THE SPECTRA OF VARIABLES OF THE RV TAURI AND YELLOW SEMIREGULAR TYPES

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ABSTRACT

Spectrograms of low dispersion and photometric observations have been obtained for a number of variables of the RV Tauri and yellow semiregular types. A revised list of members of the RV Tauri class is given, together with a preliminary description of certain spectroscopic similarities of the members of the class. A division of the RV Tauri stars into two groups is suggested. A period-luminosity relationship is found for some kinds of variable stars located in globular clusters. Attention is called to the remarkable spectroscopic variations of AC Her. The latter appears to be related to the carbon stars.

In the past, many investigations have been carried out to determine certain general characteristics of the spectra of variable stars from which it might be possible to enable an experienced observer to identify an intrinsic variable from a few scattered spectrograms alone.[1]

Particularly interesting, from this point of view, are the so-called "semiregular" variables of intermediate period; these stars lie between the classical cepheids and the Mira-type stars. Classification from predominantly photometric data has not been completely successful up to now because the periods of several physically different groups overlap, while the light-curves are more or less irregular and at times appear completely erratic.

However, if we consider not only the light-curves but also the available spectral types, all these variables can be classified into three distinct groups—the RV Tauri variables; the yellow semiregulars of spectral class F, G, or K; and the red semiregulars of classes M and N. The study of their spectroscopic properties is important because of the possible relationship between these stars and the adjacent groups, the cepheids (either classical or of the type of W Virginis), and the long-period variables. Spectra of the red semiregulars of small amplitude have been recently examined by P. C. Keenan;[2] we shall deal here with the RV Tauri variables and yellow semiregulars.

We shall adopt the following criteria for the RV Tauri type of variation: (*a*) Most of the time the variable follows a light-curve, with well-marked alternate deep and shallow minima, which occasionally interchange. (*b*) Irregularities in the light-curve or period, absence of shallow minima, erratic variations, etc., may be present—provided that they are only secondary and transitory characteristics of the general light-curve. (*c*) The mean brightness may be constant, or variable with a long period. (*d*) The mean spectral type is F, G, or K.[3] The last condition is necessary to prevent the inclusion of spurious members of completely different type; some long-period variables of class Me or Ne have light-curves with deep and shallow minima. As a rule, when spectral types are not available, the criterion that the period should not be longer than 150 days can be used.

The members of the RV Tauri class, according to the above definition, are listed in Table 1. There are only twenty-five variables in this table, about twice as many as were given by B. P. Gerasimovič more than twenty years ago. In the *General Catalogue of*

[1] A. H. Joy, *Pub. A.S.P.*, **54**, 15, 1942.

[2] *Ap. J.*, **95**, 461, 1942.

[3] These criteria do not differ substantially from those assumed in *Harvard Ann.*, **113**, 1, 1942, by C. P. Gaposchkin, V. K. Brenton, and S. Gaposchkin.

TABLE 1

VARIABLES OF THE RV TAURI TYPE

Variable	*l*	*b*	Period (Days)	Magnitude		Mean Ampl.	Spectral Range	Observer	Mean Radial Velocity (Km/Sec)	Notes
				Max.	Min.					
EZ Aql	7°	+ 5°	38.6	*11.6*	*13.6*	*0.8*	cK0	....	....	
RY Ara	306	− 9	143.5	9.2	12.1	2.9	G–K0	Cannon	....	1
UY Ara	299	−15	57.2	11.1	12.2	1.1	G	....	....	
TW Cam	116	+ 6	85.6	10.4	11.6	1.2	F8 I*b*–G8 I*b*	Rosino	....	2
RX Cap	358	−25	67.9	11.6	13.7	1.3	....	....	....	
GK Car	258	+ 3	55.6	12.5	14.0	1.5	....	....	....	
EQ Cas	82	− 7	58.4	11.9	13.6	1.7	....	....	....	
RU Cen	263	+17	64.7	8.8	10.3	1.5	G2–K2	Shapley	....	1
SX Cen	266	+14	32.8	9.9	12.4	1.5	F5	Cannon	....	1
CN Cen	260	+ 1	51.0	12.5	14:	1.5	G4	....	....	
DF Cyg	44	+ 8	49.8	10.8	15.2	1.8	cG7–cK2	Joy	....	3
V 360 Cyg	44	−13	70.4	10.8	13.3	2.5	....	....	....	
SS Gem	156	+ 2	89.3	8.8	10.2	1.4	F8 I*b*–G5 I*b*	Rosino	....	4
SU Gem	153	+ 6	50.1	*9.9*	*12.2*	*1.5*	K0–M3	Cannon	....	1
AC Her	17	+13	75.2	7.1	9.4	1.1	F4p I*b*–Rp	Rosino	−32	5
EP Lyr	28	+ 6	83.3	10.2	11.6	1.4	....	....	....	
U Mon	193	+ 5	92.3	6.8	8.2	1.4	F8e I*b*–K0p I*b*	Rosino	+35	6
TT Oph	348	+27	61.1	9.9	11.7	1.4	F5pe	Adams-Joy	....	
UZ Oph	356	+22	87.4	10.5	13.1	1.8	F8–K5	Gerasimovič	....	
AR Pup	222	− 2	75:	8.7	10.9	2.2	Rp	Rosino	....	
R Sge	25	−11	70.8	9.0	11.5	1.2	G0 I*b*–G8 I*b*	Rosino	+10	7
AI Sco	322	− 5	71.8	9.4	11.6	....	....	....	....	
R Sct	356	− 2	144:	6.1	8.6	2.5	G0e I*a*–K0p I*b*	Rosino	+40	8
RV Tau	142	−11	78.6	9.8	13.3	1.3	G2e I*a*–K3p	Rosino	....	9
V Vul	36	−10	76.0	9.0	11.0	1.5	G1 I*a*–I*b*—G8 I*a*–I*b*	Rosino	−10	10

