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THE NATURE OF THE VISUAL COMPANIONS OF Ap AND Am STARS

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ABSTRACT

We have classified the stars in 43 visual multiples with Ap or Am primaries, and we count the fraction of systems that have Ap or Am secondaries. The numbers of Ap secondaries are too few to be informative, but we found an apparent excess of Am secondaries. That result is understandable in terms of the (published) moderate correlation in rotational velocities between components in visual multiples. But in various open clusters the variations in frequencies of Ap and Am stars can be explained probably as statistical fluctuations in small numbers of stars, indicating no tendency for abnormal stars to group together for dimensions larger than those of visual multiples.

Subject headings: clusters: open —stars: metallic-line — stars: peculiar A — stars: spectral classification — stars: visual multiples

I. INTRODUCTION

We are interested in knowing whether Ap (and Am) stars tend to occur together. There is some evidence that such associations occur in open clusters. Consider the clusters NGC 2516 and M39, both with nearly the same ages ($10^{8.1}$ and $10^{8.0}$ yr, respectively). The former has seven Ap stars (of Si, Hg-Mn, or Sr-Cr overabundances) out of 24 stars in the B4–F1 range, while the latter cluster has only one Ap star out of 17 stars. Or consider M39 that has five Am stars out of 17 stars in the B9–F1 range, while M34, of nearly the same age, has only one Am star out of 16. Or consider the many visual pairs such as 17 Com, ζ UMa, μ Lib, ν Dra, and 5 Aql that consist of Ap + Ap or Ap + Am or Am + Am stars. Do these statistics indicate that Ap (or Am) stars tend to occur together in some clusterings?

This is a study of the visual companions of Ap and Am primaries to see whether or not they also tend to be Ap and Am stars. Specifically, we have selected all the observable systems that have Ap or Am primaries and physical secondaries that are not more than 2 mag fainter. By observable we mean with declinations larger than $\delta = -30°$ and separations or orientations such that we could obtain separate spectra for the components. We observed all such systems in the Bertaud and Floquet (1974) catalog of Ap and Am stars, and we quote a few more recent types from Abt (1981) and Abt and Cardona (1983). An important point is that the selection was made without knowledge or consideration of the types of the secondaries.

II. CLASSIFICATION AND DISCUSSION

The spectra for 32 of the 43 systems were obtained with the Kitt Peak 2.1 m Cassegrain spectrograph at a dispersion of 39 Å mm^{-1} and width of 1.2 mm for stars brighter than $B = 9.0$ mag and half that width for fainter stars. They were classified on a Boller & Chivens spectra-comparator against standards by Morgan, Abt, and Tapscott (1978). The types for the remaining systems are quoted from Abt (1981) or other sources specified in the footnotes of Table 1.

The basic data are listed in Table 1 where the first column gives the ADS (Aitken 1932) numbers and components observed; the second and third give the HD numbers and other designations; and the fourth gives the classifications. It turned out that in seven cases the primaries are judged to be normal, so those systems are not useful for this study. Our agreement with classifications by other people is good, but marginal cases arise where one person classified a star as abnormal (or normal), and another judges it otherwise. Our main reasons for using our types over those of others are that our spectra are much wider and of higher dispersion (which is an aid for classifying abnormal spectra but not necessarily for normal spectra of various rotational broadenings).

Table 1 contains 19 systems with Ap primaries. Of their 17 secondaries that are in the spectral range (B4–F1) of the Ap stars, only one (ADS 13831B) has an Ap spectrum. Since the 17 primaries have an average age of $\leq 10^{8.5}$ yr (see Abt and Cardona 1983 for the calibration assumed), we would predict 14.5% of the secondaries (if we use the results from open clusters) or 17.6% (for results from visual multiples) to be Ap stars if there is no correlation between secondary and primary types. These percentages give predictions of 2.5–3.0 Ap secondaries, compared with one observed. We also observe six Am secondaries, whereas data from large numbers of field stars (Abt 1981) indicate that 5% of the A0–A3 and 32% of the A4–F1 dwarfs should have Am spectra. Those frequencies translate to 2.6 Am secondaries predicted if there is no correlation between secondary and primary types. These numbers are given in Table 2.

