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THE FREQUENCY OF PECULIAR A AND METALLIC-LINE STARS IN OPEN CLUSTERS

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ABSTRACT

MK spectral types were determined for 263 B and A stars in the southern galactic clusters NGC 2287, 2422, 2451, 2516, 2547, 3228, and 3532 in order to investigate the frequency of Ap and Am stars in galactic clusters.

In these seven clusters 11 Ap stars and 203 normal B5 to A5 dwarfs were found. This frequency is lower than that found in two independent field samples. When this sample is combined with published data for other clusters, a χ^2 test indicates that the cluster frequency is lower than the field frequency at the 99.4 percent and 98.6 percent confidence levels for two field samples. Several systematic effects that may have influenced this result are investigated. It is possible that systematic effects may account for the apparent deficiency, but further work is required to show this. There is an indication that the frequency of Ap stars may increase with age, but this result is not statistically significant. Some Ap stars appear in peculiar positions in the cluster color-magnitude diagram, probably because of the effect on their color of flux redistribution caused by the peculiar abundances.

The frequency of Am stars in galactic clusters appears to be normal compared with the field. The frequency of Am stars appears to increase with cluster age. A χ^2 test indicates this increase is significant at the 96.5 percent confidence level.

Subject headings: clusters: open — stars: evolution — stars: metallic-line — stars: peculiar A — stars: stellar statistics

I. INTRODUCTION

Galactic clusters and associations provide a potentially powerful tool for the study of the origin and evolution of Ap and Am stars. By looking at stars in clusters we gain several valuable pieces of information including the ages and the rotational velocities of the Ap, Am, and normal stars which formed from the same cloud. Jaschek and Jaschek (1967) compiled from the literature a list of Ap and Am stars found in clusters in the course of other spectroscopic investigations. Recently, Young and Martin (1973) searched for Ap stars in galactic clusters. They found only three Si Ap stars in a sample of 62 stars from 13 clusters. This led them to suggest that there is a deficiency of Ap stars in galactic clusters and that those which are found in galactic clusters are milder than those found in the field. In their work, however, the spectra were not widened enough to detect weak lines nor was reddening taken into account in selecting the program stars. Conti and van den Heuvel (1970) and Smith (1972) have both conducted searches for Am stars in clusters and associations. In both cases the frequency of Am stars they found in the clusters searched was normal compared with the field. Preston (1974) reviewed the question of the frequency of Ap and Am stars in clusters and compiled all available data from the literature. He did not examine the problem statistically, but concluded that the question of the frequency of Ap stars in clusters was undecided.

The present study was undertaken to extend the number of clusters which have been examined for Ap and Am stars and to use this enlarged sample for a statistical examination of the question. The basic motivation for this work was the result of Young and Martin (1973) on the Ap stars. The Am stars were included in the study because the appropriate spectral range had been searched, and it seemed useful for comparison with the results for the Ap stars. Stars were selected in seven southern galactic clusters for this program. These clusters were chosen because they had not previously been extensively or completely investigated spectroscopically and because any Ap or Am stars found would be bright enough to allow future study at higher dispersion.

The search for Ap and Am stars was carried out using spectra of classification dispersion. In principle the results using this technique could be directly compared with the large systematic study of the field stars by Cowley *et al.* (1969). This method is best suited for Ap stars of the types Si, Sr, Cr, or Eu, and the classical Am stars. It is much less suitable for Hg–Mn stars which are difficult to recognize at classification dispersion (see Wolff and Wolff 1974) and the so-called "hot" Am stars (see Conti 1965). For this reason Hg–Mn stars and the "hot" Am stars were excluded from the present study. When the present

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author refers to Ap stars he means only those of the Si, Sr, Cr, or Eu types and by Am stars he means only the classical Am stars. It seems appropriate to exclude the Hg–Mn stars from the present study because their properties suggest that they may be fundamentally different from the Si–Sr–Cr–Eu stars (Preston 1974).

II. A SEARCH FOR Ap AND Am STARS IN SOUTHERN GALACTIC CLUSTERS

a) *Selection of Stars for Observation*

In a program such as this it is clearly desirable to optimize the use of telescope time by observing as few nonmembers as possible. In doing this, however, care must be taken not to exclude the Ap or Am stars for which one is looking! The stars to be observed in this program were selected from photometric studies of the cluster fields. When proper-motion studies or radial velocities were available, only the most probable members on these bases were included. At the outset it was realized that Ap or Am stars may occupy peculiar positions in the color-magnitude diagram so that the color-magnitude diagram was not used to select stars for observation. Instead stars in the approximate $(B - V)_0$ range -0.15 to $+0.30$ were selected for observation independent of their magnitudes. Finally, it was felt that one is more likely to find members near the apparent center of a cluster, and, generally, stars near the edge of the cluster were observed only as telescope time allowed.