NOTES TO TABLE 1

1. The spectral types were derived from Harvard plates taken for the *Henry Draper Catalogue.*
2. No spectral types were previously available.
3. Joy (*Pub. A.S.P.*, **44,** 386, 1932) writes: "The spectrum is like that of R Scuti at maximum. The enhanced lines are very strong. Six plates have been obtained. . . . On plates γ 18070 and C 5751 the hydrogen lines are very weak and may be cut down by the presence of incipient emission. No bright lines or titanium bands have been detected."
4. Russell (*Ap. J.*, **66,** 128, 1927) gives the spectral range G1–G8.
5. Sanford (*Ap. J.*, **73,** 364, 1931) found a spectral range F1–K4. He observed striking changes during each period in the G band and in all the absorption features of the spectrum; hydrogen lines were present in absorption at all times, with associated emission during certain phases from principal minimum to maximum. Some peculiarities of this star to which we shall refer later, particularly the *CH* characteristics and the strength of *CN*, have not been noted by Sanford. His spectra with a dispersion of 37 A/mm at $H\gamma$ were obtained mainly for the study of the radial velocities.
6. Sanford (*Ap. J.*, **77,** 120, 1933) observed *TiO* bands and strong hydrogen lines in absorption at the deep minimum and hydrogen lines in emission during increasing light. Spectral range F7–G8.
7. cG7, according to Sanford (*Ap. J.*, **79,** 77, 1934): "G-band most intense at the minima and least intense at the maxima. The absorption at $H\gamma$ shows two maxima near the phases of light minima and two minima with the phases at or slightly preceding the light maxima."
8. McLaughlin, in an extensive study of R Sct based on 303 spectrograms (*Pub. Obs. U. Michigan,* **7,** 57, 1938), found a spectral variation gG0–K0 with marked *TiO* bands at minimum, as strong as in an M4–M5 star. The G band and *Ca* 4227 were weak at maximum and very strong at minimum. During increasing brightness he found hydrogen lines in emission, the intensity of which was associated with the magnitude at the preceding minimum and with the magnitude range.
9. Almost nothing was known about the spectrum of this star. Two Harvard plates gave spectral types K2 and K.
10. Sanford (*Ap. J.*, **79,** 81, 1934) observed *TiO* bands at minimum. Spectral type cG5p.

Variable Stars by Kukarkin and Parenago several other stars are attributed to the RV Tauri class; additional observations are needed, however, before these identifications can be accepted with certainty. Table 1 is incomplete, but we believe that no spurious members have been included.

The first three columns in Table 1 contain the name of the variable and its galactic co-ordinates; the fourth column gives the photometric period, which is defined as the mean interval between two deep minima. If we consider the significant period to be the interval between two successive maxima, as for cepheids and long-period variables, we must take half the values given in the fourth column. The fifth and sixth columns contain the apparent photographic magnitudes at maximum and minimum and the mean photographic amplitudes; the few visual values are given in italics. The amplitude is defined as the mean difference between the magnitude of the variable in a deep minimum and the magnitude in the following maximum. As we have noted, the mean brightness can be variable with an amplitude of several magnitudes, so that the total range does not necessarily coincide with the mean amplitude. The seventh and eighth columns give the adopted spectral range and the observer. The ninth column contains the average radial velocity of the center of mass, according to R. F. Sanford[4] (AC Her, U Mon, R Sge, and V Vul) and to D. B. McLaughlin[5] (R Sct). All the stars examined by these authors show a velocity variation with the same period as the photometric variation, in the sense that, roughly, the velocity-curve seems to be a reflection of the light-curve, shifted so that the radial-velocity maxima generally follow the photometric minima. The observations are scattered, however, and it is difficult at the present time to derive a correlation between the photometric and radial variations. The last column refers to the notes to the table.

There are several variables that, although certainly related to the RV Tauri stars, cannot be included in Table 1 because their light-curves do not fulfil all the imposed conditions. The spectral types are F, G, or K, and the light-curves sometimes show double maxima, but they have too long periods and ill-defined alternations of deep and shallow minima or long intervals of erratic changes of light. Table 2 contains the most regular and important of these stars, previously called "yellow semiregulars." The different columns have the same meaning as in Table 1. The period is now defined as the mean interval between two successive maxima. The mean radial velocities of WY And, AG Aur, UU Her, and SX Her were derived by A. H. Joy,[6] that of SV UMa by Redman.[7] Table 2 is certainly not complete, but we hope that no spurious members have been included.

Spectra of RV Tauri variables and yellow semiregulars have been obtained in the past with various instruments, from objective-prism cameras to spectrographs of high dispersion, and they have been classified with different criteria. The references and short abstracts of the most important papers are given in the notes to Tables 1 and 2. From November, 1949, to July, 1950, we observed as many of the stars in Tables 1 and 2 as possible, with the one-prism spectrograph attached to the 40-inch refractor. This instrument gives a dispersion of 123 A/mm at $H\gamma$. Eastman 103*a*-O plates were used.

In order to obtain the phases at which the spectra were taken, the stars on the program were followed on the Eastman 33 emulsion with the 6-inch UV camera. Photographic magnitudes were then derived through the comparison stars given in *Harvard Ann.*, **113**, 1. The light-curves obtained in this way are, in general, well defined, so that there are no serious uncertainties about the phases of the spectrograms or the run of the light-variation. The spectrograms were compared with Morgan's standard spectra of supergiant stars and in some cases with those of cepheids.

[4] *Ap. J.*, **73**, 364, 1931; **77**, 120, 1933; **79**, 77, 1934.

[5] *Pub. Obs. U. Michigan*, **7**, 57, 1938; *Ap. J.*, **94**, 94, 1941.