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TABLE 1

SPECTRAL CLASSIFICATIONS

ADS	HD	Name	Classification
104A	416		F1 IV
B	....		F7 V
582A	3891		B9.5 Vp(Sr,Si)s
B	....		A1 Vs
1507A	11502	γ^2 Ari	A2 IVp(Si,Sr,Cr st; Ca wk)
B	11503	γ^1 Ari	B9.5 Vn
1615A	12447	α Psc	A0 p(Si,Sr)[a]
B	12446		A3m[a]
2115A	17198		A5 V + G5 III
B	....		A1 V
....A	18473		B7 Vp(Si v.st;He wk)
B	....		B9.5 V
2592A	21769	HR 1068	Am(K/H/M=A3/A7/F0)
B	....		F2 V
3318A	29173	HR 1460	Am(K/H/M=A1/A6V/A7)
B	29172		A8 V
3468A	30584		A0 II-IIIp(Si)
B	....		B9.5 V
3824A	33959	14 Aur	A9 V
C	....		F4 V
6915A	73618		Am[b]
C	73619		Am[b]
7093A	76370	17 Hya	A2m[a]
B	76369		A7m[a]
7662AB	88021,2		Am(K/H=A2/F1)+F5 III
7705A	88849	HR 4021	Am(K/H/M=A4/F1/F2)
B	88850		Am(K/H/M=A5/F0/F1)
8568A	108662	17 Com	A1 IVp(Sr,Cr st; Ca wk)
B	108651	HR 4751	Am(K/H/M=A2/A9V/F0)
8690A	111845		Am(K/H/M=A3/F0V/F2)
B	111844		F8 V
8701A	112310		F4: V
B	....		F8 V
8706A	112413	α^2 CVn	A1 IV-Vp(Si v.st; Ca v.wk)
B	112412	α^1 CVn	F1 V
8714A	112515		F3 IV
B	....		F6 V
8891A	116656	ζ UMa	A1 Vp(Sr,Si)
B	116657		Am(K/H/M=A1/A2/A7)
... A	120710	3 Cen	B5 IIIp(P)[c]
B	120710		B9 V[d]
9338A	129174	π^1 Boo	B9 IIIp(Hg,Mn,Si)
B	129175	π^2 Boo	A6 V
9396A	130559	μ Lib	A0 III:p(Sr,Cr)s
B	....		Am(K/H/M=A2/A6/A8)s
9477A	133029	BX Boo	A0 Vp(Si v.st, Sr, Cr st; Ca wk)s
B	....		F4 V
9853AB	144463		Am(K/H/M=A3/A8V/F2) + F6: V
10526A	157779	ρ Her	B9.5 IIIp(Si)
B	157778		A0 Vn
10628A	159560	ν^2 Dra	Am(K/H/M=A4/F2V/F3)
B	159541	ν^1 Dra	Am(K/H/M=A4/F1V/F1)
11639A	173648	ζ^1 Lyr	Am(K/H/M=A5/F0V/F3)
D	173649	ζ^2 Lyr	A8: Vn
11667A	173654	5 Aql	Am(K/H/M=A1/A7V/A7)
B	....		Am(K/H/M=A5/F1/F2)
12019A	178001	BH Dra	A0 V
B	....		Am(K/H/M=A1/A8V/A8)
12594A	184360		Am(K/H/M=A3/A8V/A8)
B	....		F3 Vs
12893A	186901	HR 7529	B9.5 Vp(Si)s
B	186902		A0 Vn
13506A	191984	HR 7717	A0 V
B	....		A0 Vp(Sr,Cr st; Ca wk)
13813A	194613		A0 II-IIIp(Si)
B	....		A0 III-IVp(Si)
14068A	196542		A6 Vp(Sr v.st; Cr st; Ca wk)
B	....		Am(K/H/M=A5/F2/F3)
14682A	201433	HR 8094	B9 Vp(Si)s
B	....		Am(K/H/M=A2.5/A7V/A9)n
14710A	201671	HR 8101	Am(K/H/M=A0/A2V/A2)
B	....		A4 V
15407A	208132	HR 8361	Am(K/H/M=A1/A9V/F0)
B	....		Am(K/H/M=A2/A6/F2)
15493A	208718		Am(K/H/M=A2.5/A8:/F2)
B	....		F1 V
15600A	209790	ξ Cep	Am(K/H/M=A3/F1/F2)
B	209791		F7 V[d]
15951A	212939		A0 IIIp(Si)
C	....		B8 V
17020AB	223358		A2 Vp(Sr,Si st;Ca wk)
C	....		B9 IV
17090A	223991	HR 9044	Am(K/H/M=A1/A8V/F0)
B	....		Am(K/H/M=A1/F1/F0)

[a] Cowley *et al.* 1969.
[b] Bidelman 1956.
[c] Bidelman 1960.
[d] Slettebak 1963.

Turning to the 17 systems in Table 1 with Am primaries, none have Ap secondaries. That is not surprising because most of the primaries are basically late A stars as judged by their hydrogen types, and fainter companions would be outside the region of most Ap stars. But seven of the secondaries have Am spectra. If there were no correlation between primary and secondary types, we would predict 3.8 Am secondaries. These results are also listed in Table 2.

What can we conclude from the results in Table 2? Unfortunately the numbers of observed and predicted Ap secondaries are too small for us to reach any conclusions beyond a rough indication of consistency. The observed numbers of Am secondaries (13) are 1.8 σ above the expected number (6.4), giving marginal evidence for an excess. A 2×2 contingency test shows that the frequency of Am secondaries to be excessive at an 85% confidence level, which is only partly convincing.

