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SPECTRAL CLASSIFICATION OF A-TYPE SPECTROSCOPIC BINARIES*

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ABSTRACT

MK spectral types have been determined or are quoted for ninety-eight of 101 known spectroscopic binaries with primaries in the range A2–F3. Half of these stars are metallic-line (Am) stars; most of the remainder are outside the domain (approximately A4–F1 IV, V) of the Am stars. The remaining nine normal stars in the domain have periods of either less than 2.5 or more than about 100 days. It is concluded that all stars in the range A4–F1, IV, V that are primaries of binaries with periods of approximately 2.5–100 days have metallic-line spectra.

I. INTRODUCTION

Two intensive studies (Abt 1961, 1965) of the binary frequencies of abnormal and normal A-type stars led to the following results: (1) Among twenty-five metallic-line (Am) stars, twenty-two were found to be spectroscopic binaries, mostly with periods less than 100 days, indicating that, after allowance is made for low-mass companions and unresolved double-lined systems, probably all Am stars are members of binary systems. (2) Of fifty-five A4–F2 IV, V stars, seventeen were found to be spectroscopic binaries, all with periods greater than 100 days. It was concluded that, if the primary of a spectroscopic binary is in the color range equivalent to A4–F2 on the main sequence and with a period less than 100 days, the star has an abnormal spectrum.

However, it has been argued (Batten 1967*a*) that many additional binaries with known orbital elements have primaries in the range A4–F2 and that these stars are not known to be Am stars. Since most of these stars were classified before the advent of the two-dimensional MK system (Morgan, Keenan, and Kellman 1943) and the recognition of the Am stars as a class (Titus and Morgan 1940; Roman, Morgan, and Eggen 1948), it is necessary to reclassify those stars. The main purpose of the present investigation is to see whether the results as stated above, or as modified slightly, are still true after analysis of a larger body of material.

A second purpose of this investigation is to delineate the Am-star region in spectral type, luminosity, and binary period. The original selection of normal stars was by color ($+0.07 \leq B - V \leq +0.35$), but since the Am stars, particularly those of later types like τ UMa, are reddened by excessive line blanketing, the color limits of the Am stars may be inappropriate for normal stars. An indirect way to determine the spectral-type limits of the Am-star region is to note where binaries of short periods and normal members start to occur; this method will be used below. Also, the original samples of stars included no W UMa systems, because such stars are not represented among the A-type stars brighter than $V = 6.0$ mag.

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Finally, it should be emphasized that the original selection of Am stars comprised those stars with markedly peculiar characteristics, i.e., generally for each star, at least five spectral subclasses of discrepancy between its spectral type derived from its K-line and that derived from its metallic lines. The binary characteristics are not yet known for the borderline Am stars discussed by Weaver (1952) in the Coma Cluster and other clusters, or the early A-type abnormal, or Sirius-type, stars discussed by Conti (1965).

II. SPECTRAL TYPES AND DISCUSSION

Spectra for classification were obtained for nearly all of the spectroscopic binaries in the *Fifth Catalogue of the Orbital Elements of Spectroscopic Binary Stars* (Moore and Neugebauer 1936) brighter than $V = 7.5$ mag, north of decl. $-30°$, and lacking MK types but having preliminary types in the range A2–F3. The *Sixth Catalogue* (Batten 1967*b*) was not available when the observing was done. The spectra were obtained with the Meinel spectrograph on the Kitt Peak 36-inch telescope, using a dispersion of 63 Å mm^{-1} and projected slit dimensions of $20\ \mu \times 0.87$ mm. Although this dispersion is better for resolving double-lined spectra, it was learned that it is less satisfactory for spectral classification of A stars than a dispersion of about 125 Å mm^{-1}. Similar spectra of standards of spectral type (Johnson and Morgan 1953) were obtained.

These spectra were classified independently by one of us (W. P. B.) and by Dr. W. W. Morgan. The former tended to classify the stars as being normal or abnormal to varying degrees of abnormality (possible, probable, definite, and pronounced) and provided a number of additional unpublished types based on spectra obtained at the Lick and Dominion astrophysical observatories. In general, the agreement between the two investigators is good. The greatest discrepancy occurs for the borderline Am stars; Bidelman was more likely than Morgan was to classify such stars as Am. The classification system for A stars of various luminosity classes and degrees of peculiarity is currently under investigation by Dr. Morgan, so, in a sense, this paper is premature in treating these problems. However, except for a few cases, such as 2 Sge, ι Del, π Cas, and UY Vir, the disagreements in classification are irrelevant. The references to classifications by others are far from complete; in general, these were included only when types by Bidelman or Morgan are lacking.