[6] *Pub. A.S.P.*, **46**, 51, 1934.

[7] *M.N.*, **92**, 116, 1931.

In addition to the Yerkes material, fifteen spectrograms of RV Tauri stars and semiregular variables, taken with the 82-inch reflector of the McDonald Observatory, were made available through the kindness of Dr. W. P. Bidelman. Thirteen of these spectrograms have a dispersion of 76 A/mm at $H\gamma$; two (of R Sct) of 25 A/mm.

In the spectral classification of the RV Tauri variables we have avoided as far as possible the use of the lines of hydrogen and *Ca* 4227, since these, in most cases, are abnormal. The spectral class was assigned mainly from the appearance of the G band, from the ratio λ 4271:violet side of the G band and from a general comparison with the standards. The data pertaining to the individual spectroscopic and photometric observations are given in Table 3. Figures 1 and 2 reproduce some of the light-curves with the spectral types observed at different phases. The spectral ranges derived from the present observations are contained in the seventh column of Tables 1 and 2. The variables of the RV Tauri type observed here have the following characteristics:

a) They are stars of high or very high luminosity (Morgan's class I*b* or I*a*).

b) The maximum excitation and the earliest spectral types are reached halfway

TABLE 2

YELLOW SEMIREGULAR VARIABLES

Variable	*l*	*b*	Period (Days)	Magnitude		Mean Ampl.	Spectral Range	Observer	Mean Radial Velocity (Km/Sec)	Notes
				Max.	Min.					
WY And...	79°	−14°	107.2	9.5	10.6	1.1	cG5e	Joy, Rosino	−181	1
AC Aqr.....	18	−34	67.2	11.2	12.0	0.8	F8	....	....	2
XY Aqr....	23	−68	72.7	9.4	10.1	0.7	G0	....	....	2
SZ Aqr.....	5	−61	108.5	10.1	12.3	2.2	K5e	Cannon	....	
AG Aur....	135	+17	96.0	10.8	12.4	1.6	G0e I*b*–K0ep	Rosino	+196	3
UY CMa...	192	−13	116:	10.8	12.8	2.0	G4	Becker	....	
SX Her.....	8	+45	103.2	9.0	11.1	2.1	gG3e–K0p	Joy	+ 20	4
UU Her....	28	+41	72–90	8.5	10.6	2.1	F2 I*b*–cF8	Rosino, Joy	−132	5
TX Oph....	353	+26	138?	9.8	12.1	2.3	G0	....	....	2
AZ Sgr.....	330	− 9	113.5	11.2	12.8	1.6	F9	....	....	2
SV UMa...	120	+55	75.3	9.0	10.3	1.3	G1 I*b*–K3p I*a*	Rosino, Keenan	−102	6

NOTES TO TABLE 2

1. Joy (*Pub. A.S.P.*, **46**, 51, 1934) gives the spectral class cG6e. His spectrograms show very strong interstellar H and K.

2. The spectral class has been taken from the *General Catalogue of Variable Stars*, by Kukarkin and Parenago.

3. Joy (*Pub. A.S.P.*, **46**, 51, 1934) gives the spectral type cG5e. He found strong interstellar sodium, from which he derived a distance of at least 2000 parsecs.

4. Joy (*Ap. J.*, **75**, 127, 1932) describes the spectral variations of SX Her as derived from twenty-one spectrograms taken at different light-phases. Hydrogen lines in emission were observed on thirteen spectrograms. They were found to reach their greatest strength slightly before maximum and to disappear at the time of minimum, giving place to absorption lines. *TiO* bands were observed at minimum when the spectral class was K0.

5. The variable follows two different periods, which interchange. When the 90-day period is dominant, the light-curve is of the RV Tauri type, with alternating deep and shallow minima; when the period of 72 days prevails, the light-curve presents cepheid-like oscillations, with an amplitude ranging from more than a magnitude to a few tenths of a magnitude. Joy (*Pub. A.S.P.*, **46**, 51, 1934) gives a spectral class of cF8.

6. Keenan (*Ap. J.*, **95**, 463, 1942) writes: ". . . the line ratios suggest high luminosity, but all lines in the spectrum are so weak that the application of luminosity criteria is uncertain. There is some similarity to the spectra of V Vul and R Sct." Spectrum, K3p I*a*.