An excess of Am secondaries would be reasonable because of the following logic. Field Ap and Am stars have systematically lower rotational velocities (Abt, Chaffee, and Suffolk 1972; Abt 1975) by factors of 4 than normal stars, both in average values and in upper limits (about 100 km s^{-1} for Ap and Am stars). This means that Ap and Am primaries are genuinely slow rotators beside having sharp lines. Statistically none of the normal stars of these types have slow rotational velocities. But Steinitz and Pyper (1970) and Bernacca (1972) found a moderate correlation in rotational velocities between the primaries and secondaries of visual multiples. The Steinitz and Pyper correlation coefficient of 0.46, compared with 0.001 if components are matched at random, is more appropriate for the present study because they did not exclude abnormal stars. Whether a low rotational velocity is a cause or a consequence of the abnormal composition is still a moot question—the former hypothesis is more likely due to magnetic braking (in Ap stars) and tidal braking in binaries (in Am stars). But if there is a moderate correlation between the primary and secondary rotational velocities, we would expect Ap and Am primaries to tend to have Ap and Am secondaries. The Am secondaries are consistent with the correlation. Thus, the many known cases listed in the first paragraph of this paper of Ap + Am and Am + Am systems is understandable.

What can we say about open clusters with seemingly large or small fractions of Ap and Am stars? First, are they really significantly different or are they simply statistical extremes? In Table 3 we list the eight open clusters with log age = 8.0 ± 0.5 as discussed in Abt (1979). We limit the clusters to that narrow range of ages because the frequencies of Ap stars are age-dependent (Abt 1979). The third and fourth columns give the numbers of stars in the range (B4–F1) of the Ap stars and the observed numbers of Ap stars, respectively. If the frequency of Ap stars was 12.9% in each cluster as it is for the average of the eight clusters, we derive the predicted numbers of Ap stars listed in the last column. If we define the individual probable errors as the square roots of the observed numbers, the average observed *minus* predicted number is 0.8 p.e., indicating that the scatter is entirely statistical. If we conduct a χ^2 test, we find that the distribution in Table 3 differs from random statistics at only a 60% confidence level, which is far from significant.

In Table 4 we list the observed and similarly predicted numbers of Am stars in the range B9–F1 in 14 clusters (Abt 1979). We can use the whole range of cluster ages here because the frequency of Am stars does not seem to be age-dependent for ages $> 10^6$ yr (Abt 1979). We find that the observed *minus* predicted numbers average 0.94 p.e., indicating that the scatter is statistical. A χ^2 test shows the distribution in Table 4 to differ from random at an 82% confidence level, which is not significant. Therefore, clusters such as NGC 2516 or M39 with large or small frequencies of Ap or Am stars are probably simply statistical extremes that are not significantly different than the frequencies for the other clusters.

There seems to be an inconsistency here: whereas Am stars tend to have Am visual companions at twice the normal rate, the occurrence of Am stars in clusters does not lead to additional Am stars. But there may be a reasonable explanation

TABLE 2

OBSERVED AND PREDICTED Ap AND Am SECONDARIES OF Ap AND Am PRIMARIES

SECONDARIES		PRIMARIES Ap (19)	Am (17)
Ap	Observed	1	0
	Predicted	2.5	0
Am	Observed	6	7
	Predicted	2.6	3.8

TABLE 3

OBSERVED AND PREDICTED NUMBERS OF Ap STARS IN EIGHT OPEN CLUSTERS

Cluster	Log Age (yr)	Number of Stars	Number of Ap	Predicted Ap (12.9%)
IC 4665	7.5	18	1	2.3
Pleiades	7.7	33	4	4.3
M39	8.0	17	1	2.2
M34	8.1	17	2	2.2
NGC 2516	8.1	24	7	3.1
NGC 6633	8.2	19	1	2.4
NGC 6475	8.4	27	3	3.5
UMa	8.5	62	9	8.0

TABLE 4

OBSERVED AND PREDICTED NUMBERS OF Am STARS IN 14 OPEN CLUSTERS

Cluster	Log Age (yr)	Number of Stars	Number of Am	Predicted Am (15.4%)
Orion Nebula	5.7	14	4	2.2
Orion OB1	6.7	29	7	4.5
Lac OB1	7.1	2	0	0.3
IC 2602	7.1	8	0	1.2
α Per	7.4	28	4	4.3
IC 4665	7.5	11	1	1.7
Pleiades	7.7	34	4	5.2
M39	8.0	17	5	2.6
M34	8.1	16	1	2.5
NGC 2516	8.1	18	0	2.8
NGC 6633	8.2	17	4	2.6
NGC 6475	8.4	16	3	2.5
UMa	8.5	72	7	11.1
Coma	8.8	17	6	2.6

for this difference. Am (and Ap) stars probably have their unusual surface compositions because of a diffusion mechanism. That mechanism will not work for rotational velocities above about 90 km s^{-1} (Michaud 1982). Most protostars of several solar masses will have higher rotational velocities, so there must be one or more ways that those stars lose part of their angular momentum. Those ways may be magnetic braking in most Ap stars and tidal braking in binaries in most Am stars. Angular momentum can also be exchanged in visual multiples, probably during their formation, but the interactions of stars in open clusters are probably too distant to change the rotational velocities. Thus, slowly rotating visual primaries that become Am stars may cause slowly rotating secondaries that also become Am stars, but the slow rotation of one star in a cluster is unlikely to cause other stars in the cluster to be slowly rotating.

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