The stars and their types are divided into groups as listed in Tables 1, 2, and 3. Table 1 contains stars classified as normal and being outside the spectral-type and luminosity range of the Am stars. The first part of the table lists stars as late as A2 and A3 in short-period binaries, indicating that the region of the Am stars starts at about A4. This implication is contingent upon the result given below that, within the Am region, only Am stars occur as the primaries in binaries of periods from a few days to about 100 days. The second part of the table lists normal late A-type stars of luminosity class III or brighter, some in short-period binaries, indicating that the Am region is confined to luminosity classes IV and V. In passing, it should be stated that the luminosity classification of the shell spectrum of V367 Cyg should not be used to imply that the underlying star is of high luminosity; its location in the H-R diagram is unknown. The third part of Table 1 lists normal early F-type stars in binaries, some of which are as early as F2. This indicates that the Am region terminates at about F1.

Table 2 lists binaries having Am primaries of varying degrees of abnormality and a few other peculiar stars, such as the well-known Ap star β CrB, and the as yet unspecified peculiar stars 14 Aur and 26 Vul; δ Del, which was not included in the *Fifth Catalogue*, would also be such a star. The fact that all the periods in Table 2 are less than about 100 days is not astrophysically significant, because Am stars in binaries of larger periods are known (Abt 1961); the deficiency in Table 2 simply demonstrates that previous observers neglected to analyze possible spectroscopic binaries with small velocity ranges.

Table 3 lists binaries with fairly normal spectra that are well within the Am region.

TABLE 1

SYSTEMS WITH PRIMARIES OUTSIDE THE REGION OF AM STARS

FIFTH CAT. No.	NAME OR HD No.	HR	PERIOD (days)	SPECTRAL TYPE WPB	WWM	Others	SOURCES AND COMMENTS
			Systems Earlier than the Am Region				
10.	2421	104	3.96	Normal	. .	A2 Vs	Cowley *et al.* (1969)
68....	b Per	1324	1.53	Normal	A2:	A2 V	WWM: low weight; Cowley *et al.* (1969)
84....	7 Cam	1568	3.88	.	. .	A1 V	Slettebak (1954); Cowley *et al.* (1969)
157. ..	α Gem A	2891	9.21	. .	...	A1 V	Slettebak (1954); Cowley *et al* (1969)
190. ..	79763	3676	15.99	Normal	A1 V	. .	
214. .	55 UMa	4380	2.5	Normal	. .	A2 V	Osawa (1959); Cowley *et al.* (1969)
223 ...	95 Leo	4564	6.63	Normal	. .	A3 V	Osawa (1959); Cowley *et al.* (1969)
246.	ζ UMA A	5054	20.54	...	...	A2 V	Slettebak (1954); Cowley *et al.* (1969)
322	158261	6506	5.92	Normal	A0 V	. .	
328 .	162132	6641	2.82	Prob Am	A2 V	. .	
346 ..	169981	6917	9.61	Normal	. .	A2 V	Osawa (1959): A2 with A4 metallic lines; Cowley *et al.* (1969): A2 IV
384....	ϕ Aql	7610	3.32	Poss. Am	A1 V	.	
414. .	14 Del	7974	10.88	Normal	A1 V	. .	
			Systems More Luminous than the Am Region				
36 .	β Tri	622	31.40	.	A5 III	.	Johnson and Morgan (1953)
74 ...	θ^2 Tau	1412	140.75	. .	A7 III	. .	Johnson and Morgan (1953)
85 .	ϵ Aur	1605	27.08 yr	A8e Ia	.	. .	
164	3 Pup	2996	137.77	A3ep II	. .	. .	
394 ..	18 Vul	7711	9.32	Normal	. .	A3 III	Osawa (1959); Cowley *et al.* (1969)
413 ..	V367 Cyg	...	18.60	F2pe	A3:Ia:	. .	Abt (1954): shell spectrum
			Systems Later than the Am Region				
28. ..	10308	484	4.43	Normal	F5 V	. .	WWM: approx. equal components
30....	α Tri	544	1.74	. .	F6 IV	. .	Johnson and Morgan (1953)
38 ...	6 Tri B	. .	2.24	.	. .	F5 V	Stephenson (1960)
57	22124= IX Per	...	1.33	Normal	F5 IV–V	.	
95	34335	.	3 43	Normal	F5 IV	...	WWM: approx, equal components
149	R CMa	2788	1.14	Normal	F2 IV	.	
161	61859	2962	31.50	F2 V:	. .	.	
174	1 Hya	3297	1.56	Normal	F5 V	...	
237.	110317	4821	1.46	Normal	F4 IVn	.	WWM: Visual companion=F5 III
249...	118216	5110	2 61	Normal	F4 IV	.	
254....	3 Boo	5182	36.04	F3 V:	.	.	
268 .	129132	5472	3320.00	Normal	F5 IV	...	
270..	39 Boo	5538	12.82	Normal	F5 V	.	
277 ...	ϵ Lib	5723	226.95	F5 V	. .	. .	
304..	39 Her	6213	2.31	Normal	F3 V:	. .	WWM: components equal

