1952ApJ...116...21M

SPECTROSCOPIC OBSERVATIONS OF STARS OF CLASS S

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Received February 27, 1952

ABSTRACT

This paper presents a brief survey of S-type spectra based largely on spectrograms with dispersion 9 A/mm of eight stars obtained by I. S. Bowen with the 200-inch telescope. The intensities of several groups of absorption lines and bands and of the more important emission lines are compared in various stars. Radial velocities from both bright and dark lines and a supplementary list of absorption lines identified in the green region are included. The remarkable behavior of certain bright lines of *V* I and of *Cr* I in the spectrum of R Cygni is described.

The spectrograms that, many years ago, led to the recognition of a third type of red stars[1] paralleling the M-type and N-type branches were taken with the 60-inch and 100-inch telescopes with a dispersion at $H\gamma$ of about 35 A/mm.[2,3] The spectrum was well shown only between $H\beta$ and $H\gamma$. More recently, special studies of R Andromedae[4,5] and of χ Cygni,[6] a long-period variable apparently intermediate between classes M and S, were made with a scale of 10 A/mm, and the spectral region studied was extended shortward to about λ 3400. With the 100-inch telescope, unduly long exposures would be required to obtain satisfactory spectra of additional stars on the same scale. The Hale telescope, with its greater light-gathering power and its larger coudé spectrograph (allowing the use of a wider slit), has greatly reduced the necessary exposure times and has thus made it feasible to obtain observations of additional S-type stars.

This paper presents a brief survey of S-type spectra based largely on spectrograms of eight of the brighter S-type stars (Table 1) obtained by I. S. Bowen during the course of testing and adjusting the 200-inch telescope and coudé spectrograph. I am greatly indebted to him for these valuable photographs.

The new material provides more detailed information than that previously available concerning the atomic lines in the spectra of six long-period variables near maximum light; one irregular variable of small range, AA Cygni; and one nonvariable star, HD 22649. Three plates of R Cygni at intervals of a month show marked changes, especially in the bright lines.

The intensities of several features of the spectrum are indicated by the estimates in Table 2. Several additional variables are included for comparison. The wave lengths upon which these estimates are chiefly based are listed in Table 3.

Estimates of the intensities of *ZrO* and *TiO* bands are accordant with those previously made[3] on low-dispersion spectrograms. Stars with pure, well-advanced S-type spectra—bands of *ZrO* well marked, those of *TiO* weak or absent—are R Gem, T Sgr, and R Cyg. The star R And is of type S with fairly strong bands of *TiO*. Stars that may be said to be intermediate between types S and M are U Cas, HD 22649, AA Cyg, Z Del, and

[1] *Trans. I.A.U.*, **1**, 98, 1922.

[2] P. W. Merrill, *Mt. W. Contr.*, No. 252; *Ap. J.*, **56**, 457, 1922.

[3] P. W. Merrill, *Mt. W. Contr.*, No. 325; *Ap. J.*, **65**, 23, 1927.

[4] P. W. Merrill, *Mt. W. Contr.*, No. 730; *Ap. J.*, **105**, 360, 1947.

[5] P. W. Merrill, *Mt. W. Contr.*, No. 743; *Ap. J.*, **107**, 303, 1948.

[6] P. W. Merrill, *Mt. W. Contr.*, No. 735; *Ap. J.*, **106**, 274, 1947.

χ Cyg. An example of pure M type is R Leo; *o* Cet and R Hya are principally M type but with departures in the direction of the S-type characteristics.

Lines of *Ba* II λ 4554 and λ 4934 appear especially strong in S-type stars. In comparing estimates of their intensities in various stars, however, it should be remembered that *TiO* bands, when present, tend to obscure these *Ba* II lines.

