ANOMALOUS SPECTRA OF STARS OF CLASS A

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ABSTRACT

Objective-prism plates with a dispersion of 95 A/mm at $H\gamma$ have revealed 41 peculiar A stars and 8 metallic-line A stars. The material examined shows that, at low galactic latitudes, 13 per cent of the A stars between magnitudes 5.5 and 9.5 have spectra characterized by abnormal intensity of the lines of chromium, silicon, europium, or strontium.

I. INTRODUCTION

In the course of the classification of objective-prism spectra taken recently at the Harvard Observatory, I have found a number of A stars with anomalous spectra. The plates were taken as part of a program designed to adapt the Morgan-Keenan-Kellman system of spectral classification to objective-prism spectra. The spectra, taken with the 12-inch Metcalf doublet (the MA) equipped with a crown-glass objective prism of 12°, have a dispersion of 95 A/mm at $H\gamma$. Experiment showed that Eastman emulsion II*a*-O and development in DK20 for 15 minutes at 65° gave spectra of highest quality. Three luminosity classes can be assigned to most spectra obtained in good seeing, but a detailed luminosity classification of the A stars is possible only on plates of superior quality. On the other hand, certain peculiar features are very marked, and these are easily distinguished from luminosity effects on all plates.

II. THE PECULIAR A STARS

The spectra of the peculiar A stars (as distinguished from the metallic-line stars) appearing on the MA plates fall into three groups, which are characterized by the element that gives rise to the most marked anomalous feature. These groups—the silicon, the chromium-europium, and the strontium stars—are represented by prototypes which have been described in detail by Morgan.[1]

Table 1 contains a list of the 41 peculiar A stars detected on the MA plates; only 2 of these stars were previously known to be peculiar. The first five columns of the table require no explanation. The photovisual magnitude in the sixth column is taken from the *Henry Draper Catalogue* when the star is included in that catalogue; otherwise it is taken from the BD catalogue. The new spectral type is based on the intensity of the K line relative to the near-by Balmer lines. Since this line is weak in nearly every case, all the stars, with one exception, have been designated either B9 or A0. This classification is not altogether satisfactory, since it conveys very little information about the general appearance of the spectrum. The descriptions in the notes which follow the table are more informative. Following to some extent the notation adopted by Deutsch,[2] I define, below, the symbols describing the peculiar features listed in the table:

"*Cr*" means that λ 4077 and λ 4171 of *Cr* II are strong.
"*Sr*" means that λ 4077 and λ 4215 of *Sr* II are strong.
"λ 4200" means that this unidentified line is strong.
"*Eu*" means that *Eu* I is implied by the fact that the general features of the spectrum match a typical chromium-europium star.
"*Si*" indicates that the blend at λλ 4128–4131 is strong and that the general features of the spectrum correspond to a typical silicon star.

[1] Morgan, Keenan, and Kellman, *An Atlas of Stellar Spectra* (Chicago: University of Chicago Press, 1943); W. W. Morgan, *Ap. J.*, **77**, 77, 1933; *ibid.*, **74**, 24, 1931.

[2] *Ap. J.*, **105**, 297, 1946.