TABLE 3

PHOTOMETRIC AND SPECTROSCOPIC OBSERVATIONS

JD 2430000+	m_{pg}	Sp	Notes
		U Monocerotis	
3255.96	....	F8 I*b*	1
258.84	....	G0e I*b*	10
264.71	6.8	....	
266.78	....	G5 I*b*	1
270.94	....	G5 I*b*	1
273.83	....	G8 I*b*	1
278.60	7.3	....	
279.74	....	G8 I*b*	2
288.58	7.8	....	
289.66	....	K0p I*b*	3, 4
292.58	8.3	....	
293.75	....	K0p I*b*	3, 4
301.60	7.2	....	
309.71	6.7	G0e I*b*	10
322.58	6.9	....	
323.60	....	G2 I*b*	1
329.74	6.95	....	
331.70	....	G2 I*b*	2
332.65	7.05	....	
335.57	....	G2 I*b*	2
337.70	....	G2 I*b*	2
339.63	7.05	....	
345.65	....	G1e I*b*	10
347.75	6.95	....	
349.74	....	G0e I*b*	10
354.69	6.8	....	
359.59	....	G0?	6
373.57	7.2	G5 I*b*	2
383.58	7.7	....	
386.58	7.6	....	
387.58	....	G8?	
393.58	7.0	G0e I*b*	10
404.60	....	G0e I*b*	7
		V Vulpeculae	
3256.57	....	G2–G5	1
385.78	9.6	....	
409.78	9.8	....	
417.77	11.2	....	
421.86	11.3	....	
422.85	11.2	G8 I*a*–I*b*	8
429.83	11.2	....	
439.88	8.9	....	
443.77	9.1	G1 I*a*–I*b*	1
		RV Tauri	
3249.79	....	G8 I*a*	
263.60	12.0	....	
264.82	11.9	K3p	8, 9
		RV Tauri (*cont.*)	
3278.55	11.0	....	
279.56	....	G2e I*a*	10
280.54	10.9	....	
287.48	10.7	....	
288.55	10.8	....	
289.56	....	G8 I*a*	10
290.60	11.0	....	
292.54	11.0	....	
301.54	11.5	....	
309.56	11.1	....	
315.54	10.7	....	
322.60	10.7	....	
323.67	....	G5e	7, 9
329.71	11.4	....	
332.75	11.5	....	
339.63	11.9	....	
343.63	11.9	....	
347.73	11.9	....	
354.63	11.5	....	
359.59	11.5?	G5e	10
		R Scuti	
1999.70	....	G2 I*a*	1
2445.66	....	G5 I*a*	1
643.99	....	K0p	4
650.94	....	K0p	4
671.92	....	G0	1
672.96	....	G0e	10
3347.97	7.2	K0p I*b*	4
385.79	6.1	....	
389.90	....	G0 I*a*	1
393.79	....	G0 I*a*	1
403.78	6.4	....	
409.81	6.4	....	
417.79	6.4	....	
420.82	....	G2 I*a*	1
429.75	6.6	G5 I*a*–I*b*	1
439.85	6.7	....	
446.79	....	G8 I*a*–I*b*	2
448.76	....	G8?	
458.69	....	G8p I*a*–I*b*	2, 8
		AG Aurigae	
3251.96	....	G0e	11
278.65	10.5	....	
280.87	11.0	G2e	11
288.48	10.8	....	
292.60	10.8	....	
301.61	11.2	....	

TABLE 3—*Continued*

JD 2430000+	m_{pg}	Sp	Notes
	AG Aurigae (*cont.*)		
3308.89	...	G5–G8	
309.58	11.5	...	
315.56	11.8	...	
329.75	12.5	...	
332.65	12.4	...	
339.66	12.1	...	
343.65	12.1	...	
349.76	...	K0ep	4, 11
354.66	11.4	...	
373.66	10.9	G0e I*b*	11
383.62	10.8	...	
386.60	11.0	...	
393.65	10.8	G0e I*b*	10
	WY Andromedae		
3251.67	...	G5e	10
	TW Camelopardalis		
3258.79	...	F8 I*b*	2
265.69	10.4	...	
275.58	...	G0 I*b*	
279.60	10.9	...	
288.47	10.8	...	
289.75	...	F9 I*b*	14
292.57	10.6	...	
301.58	10.5	...	
309.60	10.8	...	
315.56	11.1	...	
322.61	11.3	...	
323.75	...	G5	
329.76	11.7	...	
332.64	11.6	...	
335.66	...	G8 I*b*	14
339.64	11.5	...	
347.80	10.8	...	
354.65	10.5	...	
386.63	10.4	...	
	SS Geminorum		
3262.78	...	G0 I*b*	
263.64	8.8	...	
264.69	8.8	...	
278.58	9.9	...	
279.82	...	G2–G5 I*b*	12, 13
280.54	9.9	...	
287.49	10.0	...	
292.56	9.95	...	
	SS Geminorum (*cont.*)		
3293.67	...	G5 I*b*	12, 13
301.56	9.15	...	
309.58	9.4	G2 I*b*	
315.55	9.7	...	
317.57	...	G2–G5 I*b*	5
329.72	9.9	...	
331.71	...	G2–G5 I*b*	13
332.63	9.9	...	
335.66	...	G2–G5 I*b*	13
337.74	...	G2–G5 I*b*	13
339.63	9.8	...	
343.62	9.6	...	
345.61	...	G0 I*b*	3, 13, 15
347.74	9.3	...	
349.70	...	G0 I*b*	3, 15
354.62	9.1	...	
359.64	9.5	...	
373.53	10.1	...	
383.59	10.0	...	
386.65	9.8	...	
387.63	...	F8 I*b*	
393.59	9.2	...	
	R Sagittae		
3250.57	...	G0 I*b*	2, 12
385.80	10.7	...	
409.78	10.4	...	
417.75	11.1	...	
420.85	11.4	...	
421.84	...	G8 I*b*	
422.85	11.4	...	
439.86	11.0	...	
448.85	...	G5?	6
461.75	...	G2 I*b*	14
	SV Ursae Majoris		
2660.70	...	G1 I*b*	1
3288.54	10.6	...	
292.61	10.4	...	
301.63	10.5	...	
308.98	...	G5?	
309.61	10.5	...	
347.80	10.5	G2–G5 I*b*	
354.68	10.6	...	
377.67	10.2	...	
383.65	10.3	...	
389.72	10.3	G2 I*b*	
393.60	10.4	...	

