN bands in AC Her and 9 Peg in Fig. 3, *a*). Thus, if the color indices are reliable temperature indicators, it may be the atomic line rather than the carbon bands that are abnormal in AC Her. This possibility is worthy of detailed examination.

V. DISCUSSION

a) *Summary of Results*

To summarize the results of the preceding sections:

1. It is possible to identify three spectroscopic subgroups among the RV Tauri stars. While the spectral-class boundaries of these groups have not been established in a precise way, the defining characteristics of the groups differ sufficiently to make it improbable that they are subdivisions of any simple continuous spectral sequence.

2. The range in the $U - B$ and $B - V$ color indices is correlated with spectral appearance. Taking into account the uncertainties in the color excesses, the color indices lie surprisingly near the locus for non-variable I*b* supergiants. While there is a significant difference between the color indices of group A relative to those of groups B and C, it does not seem possible to distinguish between groups B and C by means of U, B, V photometry alone.

3. Systematic differences in the shapes of the V and $B - V$ curves lead to different phase shifts for group A and groups B and C. For the latter two groups the shift depends on phase itself.

4. It appears possible to distinguish between SRd and RV Tauri variables on the basis of the strength and duration of the hydrogen-emission lines that occur near maximum light. Our U, B, V data for a single SRd variable, SX Her, supports the conclusion of Kameny (1956) that SRd variables can also be distinguished from the RV Tauri stars photometrically.

Since the majority of the SRd variables (*a*) have systematically high radial velocities, (*b*) are photometrically and spectroscopically distinguishable from all RV Tauri stars, and (*c*) lie near the giant sequences of halo globular clusters in the $U - B$, $B - V$ plane, it is reasonable to suppose that the SRd variables are unrelated to the RV Tauri stars of group A, which have systematically lower radial velocities and lie within the Hertzsprung gap. That the two kinds of objects are frequently confused is merely an indication of the inadequacy of photometric and spectroscopic coverage and the general lack of multicolor photometric observations. If this surmise is correct, then the subgroups proposed by Joy (1952) can be improved by defining them so that they are independent of their kinematic properties. The SRd variables constitute one such group. Their kinematic properties are those of the halo (little galactic rotation or concentration to the galactic plane). The RV Tauri stars of group A constitute another. They have the kinematic properties of a disk-type population (intermediate galactic rotation and concentration to the galactic plane). Neither of these two groups appears to be present in both the halo and the disk. The meager radial-velocity data in Table 7 suggest that group B may be associated with the disk and group C with the halo or, alternatively, that the two groups may be parts of a larger family that populates both the halo and the disk. It should be noted that an analogous continuum in the strength and/or duration of CN absorption among the members of groups B and C could exist undetected by our survey-type observing program. In any event, it is difficult to avoid the puzzling conclusion that, even after removing the SRd and other-type variables from consideration, there remain at least two and possibly three kinds of RV Tauri stars within the halo and disk populations. Further progress in this problem will require a larger working sample of stars, and this in turn will require that discovery, classification, and radial-velocity surveys be extended to fainter members of the class.

TABLE 7

RADIAL VELOCITIES OF MEMBERS OF GROUPS B AND C

Group	Star	V_{rad} (km/sec)	Source
B	AC Her	−30	Joy (1952)
	EP Lyr	+15	Preston (unpublished)*
C	V360 Cyg	−250	Joy (1952)
	UU Her	−131	Joy (1952)
	V453 Oph	−95	Joy (1950)
	M2 No. 11	−4	Joy (1949)
	M56 No. 6	−132	Joy (1949)

* Based on seven 16 A/mm spectrograms

b) *Comments on a Recent Binary Interpretation of EP Lyr*

While our survey was in progress, Wenzel (1961*a*) reported that EP Lyr, a member of our spectroscopic group B, is not an RV Tauri star but rather is an eclipsing system composed of A- and G-type supergiants. He attributed irregularities in the light-curve near primary minimum to intrinsic variability of the G-type component. These conclusions (Wenzel 1961*b*) were based on the stability of the light-curve, on the fact that no interchanges of minima had been observed from 1928 to 1960, and on the appearance of three objective-prism spectra obtained in 1960 and 1961.

We make the following comments regarding this conclusion:

1. It is true that low-dispersion spectrograms of EP Lyr between primary and secondary maxima (as in Fig. 3, *b*) can be matched by that of a late A-type I*a* supergiant. However, for approximately half of the light-cycle, strong bands of CN and CH are present simultaneously with the A-type K line. It is difficult to understand how an A-type star could dominate the spectrum at λ 3933 and not at λ 3883. If the CN is attributed to gas streaming, an envelope surrounding the system, or some other complication, then it may be dangerous to draw any conclusion at all from the spectra. Finally, if the spectral characteristics are admitted as evidence of duplicity, then all members of our group B are suspect, including AC Her, one of the brightest and best-studied of the RV Tauri stars.

2. EP Lyr and AC Her are alike photometrically. Both have relatively stable light-curves, their $B - V$ and $U - B$ ranges are similar, and both exhibit the same phase shifts between the V, $B - V$, and $U - B$ curves. The latter characteristic is particularly damaging to a binary interpretation.

3. Hydrogen emission is not visible on Crossley spectrograms of either EP Lyr or AC Her. However, on 16 A/mm spectrograms, centrally reversed hydrogen emission is conspicuous in AC Her during the rise from primary minimum. Hydrogen emission with a similar profile is also present on the single 16 A/mm spectrogram of EP Lyr that we have obtained during rising light.

4. On the basis of a large number of photographic observations, the depth of secondary minimum for AC Her, as predicted from a uniform ephemeris, was found to exceed that of primary minimum only five times in a 40-year period (Gaposchkin, Brenton, Gaposchkin 1943). These occasions may merely be manifestations in AC Her of the same kind of irregularities encountered by Wenzel in EP Lyr. It is clear that both EP Lyr and AC Her are remarkably stable in this respect.

It would be very remarkable if such detailed similarity could exist in the properties of a binary system (EP Lyr), on the one hand, and a pulsating star (AC Her), on the other. It is our opinion that the preponderance of evidence favors the pulsation interpretation for EP Lyr (and all members of group B). However, given sufficient imagination, it might be possible to devise a binary model that would satisfy our observations. Wenzel's discovery that EP Lyr does not undergo interchanges certainly removed the biggest obstacle to such an enterprise and, in any event, should provide incentive to investigate the long-term stability of other members of group B.

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