TABLE 1—*Continued*

Fifth Cat No	Name or HD No	HR	Period (days)	Spectral Type WPB	Spectral Type WWM	Spectral Type Others	Sources and Comments
				Systems Later than the Am Region—*Continued*			
308. ..	152830	6290	11.86	Normal	F4 III	...	WWM: λ4226 weak?
321...	157950	6493	26.27	. .	..	F3 V	Slettebak (1955)
368. .	178619	7267	4.81	Normal	F5 IV:	.	WWM: mean of approx. equal components
380	185912	7484	7 64	Normal	F6 IV–Vn	.	
427	205539	8257	12.21	Normal	F2 IV, V	.	WPB: rather weak lined
433.	206874		3 75	Normal	F2 IVn	.	
434 .	κ Peg	8315	5 97	. .	.	F5 IV	Slettebak (1955)
439 ..	207826		2.73	F3 IV–V		.	
480	224355	9059	12.16	Normal	F5 IVn	.	

These fall into two groups of periods. One group, represented here by only β Ari, has periods greater than about 100 days (in fact, this star determined the breakpoint as being about 100 days rather than 75 or 150 days). Further examples, such as the fourteen new binaries discovered by Abt (1965), were found subsequent to the publication of the *Fifth Catalogue.*

The second group in Table 3 comprises normal binaries of very short period ($<2^{d}5$); they are contact or semidetached systems. Their spectra may not be completely normal; hence the discrepancies between the various classifications. That these short-period binaries have normal, rather than metallic-line, spectra has a straightforward explanation if one attributes metallic-line spectra to slow rotation and normal spectra to rapid rotation. Synchronism between orbital and rotational periods will probably occur in all systems with periods less than about a week, but whereas synchronism will cause a low rotational velocity ($V = 15$ km sec^{-1}) for a 7-day binary, it will cause a relatively high rotational velocity (90 km sec^{-1}) for a 1-day binary. In fact, three out of the five systems having periods less than $2^{d}0$ and listed in the second part of Table 3 have been classified as having nebulous lines, while two of the three systems with periods in the range $2^{d}0$–$2^{d}4$ were classified as having sharp lines at moderate dispersion. Consideration of their velocity amplitudes and periods shows that this difference is not due to systematically different orbital inclinations with respect to the lines of sight.

It is interesting that not all A4–F1 binaries on the main sequence and with periods less than $2^{d}5$ have normal spectra. Table 2 lists five such systems having Am primaries, some of which (HR 4646, δ Cap) are rather extreme examples. Why does the 1-day binary δ Cap have an Am primary while the 1-day binary 35 Psc has a normal primary? We can only guess at present that perhaps a low rotational velocity is a necessary but not sufficient condition to produce an Am star; perhaps the length of time during which the star has had the low rotation will determine whether the abundance peculiarities have had time to develop or decay. Nevertheless, rotational velocities for both normal and Am stars in binaries with periods less than $2^{d}5$ would be of interest.

Finally, we should mention three composite systems for which MK types are still not available, namely, τ Per (*Fifth Catalogue* No. 48), 58 Per (No. 75), and HD 144208–9 (No. 289). Since all three systems have periods greater than 100 days, it is irrelevant for the above argument whether the primaries fall within or outside the Am region and are Am or normal stars.