1951ApJ...113...60R

TABLE 3—*Continued*

JD 2430000+	m_{pg}	Sp	Notes
		UU Herculis	
3079..........	....	F2 I*b*	
329.77.......	9.5	....	
347.87.......	9.3	F5 I*b*	3, 13
354.74.......	9.2	....	
361.78.......	....	F2 I–II	
365.80.......	9.1	....	
373.74.......	9.1	F2 I–II	
377.78.......	9.2	F2 I–II	
385.69.......	9.3	....	
387.70.......	....	F2 I–II	
393.65.......	9.4	....	
403.76.......	9.4	....	
404.66.......	....	F2–F5	13
409.71.......	9.4	....	
417.71.......	9.3	....	
429.82.......	9.5	....	
438.84.......	8.8	....	
443.63.......	....	F2 I*b*	
		AC Herculis	
3347.94.......	8.1	Rp (G2)	16, 13, 17
365.81.......	8.4	....	
		AC Herculis (*cont.*)	
3373.78.......	8.3	....	
377.80.......	8.4	....	
378.86.......	....	Rp (G5)	3, 13, 17
385.70.......	8.5	....	
387.74.......	....	Rp (G8)	9, 13, 17
389.79.......	....	Rp (G8)	9, 13, 17
393.75.......	9.0	Rp (K0)	9, 13, 17
403.72.......	9.1	....	
417.72.......	8.2	....	
420.85.......	....	Rp (G2)	3, 13, 17
421.81.......	8.1	....	
429.80.......	8.5	Rp (G5)	3, 13, 17
439.85.......	8.7	....	
443.70.......	8.4	F4p	3, 15
446.83.......	8.4	F4p	3, 15
448.79.......	8.4	G0p	3, 15
458.64.......	....	Rp (G2)	9, 13, 17
461.65.......	....	Rp (G5)	9, 13, 17
		AR Puppis	
3274.42.......	....	Rp	18

NOTES TO TABLE 3

1. Hydrogen lines weakened by emission.
2. Hydrogen lines slightly weakened.
3. Veiled.
4. *TiO* bands.
5. The spectrum is overexposed.
6. The spectrum is weak.
7. Hydrogen lines greatly weakened or in faint emission.
8. Incipient *TiO* bands.
9. Strong *CN*.
10. Hydrogen lines in emission.
11. Hydrogen lines strong in emission.
12. *Ca* 4226 weak.
13. Hydrogen lines abnormally strong.
14. Hydrogen lines slightly enhanced.
15. Hydrogen lines broadened.
16. *CH* star. The spectral peculiarities are described in the text. Equivalent spectral types are given in parentheses.
17. Strong *CH*.
18. *CH* star? Strong G band, neutral lines greatly weakened, very strong λ 4325.

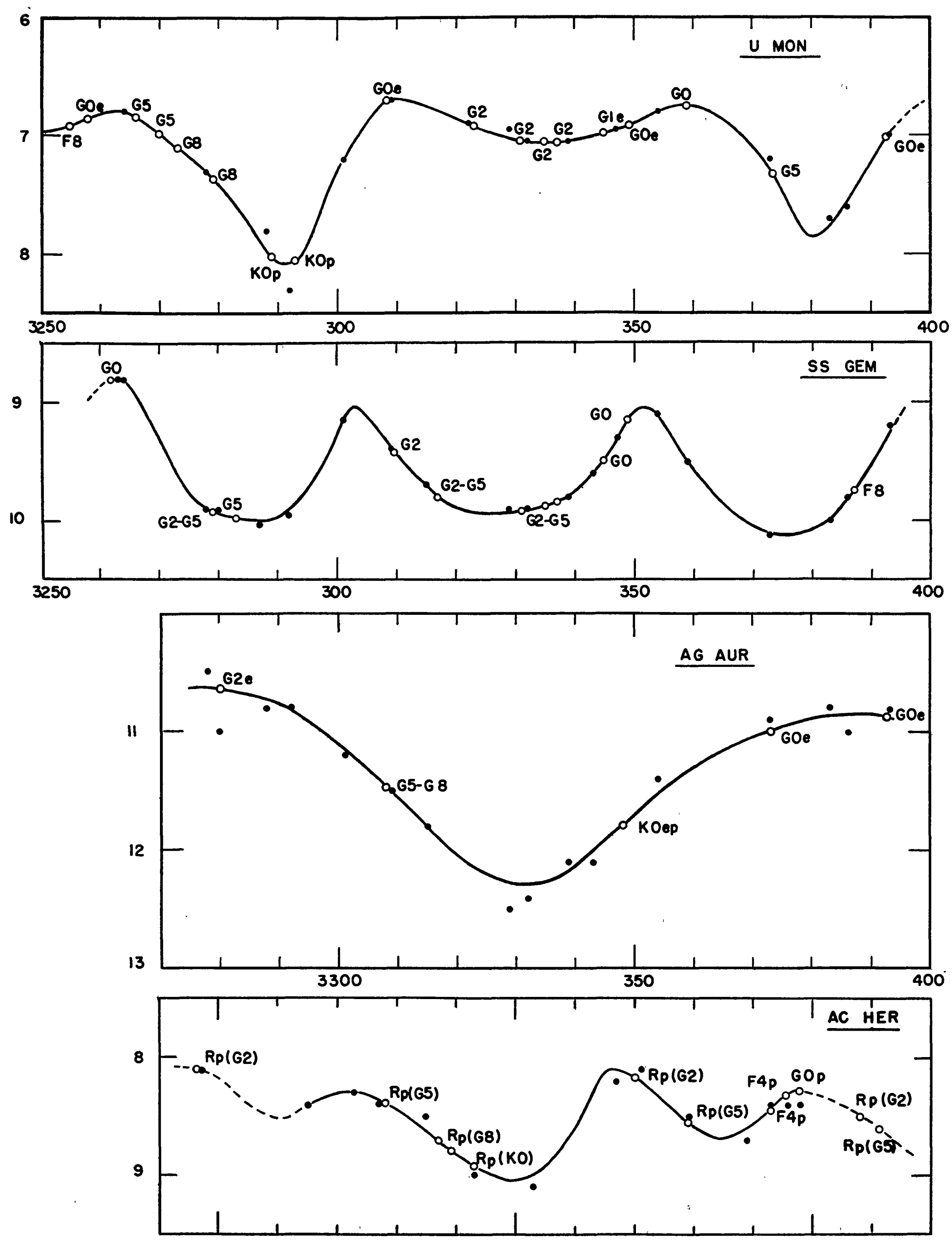

FIG. 1.—Photographic light-curves and spectral variations of U Mon, SS Gem, AG Aur, and AC Her. The dots indicate the observed magnitudes, and the open circles the phases of the spectrograms. Equivalent spectral types are given in brackets for AC Her.