TABLE 1

LIST OF PECULIAR A STARS

MEW No.	HD No.	BD No.	α (1900)	δ (1900)	m_{pv}	HD Type	MEW Type	Peculiar Features
1.....	5797	+59° 163	$0^h54^m.5$	+59° 55′	8.8	A0	A0p	*Cr*, *Eu*, *Sr*
2.....	....	+57 184	0 57.0	+57 43	9.0	......	B9p	*Si*
3.....	7370	+60 194	1 8.8	+60 20	8.66	A	B9p	*Cr*, *Eu*
4.....	17775	+61 495	2 46.1	+61 28	8.8	A0	A0p	*Cr*, *Eu*
5.....	....	+58 538	2 50.7	+58 50	9.0	......	B9p	*Si*
6.....	18473	+59 582	2 53.1	+59 17	7.35	A0	B9p	*Si*, λ 4200
7.....	....	+59 597	3 1.4	+60 4	9.2	......	B9p	*Si*, λ 4200
8.....	19653	+60 640	3 4.8	+60 26	8.9	A0	B9p	*Cr*, *Eu*, *Sr*
9.....	22374	+22 518	3 31.0	+22 54	6.69	A0p	B9p	*Cr*, *Eu*
10.....	29580	+44 1006	4 34.4	+44 19	8.0	B9	B9p	*Si*, λ 4200
11.....	30584	+44 1036	4 43.8	+44 47	8.0	B9	B9p	*Si*, λ 4200
12.....	....	+43 1092	4 43.9	+43 40	9.0	......	B9p	*Si*, λ 4200
13.....	35479	+29 893	5 19.9	+29 54	8.06	B9	B9p	*Si*, λ 4200
14.....	44636	+15 1175	6 17.7	+15 55	8.7	B9	B9p	*Cr*, *Eu*
15.....	44738	+14 1276	6 18.3	+14 10	7.3	A0p	A0p	*Si*, λ 4200
16.....	49713	− 1 1395	6 44.7	− 1 13	7.7	A0	B9p	*Cr*, *Eu*
17.....	171279	− 7 4623	18 28.8	− 7 47	7.22	A0	B9p	*Cr*, *Eu*
18.....	....	+14 3854	19 12.0	+14 27	8.7	......	A0p	*Cr*, *Eu*
19.....	182381	+15 3798	19 19.3	+15 49	7.42	A2	B9p	λ 4128, λ 4131
20.....	189394	+34 3817	19 54.7	+34 14	8.2	A0	B9p	λ 4128, λ 4131
21.....	190275	+37 3735	19 59.1	+37 32	7.16	A2	A5p	λ 4144, λ 4272
22.....	192606	+34 3934	20 10.6	+35 6	8.42	A2	B9p	*Si*, λ 4200
23.....	193344	+35 4059	20 14.7	+35 56	8.0	B9	B9p	*Cr*, *Eu*
24.....	196178	+46 2977	20 30.6	+46 21	5.59	B9	B8p	*Si*, λ 4200:
25.....	197374	+43 3687	20 38.2	+43 28	8.5	A0	B9p	*Si*
26.....	....	+29 4202	20 46.6	+29 26	8.8	......	A0p	*Cr*, *Eu*
27.....	....	+45 3303	20 47.6	+45 40	9.2	......	B9p	*Cr*, *Eu*
28.....	200177	+48 3260	20 56.8	+48 17	7.08	A0	B9p	*Cr*, *Eu*
29.....	200311	+43 3786	20 57.6	+43 19	7.9	A0	B9p	*Si*, λ4200
30.....	200369	+46 3144	20 58.0	+46 48	8.9	A2	A0p	*Cr*, *Eu*
31.....	201174	+44 3701	21 2.8	+44 52	8.5	A2	A0p	*Cr*, *Eu*, *Sr*
32.....	208340	+52 3056	21 50.6	+52 30	8.7	A0	B9p	*Cr*, *Eu*
33.....	....	+45 3736	21 52.7	+45 40	8.7	......	B9p	*Cr*, *Eu*
34.....	209308	+53 2766	21 57.3	+53 41	9.3	B9	B9p	*Si*, λ 4200:
35. ...	209515	+43 4119	21 58.9	+44 10	5.52	A0	B9p	*Cr*, *Eu*
36.....	209664	+44 4031	22 0.0	+44 47	8.6	A	B9p	*Cr*, *Eu:*
37.....	210071	+55 2679	22 2.7	+55 51	6.22	B9	A0p	*Cr*, *Eu:*
38.....	....	+52 3127	22 6.7	+52 19	9.4	......	B9p	*Cr*, *Eu:*
39.....	219855	+57 2719	23 14.0	+57 38	8.0	A0	B9p	λ 4128, λ 4131
40.....	220147	+61 2430	23 16.4	+61 52	7.6	A0	B9p	*Cr*, *Eu*
41.....	221568	+57 2758	23 28.1	+57 21	8.0	A0	A0p	*Cr*, *Eu*

NOTES TO TABLE 1

1. On one of the better plates both *Sr* II 4077 and *Sr* II 4215 are very strong, while on another plate of nearly equal quality these lines are weaker, especially λ 4215, which is very weak or entirely absent. This suggests that the star is a spectrum variable.

8. The spectrum of this star resembles that of χ Serpentis, though the feature at λλ 4128–4131 is stronger. Except for the Balmer lines, the *Sr* II lines λ 4077 and λ 4215 are the most prominent features in the spectrum. The line at λ 4161, which may possibly be due to *Sr* II, is present. The weakening of λλ 4077, 4161, and 4215 on two of the four plates, all of relatively high quality, suggests that this star is a spectrum variable. When *Sr* II 4215 is compared with *Cr* II 4171, it is found that it appears considerably stronger on two plates and equal or slightly stronger on the other two.

9. Certain changes indicate spectral variability, though neither of the two spectra available is of sufficient quality to establish variability.