The intensities of certain low-temperature (ground-level) lines (Tables 2 and 3) may

TABLE 1

SPECTROGRAMS OF S-TYPE STARS TAKEN WITH THE 200-INCH TELESCOPE
(Dispersion 9 A/mm)

Star	Desig.	Mag. Range	Period (Days)	Plate Pc	Date 1951	Mag.	Phase (Days from Max.)	Exp. Min.
U Cas..........	004047	7.7– 15.0	281	127	July 25	8.9	+ 5	338
HD 22649......	033362	5.3	....	141	Aug. 19	5.3	....	30
				192	Oct. 16	5.3	....	45
R Gem.........	070122	6.5– 14.3	370	68	Mar. 23	7.9	+39	305
S UMa.........	123961	7.0– 12.0	229	110	June 21	8.0	+ 9	305
				254	Jan. 14*	(8.5)	(−10)	190
T Sgr..........	191017	7.2–<13.1	396	124	July 21	8.4	+18	264
R Cyg.........	193449	5.6– 14.4	428	137	Aug. 19	8.6	−39	280
				154	Sept. 16	7.9	−11	300
				191	Oct. 16	8.0	+19	342
AA Cyg........	200036	8.4– 9.2	202	115	June 26	(9)	....	220
Z Del..........	202817	8.2– 14.0	304	112	June 22	9.5	+20	460

* 1952.

TABLE 2

INTENSITIES OF LINES AND BANDS

STAR	PLATE	ABSORPTION					EMISSION					
		ZrO	*TiO*	*Ba* II	Low-Temp.	*Tc* I	*H*	*Fe* II	*Mg* I	*Si* I	*In* I	*Co* I
R And....	Ce 3522	8	3	5	8	4	10	3	2	3	3	2
U Cas.....	Pc 127	7	7	5	6	3	10	3	1	3	1	2
HD 22649.	Pc 192	2	2	5	6	1	0	0	0	0	0	0
R Gem....	Pc 68	5	0	10	7	5	10	3	2	2	3	3
S UMa....	Pc 110	1	0	7	4	1	10	3	1	2	1	1
T Sgr.....	Pc 124	7	0	7	5	3	10	3	2	3	4	3
R Cyg....	Pc 137	10	0	10	5	3	10	2	2	2	2	3
AA Cyg...	Pc 115	8	7	7	8	4	0	0	0	0	0	0
Z Del.....	Pc 112	2	7	3	3	1	10	3	1	2	0	2
χ Cyg.....	Ce 3762	5	20	3	10	3	10	3	2	5	4	2
o Cet......	Ce 4109	1	15	1	7	2	5	1	0	2	1	0
	Ce 5925	1	10	2	6	1	10	3	1	2	0	1
R Hya....	Ce 3390	1	15	3	7	1	7	3	1	3	0	1
R Leo....	Pc 40	0	20	1	10	0	10	4	4	6	3	0

be taken to indicate the temperature of the reversing layer, 8 or 10 corresponding to about 2300°, lower intensities to higher temperatures.

Lines of *Tc* I, an element believed to have no completely stable isotope, appear to be stronger in the stars with the more dominant S-type characteristics. This fact, together with others, might suggest that S-type stars represent a comparatively transient phase of stellar existence.

TABLE 3

WAVE LENGTHS OF FEATURES USED FOR ESTIMATES IN TABLE 2

Idcnt.	Wave Length
ABSORPTION	
ZrO	4471, 4620, 4638
TiO	4584, 4626, 4761, 4955
Ba II	4554, 4934
Low-temp.:	
Al I	3944, 3961
K I	4044, 4047
Ca I	4226
Cr I	4254, 4274, 4289
Sr I	4607
Tc I	4031, 4238, 4262, 4297
EMISSION	
H	$H\beta$–$H11$
Fe II	4233, 4583, 4924, 5018
Mg I	3829, 3832, 3838 5167, 5172, 5183
Si I	3905, 4103
In I	4511
Co I	3894, 3997, 4118, 4121

Identified absorption lines in the green in addition to those recorded in Table 2 of *Mount Wilson Contributions*, No. 743,[5] are listed in Table 4.