from deep minimum to maximum. At this phase the spectrum is completely abnormal and does not match any of the standard stars.

c) Lines of neutral atoms, such as *Ca* I 4227 and *Fe* I 4143 are weakened most of the time, while the lines of *Fe* II, *Ti* II, and *Sr* II, and particularly λλ 4171–4178, 4215, and 4290 are stronger than in the corresponding standard spectra. They become nearly

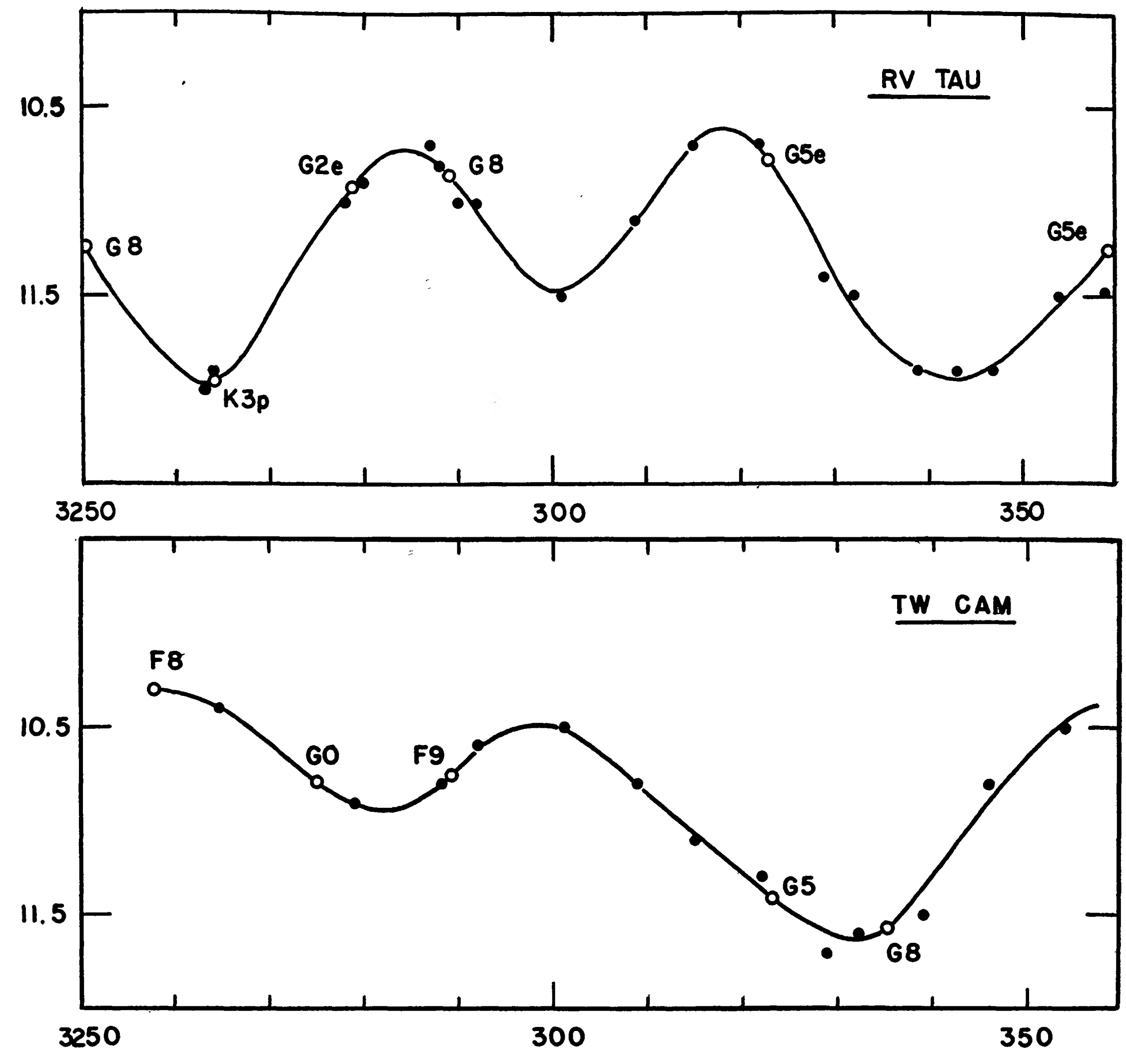

FIG. 2.—Photographic light-curves and spectral variations of RV Tau (luminosity class I*a*) and TW Cam (luminosity class I*b*). Dots and open circles have the same meaning as in Figure 1.

normal on the descending branch before deep minimum is reached. At this phase the luminosity decreases appreciably.

d) Whenever the light is increasing, bright hydrogen lines appear in the spectra of U Mon, RV Tau, R Sct, and V Vul. The presence of emission, as shown by a considerable weakening of the hydrogen absorption lines, is in evidence also for a time during decreasing brightness and disappears only for the few days preceding deep minimum. The stars SS Gem, TW Cam, and R Sge do not show emission on our low dispersion plates; on the contrary, the hydrogen lines are considerably strengthened. They become broad and hazy during increasing light, and faint emission may be associated with the strong absorption features at this phase. A slight weakening of the hydrogen lines was observed near maximum in R Sge and TW Cam.

e) *TiO* bands appear near the deep minimum in U Mon, RV Tau, R Sct, and V Vul. There is a tendency toward stronger and more persisting bands as the period increases. The corresponding spectral class, defined by the absorption features, is not usually later than K0–K3. No *TiO* bands have been observed in SS Gem, TW Cam, and R Sge.

f) The earliest spectral types are, in most cases, F8–G1. The latest are G5–G8 for the RV Tauri variables without *TiO* bands and G8–K3 for those which develop *TiO* bands at minimum. The spectral type does not seem to depend upon the period.