15. The lines λ 4026 and λ 4077 also appear, but they are not strong.

17. The spectrum of this chromium-europium star is similar to that of BD −18°3789 at phase 0.38 day. Strong lines appear at λλ 4077, 4128–4131, 4171; a fainter one seems to be present at λ 4179. The char-

NOTES TO TABLE 1—*Continued*

acteristic asymmetry of $H\gamma$, $H\delta$, and $H\epsilon$, which is produced by blends on the red side of these lines, is very marked. The K line is very weak, corresponding approximately to class B9.

19. Inferior spectrum. *He* I 4026 present.

21. The peculiarities of the spectrum of this star are so unusual that it is not possible to place it in any of the groups described previously. The K line is weak relative to the general development of the spectrum; it corresponds approximately to class A5. The metallic lines are, in general, strong, corresponding to class A7 or F0. A blend at λ 4272 and a line at λ 4144 are even stronger than the corresponding features in the F0 stars. The unusual strength of these latter two features makes one suspect that the spectrum is a composite, but it is hard to understand what types could combine to produce this anomaly. The spectrum appears on four plates.

23. The spectrum resembles very much that of BD $-18°3789$ at the phase 0.38 day, where the *Cr* II lines at λ 4077 and λ 4171 and the line at λ 4179 are at maximum strength. The blend at λλ 4128–4131 is strong; the K line is very weak.

33. The spectrum, with peculiarities at λλ 4063, 4077, 4128–4131, and 4171, resembles that of BD $-18°3789$. The relative intensity of λ 4063 and λ 4077 is not the same on two of the plates. While the spectra on these plates are not comparable, it is almost certain that they give evidence of variation.

36, 37, 38. The inferior quality of the spectra of these stars permits only an indication of the type of peculiarity; hence the classification should be considered provisional.

39. The blend at λλ 4128–4131 is not very strong but probably sufficiently so to qualify this star as peculiar.

41. There is some indication that the intensities of λ 4171 and the K line vary, but this observation is subject to confirmation.

The classifications given are provisional and subject to modification when slit spectra are available.

Peculiarities occurring in the spectra of A stars are immediately apparent, but it is often difficult to identify the ions responsible for the peculiarities in a given spectrum. Certain peculiarities are so pronounced that they may be detected even when the quality of the spectrum is inferior. This is especially true of the blend at λλ 4128–4131, which is so frequently recorded in the *Henry Draper Catalogue* as the only peculiar feature. The high percentage of silicon stars doubtless arises, in part at least, from the fact that λλ 4128–4131 appears when many of the other fainter features, such as λ 4077 and λ 4171, are washed out. Data from the *Henry Draper Catalogue* reveal that 114 of the 188 peculiar A stars in this catalogue belong to the group of silicon stars.

In general, the strength of the blend near λ 4130 is attributed to the silicon doublet at λ 4128 and λ 4131. Certainly, one can assume this to be true when the remainder of the spectrum resembles a typical silicon star, such as BD$+33°1008$ Aurigae, in which λ 4200 is strong and *Ca* II K corresponds to class B9. On the other hand, one of the stronger europium lines, *Eu* II 4129, may contribute to the strength of the blend at λλ 4128–4131. Actually, none of the strongest lines of europium, at λλ 3930, 4129, and 4205, has been detected in any of the spectra thus far examined. However, when both λλ 4128–4131 and λ 4171 appear as prominent features and the spectrum resembles that of a typical chromium-europium star like 78 Vir, the existence of features due to europium is implied. I have, therefore, designated a star as belonging to the chromium-europium group if the spectrum resembles that of 78 Vir.

The intensity of the feature at λλ 4128–4131 differs greatly from one silicon star to the next. In fact, in accordance with Morgan's previous observation,[3] it appears from the MA plates that the intensity of the feature at λλ 4128–4131 in the silicon stars deviates only in various degrees from that of a normal A star. In the case of some stars it was difficult to decide whether or not they should be classified as peculiar; in others the peculiarities are very pronounced. Most of the doubtful cases have not been included in Table 1. The chromium-europium and strontium stars, on the other hand, seem more likely to form discrete groups.