The radial velocities of these eight S-type stars measured on the coudé spectrograms are recorded in Table 5. They do not differ greatly from those measured previously[7] with low dispersion. The relative displacement of bright and dark lines tends to increase with the period of light-variation, but for the longer periods the difference is somewhat less than that previously found.[8]

In addition to the bright lines mentioned in *Mt. W. Contr.*, No. 730,[4] Tables 7–12, the green lines of *Mg* I λλ 5167, 5172, 5183 have been observed in emission in several S-type variables. These, like the ultraviolet lines λλ 3829, 3832, 3838, behave so differently from the postmaximum line *Mg* I λ 4571 that they must be produced by a different mechanism. The upper level of λ 4571, 4^3P°, is fed by the emission of λ 3832 and of λ 5172, but toward minimum light the population of this level must be increased by some other process. A promising investigation would be a comparative study of multiplets 1, 2, and 3 of *Mg* I in the spectrum of an S-type variable at various phases of its light-cycle.

[7] P. W. Merrill, *Mt. W. Contr.*, No. 649; *Ap. J.*, **94**, 171, 1941.

[8] P. W. Merrill, *Mt. W. Contr.*, No. 644; *Ap. J.*, **93**, 380, 1941.

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TABLE 4

ADDITIONAL ABSORPTION LINES IN SPECTRA OF CLASS S*

λ	El.	Mult.	λ	El.	Mult.
4799.79	*V*	3	5079.74	*Fe*	16
4937.72	*Ti*	39	5081.55	*Sc*	13
4939.69	*Fe*	16	5083.34	*Fe*	16 bl
4947.99	*Ti*	39	5083.71	*Sc*	13 bl
4964.71	*Ti*	173	5085.55	*Sc*	13
4977.73	*Ti*	173	5086.95	*Sc*	13
4978.19	*Ti*	173	5098.70	*Fe*	66
4989.14	*Ti*	173	5099.23	*Sc*	13
5021.90	*Cr*	8	5101.12	*Sc*	13
5025.57	*Ti*	173	5107.45	*Fe*	16
5035.91	*Ti*	110	5110.41	*Fe*	1
5036.47	*Ti*	110	5123.72	*Fe*	16
5038.40	*Ti*	110	5127.36	*Fe*	16
5039.96	*Ti*	5	5133.42	*Zr*	27
5040.64	*Ti*	38	5142.93	*Fe*	16
5041.07	*Fe*	16	5147.48	*Ti*	4
5041.76	*Fe*	36	5152.18	*Ti*	4
5043.58	*Ti*	38	5166.29	*Fe*	1
5045.40	*Ti*	38	5168.90	*Fe*	1
5046.61	*Zr*	62	5171.60	*Fe*	36
5048.75	*Cr*	20	5173.74	*Ti*	4
5049.82	*Fe*	114	5192.77	*Ti*	4
5051.64	*Fe*	16 bl	5206.04	*Cr*	7
5051.90	*Cr*	8 bl	5208.44	*Cr*	7
5053.30	*W*	1 ?	5210.39	*Ti*	4
5065.98	*Ti*	110	5219.68	*Ti*	4
5068.29	*Cr*	20	5225.53	*Fe*	1
5070.25	*Sc*	13	5247.05	*Fe*	1 bl
5071.48	*Ti*	110	5247.56	*Cr*	18 bl
5072.92	*Cr*	8	5254.96	*Fe*	1
5075.81	*Sc*	13	5264.15	*Cr*	18
5078.28	*Zr*	62	5265.72	*Cr*	18
5079.23	*Fe*	66			

*See *Mt. W. Contr.*, No. 743; *Ap. J.*, **107**, 303, 1948.