TABLE 2

SYSTEMS WITH AM OR PECULIAR PRIMARIES

Fifth Cat. No.	Name or HD No.	HR	Period (days)	Spectral Type WPB	Spectral Type WWM	Spectral Type Others	Sources and Comments
8	1826	..	3.28	Prob Am		.	
16	YZ Cas	192	4.47	Prob Am	..	A2 IV	Cowley *et al.* (1969)
44 .	16769	791	2.54	Def. Am	.	A4m	Appenzeller (1967); Cowley *et al.* (1969): A5 III
53 .	20210	976	5.54	Def Am	...	Am	Osawa (1959): $K/H/M$=A2/A8/F2; Cowley *et al.* (1969): A1m
56	IW Per	1078	0.92	Prob. Am	..	A3 V	Osawa (1959): M= A6; Cowley *et al.* (1969): A5m
72 .	63 Tau	1376	8.42	Pron Am		Am	Roman *et al.* (1948): $K/H/M$=A1/F0/F5; Cowley *et al.* (1969): A1m
73	28204	1401	4.20	Pron Am	.	A8m	Cowley *et al.* (1969)
76 .	88 Tau	1458	3 57	.	. .	Am	Slettebak (1949): $K/H/M$=A3/A7/A8; Cowley *et al.* (1969): A5m
80 ..	30453	1528	7.05	Pron Am	.	A4m	Appenzeller (1967); Cowley *et al.* (1969): A8m
92 .	14 Aur	1706	3.79	Poss. Am	F0 IVp?	..	WWM: like δ Del?; Cowley *et al.* (1969): δ Del
122 ..	2 Mon	2108	9.36	Am	..	. .	Bidelman (1951): K/M=A5/F0 III; Cowley *et al.* (1969): A6m
124 .	μ Ori A	2124	4 45	Prob. Am	.	Am	Slettebak (1954): K/M=A3/A7; Cowley *et al.* (1969): A2m (mild)
127	40 Aur	2143	28.28	Def. Am	.	A4m	Cowley *et al.* (1969)
132	RR Lyn	2291	9.94	Def. Am		Am	Roman (1949): H/M =A7/F0; Cowley *et al.* (1969): A3m
135	WW Aur	2372	2.53	Def. Am	.	A3m+A3m	Cowley *et al.* (1969)
156 .	α Gem B	2890	2.93	..	..	Am	Roman *et al.* (1948): $K/H/M$=A1/A5/A5; Cowley *et al.* (1969): A1m
175	71973	3352	4.28	Pron Am	.	A2m	Cowley *et al.* (1969)
179...	73619	.	12.91	Pron. Am	..	..	Bidelman (1956): K/M=A4/F2 III
207 .	93075	.	1 81	Prob. Am	A9 IVs	..	WWM: λ4226 weak?
210 .	64 Leo	4322	40.45	Prob. Am	..	A5 V	Osawa (1959); Cowley *et al.* (1969): A5m
221 .	102660	4535	2.78	Pron. Am	.	Am	Osawa (1959): $K/H/M$=A2/A7/F3; Cowley *et al.* (1969): A3m
229	106112	4646	1.27	Def. Am	.	Am	Roman *et al.* (1948): $K/H/M$=A5/F2/F5; Cowley *et al.* (1969): A5m
234 .	108642	4750	11.78	Def. Am	A2m F0	.	WWM: K/M=A2/F0, standard Am star