It would be well to emphasize that there exists very little possibility of confusing the

[3] *Pub. Yerkes Obs.*, **7**, Part III, 7, 1934.

highly luminous A stars with the chromium-europium stars. In the spectra of both types there are features at approximately λ 4130 and λ 4171, but they have distinctly different appearances in the two types. In the chromium-europium star, λλ 4128–4131 is definitely a strong blend, and λ 4171 is a fairly narrow line due to *Cr* II. On the other hand, in the supergiant the blend at λλ 4128–4131 is relatively weaker and narrower, and the feature near λ 4171 consists of two strong *Fe* II lines at λ 4173 and λ 4178. The line at λ 4077, which is strong in the chromium-europium stars, is so faint that it is hardly visible in the supergiants of classes A0 and A2. The hydrogen lines also are very different in the two types of stars under consideration. They are narrow and weak in the highly luminous stars; in the chromium-europium stars they are wide and strong, and some appear asymmetric. The K line, on the other hand, is relatively stronger in the supergiants than in the peculiar A stars of corresponding spectral type. Only on inferior plates could these spectral features be so distorted that the difference would not be evident.

Table 1 includes three stars that seem likely to be spectrum variables and two others that show indications of variability. Two of the first three, BD+59°163 and BD+60°640, belong to the chromium-europium-strontium group. For both of them it is the strong strontium lines at λ 4077 and λ 4215 which give evidence of variability. The third one, BD+45°3736, appears to be a spectrum variable similar to BD−18°3789.[4] In the case of the other two stars—BD+22°518 and BD+57°2758, both chromium-europium stars—the observations are less convincing. For each of the stars the spectral variations should be confirmed with slit spectra which show more detail. In general, objective-prism plates are not satisfactory for studying spectral variations, especially when these variations are not very pronounced.

III. FREQUENCY OF PECULIAR A STARS

Of the A0 and A2 stars brighter than the sixth magnitude (app. m_{pv}), the *Henry Draper Catalogue* lists 11 per cent as peculiar. The frequency of A stars in the *HD Catalogue* decreases to 3 per cent for stars between 6.0 and 7.0 mag., and to less than 1 per cent for stars between 7.0 and 8.0 mag. This rapid decrease in frequency is certainly a selection effect. The MA plates reveal that many more of the faint early A stars, including classes B9–A3, are peculiar. All the regions listed in Table 2 are very close to the galactic circle. In the fourth column there is given for each of the regions the total number of stars classified on the MA plates in the spectral classes B9, A0, A1, A2, and A3; in the last column are the corresponding counts of the peculiar A stars. Table 2 does not include all the peculiar A stars in Table 1, since some of them are in regions for which the classifications are not complete. The stars range in magnitude from 5.5 to 9.0, but the material is probably only relatively complete down to 8.5. Although it would be difficult to be certain that the counts are complete to any given magnitude, it is reasonable to assume that the classifications and counts are comparable in the degree of completeness for both the total number of B9–A3 stars and the number of peculiar A stars. From these data it follows that 13 per cent of the A stars at low galactic latitudes are peculiar. Since the data are rather scanty, the actual percentage must be recognized as preliminary.

IV. METALLIC-LINE A STARS

Although the metallic-line A stars have been noted for their peculiarities since the earliest work on spectral classification at Harvard, Titus and Morgan[5] were the first to recognize that these stars form a fairly homogeneous group. Usually, though not always, Miss Cannon classified these stars as composites. Miss Maury first described the characteristics of the composite spectra.[6] These puzzling spectra usually represent a

[4] Deutsch, *op. cit.*, p. 285.

[5] *Ap. J.*, **92**, 259, 1940.

[6] *Harvard Ann.*, **28**, Part I, 48–49, 1897.

combination of a late-type and an early-type star with strong hydrogen lines. When these lines appear in a spectrum which is otherwise a later type, the K line is invariably narrow and obscure. If the hydrogen lines are very strong, the K line appears as a shallow band, sometimes having a fine central core. The lines characteristic of the late type disappear from the ultraviolet, while they are strong in the interval from $H\beta$ to $H\delta$. In the metallic-line A stars, on the other hand, the metallic lines appear throughout the whole spectral range used. The K line in the two types of spectra is entirely different. In the composite spectrum the K line is broad and fuzzy, while in the metallic-line A stars it is sharp and distinct. These characteristics usually suffice for distinguishing these two types of spectra.

TABLE 2

COUNTS OF A STARS IN THE MILKY WAY

Region	Co-ordinates of Region Center		Total No. of B9–A3 Stars	No. of Peculiar A Stars
	α (1900)	δ (1900)		
SA 8	1^h03^m	+60°0′	26	2
SA 9	3 08	+60.5	23	6
SA 24	4 45	+45.0	23	3
SA 49	5 27	+29.7	7	1
Scutum Cloud	18 38	− 7.0	2	1
SA 110	18 39	+ 0.1	10	0
SA 87	19 13	+15.0	17	2
SA 64	20 00	+30.5	12	0
Cygnus Cloud	20 08	+36.0	12	3
SA 40	20 45	+45.0	30	7
SA 65	20 58	+30.2	10	1
SA 41	21 52	+45.2	30	3
	22 01	+53.9	39	3
SA 19	23 25	+60.0	21	3
Total			262	35