TABLE 5

RADIAL VELOCITIES OF S-TYPE STARS

Star	Plate Pc	Phase (Days)	Emission (Km/Sec) *H*	Emission (Km/Sec) Misc.	Abs. (Km/Sec)	No. Abs. Lines
U Cas	127	+5	−59	−56	−44.8	49
HD 22649	141	....	....	....	−16.4	30
	192	....	....	....	−13.9	31
R Gem	68	+39	−53	−51	−40.5	121
S UMa	110	+9	−5	−6	+5.2	102
	254	(−10)	+1	....	+11.2	24
T Sgr	124	+18	−8	−10	+5.4	64
R Cyg	137	−39	−40	−39	−23.3	90
	154	−11	−45	−42	−28.8	99
	191	+19	−48	−42	−32.1	126
AA Cyg	115	....	....	....	+9.0	183
Z Del	112	+20	+24	+23	+36.8	57

In the spectrum of R Gem, Plate Pc 68, numerous bright lines in addition to those of *H* are present. Elements represented are *Mg* I, *Si* I, *Ti* II?, *V* I?, *Cr* I?, *Fe* I, *Fe* II, *Co* I, *Ni* I, *In* I.

An even more remarkable set of bright lines is present on the first plate, Pc 137, of R Cyg. In *Cr* I all the strongest lines of multiplets 23, 24, 25, and 26 are present. Table 6

TABLE 6

EMISSION LINES IN THE SPECTRUM OF R CYGNI
Pc 137

λ	*J*	Intensity Lab.	Intensity Star
	V I (24) $a^6D-y^4F^\circ$		
4209.86	$4\frac{1}{2}$–$4\frac{1}{2}$	20	1
4198.61	$3\frac{1}{2}$–$3\frac{1}{2}$	4	0.7
4218.71	$4\frac{1}{2}$–$3\frac{1}{2}$	4	1
4219.51	$3\frac{1}{2}$–$2\frac{1}{2}$	2	0.3
4189.84	$3\frac{1}{2}$–$4\frac{1}{2}$	12	0.7
4182.59	$2\frac{1}{2}$–$3\frac{1}{2}$	10	1
4191.56	$1\frac{1}{2}$–$2\frac{1}{2}$	10	1.4
	V I (25) $a^6D-z^2G^\circ$		
4179.42	$4\frac{1}{2}$–$4\frac{1}{2}$	15	1.6
4159.69	$3\frac{1}{2}$–$4\frac{1}{2}$	8	1
	Cr I (22) $a^5D-z^5F^\circ$		
4351.77	5–5	100	1
4344.51	3–4	100	Tr
4339.6	{2–3, 0–1}	{75, 60}	2
4337.57	1–2	75	Tr
4384.98	4–4	75	1
4371.28	3–3	75	3
4359.63	2–2	75	1
4351.05	1–1	75	3
4412.25	4–3	40	1
4391.75	3–2	40	1.5
4373.25	2–1	35	4

shows the relative intensities in laboratory and star. The spread appears to be considerably less in the star. An equally interesting example is furnished by multiplet 22 of *Cr* I (Table 6). Here the correspondence of intensities is poor, the lines from upper-level $z^5F^\circ_1$ appearing to be unduly intense in the star. The energy of this level corresponds to a line of wave length 3247.18 A. This wave length is 0.36 A shorter than that of a strong line of *Cu* I, but the near-coincidence is probably not significant. The bright lines of Table 6 are much stronger on plate Pc 137 taken 39 days before maximum light than on plates taken, respectively, 28 and 58 days later. Thus they behave differently from most emission lines in the spectra of long-period variables, in that they are strongest a month or more *before* maximum light. The curious behavior of these emission lines poses several interesting problems: (1) Why are certain multiplets emphasized? (2) Why do the relative intensities of the lines differ from those in the laboratory? (3) Why do the intensities decrease so abruptly as the star approaches maximum light? R Cyg obviously deserves intensive spectroscopic observation at various phases of the light-cycle.

I wish to thank Mrs. Mary Coffeen for valuable assistance in measuring and computing.