The RV Tauri variables can be considered, from the above, to fall into two groups, with regard to the behavior of the hydrogen lines and the formation of *TiO* bands. The stars SU Gem, TT Oph, UZ Oph, and perhaps DF Cyg probably belong to the bright-line group, which will be called the "U Mon group."

At the deep minimum the spectral class of U Mon is K0 I*b*, but *TiO* bands as strong as in an M3 star are present, and all spectral features seem to be veiled. Near maximum the spectral class is G0e I*b;* weak hydrogen lines can be seen in emission. These lines reappear weakly in absorption or faintly in emission during phases through the shallow minimum up to the next maximum. Halfway toward the principal minimum the spectral class is G5 I*b*, and the hydrogen lines are still weakened.

The data contained in Table 3 indicate that it is possible to make the same subdivision into two groups for the semiregulars of Table 2. The stars SV UMa and UU Her were not observed to show emission lines; however, both were in a phase of peculiar photometric variation with only small fluctuations in brightness during the interval covered by our observations. It will be necessary to follow these variables during a period of normal variation to draw definite conclusions. On the contrary, five of the six spectrograms of AG Aur show bright hydrogen lines. While in the spectra of the U Mon group the emission lines appear when the brightness is increasing and are weak, in AG Aur they are still very strongly present during decreasing light. About two weeks after minimum, emission lines and *TiO* bands can be observed. Emission lines were also observed in the spectrum of WY And.

The RV Tauri variables SU Gem, U Mon, TT Oph, UZ Oph, R Sct, RV Tau, and V Vul and the semiregular variables WY And, SZ Aqr, AG Aur, and SX Her (all showing emission lines and with *TiO* bands at minimum) appear to constitute a physical group and are probably members of Baade's population II. Stars of this type are present with a certain frequency in the globular clusters, as shown in a recent paper by A. H. Joy.[8] There are five RV Tauri variables in Joy's group 4—all with emission lines on the rising branch and with photometric periods of between 51 and 90 days. Their spectral types are, however, earlier than those derived here, ranging from F4 to G5, and no *TiO* bands seem to have been observed. These differences may be explainable by the different classification criteria and by the difficulty of reaching the variables at minimum in globular clusters.

Two of the semiregular variables in Joy's group 5, with periods of 103 and 106 days, show emission lines and *TiO* bands at minimum. It is interesting to note that the four semiregulars—WY And, SZ Aqr, AG Aur, and SX Her—have the following periods: 107, 108, 96, and 103 days.

The three groups of variables, comprising the W Virginis stars, the RV Tauri variables of the U Mon group, and the yellow semiregulars like AG Aur, constitute a homogeneous sequence if we take the significant period of the RV Tauri variables to be half the photometric period given in Table 1. A period-luminosity relation can be found by the use of the absolute median photographic magnitudes of the variables in globular clusters; this is illustrated in Figure 3. The zero point is defined by assuming that the

[8] *Ap. J.*, **110**, 2, 1949.

median absolute photographic magnitude of the RR Lyrae variables is zero. The maximum luminosity is reached for periods of 35–40 days (periods of double variation, 70–80 days). This relation seems to be satisfied by the variables of Tables 1 and 2, with the sole exception of R Sct. The variables RV Tau and V Vul, with luminosity class I*a* or I*a*–I*b*, have periods of 38–39 days (photometric periods, 76–78 days), while U Mon with a period of 46 days (double period, 92 days) is only slightly more luminous than I*b*, and the semiregulars, like AG Aur or SX Her, are in the luminosity class I*b* or I–II.

Table 1 contains a very peculiar star, AC Herculis. There is no question about its inclusion in the list of RV Tauri variables, because all the conditions imposed are satisfied by the light-curve and the spectrum at maximum is type F. Its spectral variation, however, is completely peculiar and deserves a detailed description. A few days after maximum the spectrum is characterized by the presence of hydrogen lines as strong and

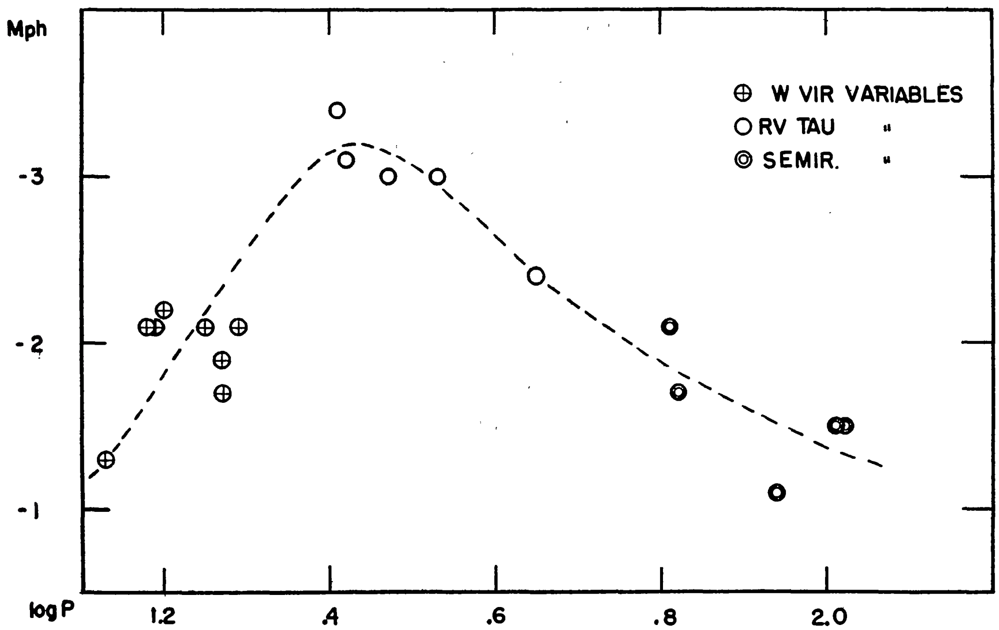

FIG. 3.—The period-luminosity relation for W Vir type, RV Tauri type, and yellow semiregular variables in globular clusters. *Ordinates*, the absolute mean photographic magnitude; *abscissae*, logarithm of the period (in days). Half of the photometric period is plotted for the RV Tauri variables.