The criteria that I have used in distinguishing the metallic-line A stars from other anomalous A stars follow closely those set forth in a recent report from the Yerkes Observatory.[7] Since the present study was nearly completed at the time that this report came out, I did not find it possible to use the list of standards published. While there seem to be fundamental differences between the metallic-line and peculiar A stars, there is occasionally a star whose spectral features at low dispersion do not place it definitely in either category. Two of these stars whose classifications are uncertain are included in Table 3, which lists the metallic-line stars discovered on the MA plates. My two classifications depend, respectively, on the relative intensities of H and K and on the strength of the other metallic lines. The notes following the table indicate precisely what the observed peculiarities are.

Most of the stars in the spectral range A0–F0 are classified primarily on the basis of the relative strength of K and H + $H\epsilon$; consequently, many classifications do not depend on the rest of the spectrum. Unless the spectra are of superior quality, it is unlikely that the anomalous strengths of the metallic lines would be apparent. It follows that many of the metallic-line A stars may not be detected.

For the stars listed in Table 3, the feature at λ 4077 is strong in every spectrum except in that of BD+59°621, in which it does not appear. If λ 4215 were also strengthened,

[7] N. G. Roman, W. W. Morgan, and O. J. Eggen, *Ap. J.*, **107**, 107, 1948.

one might be inclined to assign these stars to the strontium group of peculiar stars. The line λ 4215, however, appears normal in every star in which λ 4077 is strengthened. Several of the stars, notably BD+30°3875, BD+43°3789, and BD+28°787, substantiate the reciprocal relation between *Ca* II K and λ 4077 recognized by Weaver.[8]

References[7] are occasionally made to spurious absolute-magnitude effects apparent in the metallic-line A stars, but in no case are the features which show these effects specified.

TABLE 3

LIST OF METALLIC-LINE A STARS

MEW No.	HD No.	BD No.	α (1900)	δ (1900)	m_{pv}	HD Type	MEW Type (K Line)	MEW Type (Metallic Lines)
1	19342	+58° 564	$3^h\ 1^m.6$	+58° 22′	8.0	A2	A7	F0
2	20095	+59 621	3 8.7	+59 37	8.4	A0	B9	A5?
3	22538	+18 517	3 32.4	+19 1	7.67	A0	A5	F0
4	26039	+16 559	4 2.3	+16 16	7.52	B9	B9	A2?
5	35035	+28 787	5 16.7	+28 22	7.36	A3	A3	F0
6	43682	+16 1080	6 12.4	+15 59	8.3	A2	A5	F0
7	190537	+30 3875	20 0.3	+30 57	6.87	A2	A3	F0
8	200407	+43 3789	20 58.2	+43 47	6.72	A2	A5	F0

NOTES TO TABLE 3

1. *Sr* II 4077 and the blend λλ 4030–4034 are relatively strong for class F0. The ratio λ 4417: λ 4481 seems to indicate class V.

2. Although the K line is weak, corresponding to class B9, there are many other features which indicate a much later type. In the interval between $H\delta$ and $H\epsilon$ the lines and blends match those of an F0 star, except that λ 4077 does not appear. The lines between $H\gamma$ and $H\delta$ are faint, and it is not certain whether they correspond to those of an F star or not. While the lines between $H\beta$ and $H\gamma$ are faint, their positions seem to coincide with the lines of an F0 spectrum. Except for the failure of λ 4077 to appear, this star would qualify reasonably well as an early metallic-line A star. It is possible that this enigmatic spectrum is a composite.

4. The spectrum lies near the edge of the plate and is underexposed. The K line is very weak or absent; the metallic lines indicate spectral type A2 or later. The line λ 4077 is rather strong.

6. The quality of the spectrum prevents definite classification as a metallic-line star. The K line corresponds to A5, while the remainder of the spectrum corresponds nearly to class F0, though λ 4077 is abnormally strong.

7. *Sr* II 4077 is very strong. From the ratios λ 4444:λ 4481 and λ 4417:λ 4481 the star appears to belong to class V.

For the stars in Table 3 the usual ratios employed by Morgan, Keenan, and Kellman[9] in the luminosity classification of F0 stars indicate luminosity class V. In every case in which the ratio λ 4417:λ 4481 could be estimated, it corresponded to luminosity class V.

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[8] *Pub. A.S.P.*, **58**, 246, 1946.

[9] *Op. cit.*