TABLE 2—*Continued*

Fifth Cat. No	Name or HD No.	HR	Period (days)	Spectral Type WPB	WWM	Others	Sources and Comments
235 .	24 Com B	4791	7.34	Def. Am	A5m F2	...	WWM: K/M=A5/F2, standard Am star
238...	110326	...	2.70	Pron. Am	...	Am	Slettebak *et al.* (1961): $K/H/M$=A3/A8 V/F0
239 .	32 d² Vir	4847	38.32	Def. Am	...	Am	Roman *et al.* (1948): $K/H/M$=A6/F2/F6 IV; Cowley *et al.* (1969): A8m
264.	125335	.	7.37	Am	...	...	Bidelman (1951): K/M=A5/F2 III
265 . .	λ Vir	5359	(1.93)	Prob Am	..	Am	Slettebak (1949): $K/H/M$=A3/A8/A7; Cowley *et al.* (1969): A2m
276.. .	136403	5702	3.58	Prob. Am	..	Am	Osawa (1959): $K/H/M$=A3/A7/F0; Cowley *et al.* (1969): A2m
279....	β CrB	5747	10.50 yr	Fp	...	...	
280 . .	138213	5752	105.8	Pron. Am	...	A5m	Cowley *et al.* (1969)
282 . .	TW Dra	.	2.81	Normal	A8m F2s?	...	WWM: λ4226 weak
292..	144426	5992	8.86	Prob. Am	...	A3m:	Cowley *et al.* (1969)
300 ...	149420	..	3.39	Prob. Am	A9 IVsp	...	WWM: λ4226 weak
327...	161321	6611	3.89	Def. Am	...	A3m	Cowley *et al.* (1969)
340...	108 Her	6876	5.51	Def. Am	..	A6 V	Osawa (1959); Cowley *et al.* (1969): A5m
350....	171653	6979	14.34	Def. Am	...	A8m:	Cowley *et al.* (1969)
352 ...	ζ Lyr A	7056	4.30	Def. Am	...	Am	Roman *et al.* (1948): $K/H/M$=A4/A7/F0; Cowley *et al.* (1969): A4m
355.. .	174343	..	3.76	Def. Am	F0m F5n	...	WWM: late-type broad-lined Am star? Very strong metallic lines and λ4077
377 ...	2 Sge	7369	7.39	Prob. Am	...	A2 III?	Osawa (1959): M=A3; Cowley *et al.* (1969): A1m: (metals marginally enhanced)
407....	26 Vul	7874	11.09	Prob. Am	A6 IVsp?	...	WWM: lines much stronger than in any standard, definitely peculiar
409....	ι Del	7883	11.04	Prob. Am	...	A2 V	Osawa (1959): M=A4; Cowley *et al.* (1969): A2 V
424....	204188	8210	21.72	Def. Am	...	A8m:	Cowley *et al.* (1969)
431.. .	206546	8293	6.37	Pron. Am	...	A3m	Cowley *et al.* (1969): broad lines
436....	δ Cap	8322	1.02	Def. Am	..	Am	Slettebak (1949): $K/H/M$=A6/F2/F5 IV; Cowley *et* al. (1969): δ Del
445....	32 Aqr	8410	7.83	..	...	Am	Roman *et al.* (1948): $K/H/M$=A3/A7/F0; Cowley *et al.* (1969): A5m, metals pronounced
469....	9 And	8864	3.22	Def. Am	...	A7m:	Cowley *et al.* (1969)

TABLE 3

SYSTEMS WITH NORMAL PRIMARIES IN THE AM REGION

FIFTH CAT. No.	NAME OR HD No.	HR	PERIOD (days)	SPECTRAL TYPE WPB	WWM	Others	SOURCES AND COMMENTS
				Systems with Long Periods			
32 ...	β Ari	553	107.00	..	A5 V	A5m:	Johnson and Morgan (1953); Cowley *et al.* (1969)
				Systems with Short Periods			
5 .	35 Psc	50	0.84	Normal	A9 V	. .	WWM: combined spectrum
14...	π Cas	184	1.96	Prob. Am	A5 Vn	...	
193....	S Ant	3798	0.65	Normal	A9 Vn	...	
242	UY Vir	...	1.99	Prob Am	A9 V	A7 V	Roman (1956)
325..	ξ Ser	6561	2.29	Poss Am	.	F0 IV	Buscombe (1962); Cowley *et al* (1969): F0 IV
337. .	168092	6849	2.05	Normal	F0 IV:s	.	WWM: equal components, both sharp lined
......	204038	.	0.79	F0n III–IV	F0 Vn	. .	WWM: like γ Her (A9 III); Fitzgerald (1964)
454 .	213534	8584	2.34	Poss. Am	A9 IV?s	A8 V	Cowley *et al.* (1969)

We can now restate the results, in part, on binaries among A-type stars, namely, all stars in the approximate spectral range A4–F1 on the main sequence and that are primaries in binaries with periods between approximately 2.5 and 100 days have metallic-line or peculiar spectra.

We have been careful to state that these results on binaries refer to the primary stars, so we immediately wonder about the secondaries. Are the secondaries also Am stars and are their spectral peculiarities similar to those of the primaries? The first author and his colleagues are currently studying numerous double-lined systems to help answer these questions. What are the spectral characteristics if the primary is in the A4–F1 region but the secondary is of later type, or the secondary is in that region and the primary is earlier? What are the spectral characteristics of a binary with the period between 2.5 and 100 days and having one component in the A4–F1 range on the main sequence but the other component a giant? Such questions still need answers.

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