sharp in absorption as in an F2–F5 I*b* star. On the other hand, the G band of *CH* is present with an unusually great intensity, as marked and broad as in a late G-type star. All other lines, down to λ 4000, are weakened, with the sole exception of a strong absorption feature at about λ 4325. These peculiarities are accentuated a week later, and, in addition, there appears a very strong *CN* band from λ 4215 toward the violet.[9] The *Ca* 4226 line and all lines of neutral atoms up to λ 4000 are almost obliterated on plates of low dispersion, and *Sr* II 4077 is abnormally weak. The *CN* band becomes still stronger as the brightness approaches the deep minimum, so that it is difficult to obtain the region of the spectrum on the violet side of λ 4215 with sufficient density. The same peculiarities can be observed during the decrease of light toward a shallow minimum, but the *CN* band is less intense. The strength of the *CH* and *CN* bands and the almost complete obliteration of most of the absorption lines indicate that AC Her is a peculiar carbon star. It can be included in that small group of carbon stars which have been

[9] Dr. W. W. Morgan called my attention to the strength of the *CN* and *CH* bands and to the most interesting peculiarities of this variable.

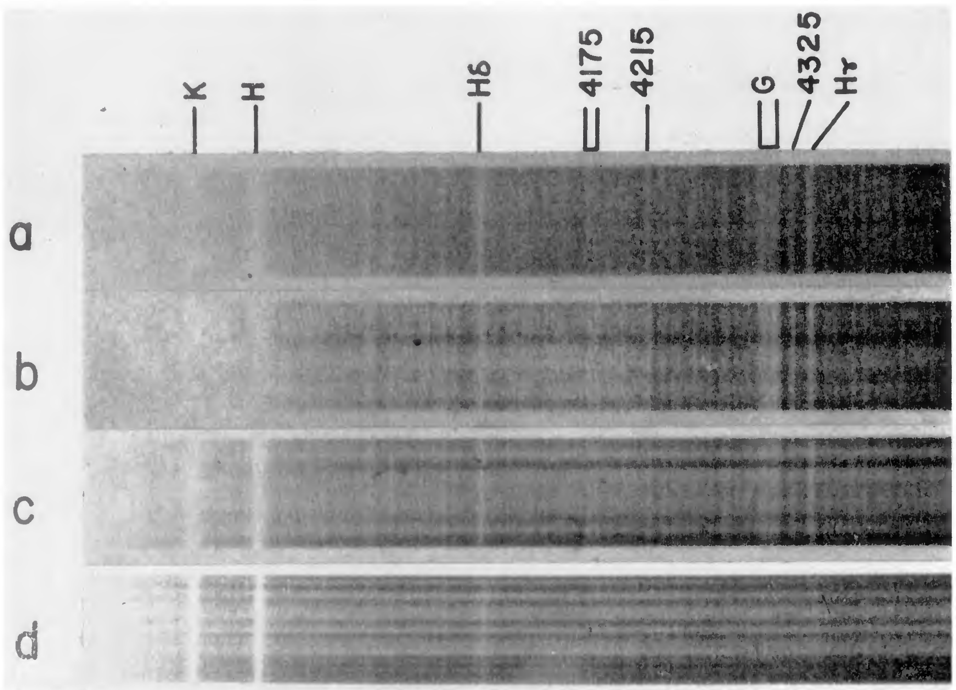

FIG. 4.—Spectrograms of the peculiar carbon variable AC Her. The phases of the spectra are listed below, together with the last three digits of the Julian dates. *a*, 348, near maximum light; *b*, 388, about halfway between maximum and deep minimum on the descending branch; *c*, 430, near a shallow minimum; *d*, 444, on rising branch, between shallow minimum and maximum. Note the remarkable weakening of all lines and the suppression of the G band on the lowest exposure. Spectrogram *b* shows a well-marked absorption of *CN*, together with an exceedingly strong G band.

described by Keenan and Morgan[10] and are called "*CH* stars." As Keenan[11] has pointed out, most of the absorption features in the spectra of *CH* stars coincide with band lines of the *CH* system. In particular, the intensity of the line at λ 4325 is due not to the iron line, which is very faint, but to the narrow and strong band of *CH* at $\lambda\lambda$ 4323–4324. The spectral types of AC Her in these phases have been described in Table 3 as "Rp." Rough equivalent types have been derived from the general appearance of the spectrum.

The changes in the spectrum of AC Her when the brightness is increasing are striking. A general veiling greatly weakens all lines, while H and K are sharp and abnormally narrow. The G band is weak and discontinuous as in an F2–F5 star, and the hydrogen lines are weak and greatly broadened. The spectrum is therefore completely different from that during decreasing light. The *CH* features and the *CN* band reappear as soon as the brightness starts decreasing. A set of spectrograms of AC Her is reproduced in Figure 4.

In conclusion, I wish to express my deepest gratitude to Dr. W. W. Morgan, who proposed this problem to me, for many helpful suggestions and for his continued and stimulating interest in the course of the investigation.

[10] *Ap. J.*, **94**, 501, 1941.

[11] *Ap. J.*, **96**, 101, 1942.