b) *Observations*

Slit spectra were obtained at Cerro Tololo Inter-American Observatory during 1974 January and February. Stars were observed with the 0.9 m (36 inch) telescope at 125 Å mm^{-1}, the 1.5 m (60 inch) telescope at 103 Å mm^{-1}, and the Yale 1 m (40 inch) telescope at a prismatic dispersion of 91 Å mm^{-1} at Hγ. All spectra were taken on IIa–O plates. In most cases no comparison spectrum was used, in order to make the spectra easier to classify. The spectra were widened to 0.6 mm with the 0.9 m and 1.5 m telescopes and to 0.8 mm with the 1 m. The projected slit widths were 25 μ, 22 μ, and 25 μ, respectively. In addition to the program stars, a grid of MK standards shown in Table 1 was taken with each telescope. In general each program star was observed only once, but to try to obtain a better exposure match between the standards and the program stars, three exposures of each standard were obtained. These exposures were typically in the ratio 0.6:1:1.4 where 1 is the optimum exposure.

A few additional stars were classified from the Michigan 10° Blue Survey Plates taken with the Michigan Curtis Schmidt telescope. These plates have a prismatic dispersion of 108 Å mm^{-1} at Hγ and are generally widened to 0.8 mm. The stars classified from these plates were selected prior to the present author's observing run. Slit spectra were obtained for any stars that looked marginally peculiar or that were poorly exposed or overlapped on the objective-prism plates.

TABLE 1

MK STANDARDS USED

Sp	V	IV	III
B3.......	ν Ori	...	...
B5.......	κ Hya	...	τ Ori
B6.......	(HR 2360)	19 Tau	...
B7.......	α Leo	16 Tau	η Tau
B8.......	18 Tau	...	27 Tau
B9.......	...	134 Tau	...
A0.......	109 Vir	...	(HR 4218)
A3.......	λ Gem	...	β Eri
A4.......	δ Leo	...	...
A5.......	(σ^2 Tau)	...	...
A7.......	21 LMi	...	θ^2 Tau
F0.......	γ Vir A + B	...	ζ Leo

c) *Classification*

The standards used to classify the slit spectra are given in Table 1. These standards were chosen to correspond as much as possible to those used by Cowley *et al.* (1969) and Cowley (1972). Since the author's observations were made from the southern hemisphere, this was not always possible and additional standards were chosen from Johnson and Morgan (1953) and Morgan and Keenan (1973). Because there were still some significant gaps in the grid of standards, additional secondary standards were chosen, following the advice of Morgan and Keenan (1973), from Hiltner, Garrison, and Schild (1969). The secondary standards are enclosed in parentheses in Table 1. They were only chosen after consultation with Nancy Houk and after they were examined by both the author and Houk on the Michigan 10° Blue Survey Plates.

To classify the objective-prism spectra Houk kindly allowed the author to use the collection of standard spectra she was using in the preparation of the University of Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars (Houk and Cowley 1975), where a list of the standards may be found.

Each program star was classified twice relative to the standards. In each case the star was compared directly with standards using a Zeiss Spectral Comparator. During the second classification all stars which were given similar spectral types were intercompared to improve the internal consistency of the spectral classification.

d) *Discussion of Results*

The final adopted spectral types for all program stars are shown in Tables 3 through 9. The stars in these tables are arranged in order of apparent magnitude. The notation used for the spectral types in Tables 3 through 9 is generally that of Houk and Cowley (1975). Those spectral types which are enclosed in square brackets were outside the grid of standards taken with the same telescope as the program spectrum. These types are naturally less reliable and are only intended to be indicative of the star's spectral type. Spectral types or parts of spectral types enclosed in parentheses are uncertain. For Am stars

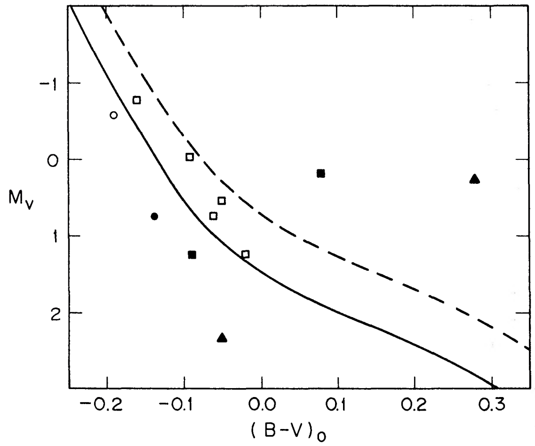

FIG. 1.—Color-magnitude diagram showing the location of the Ap stars found in the clusters studied. Solid line is the zero-age main sequence according to Johnson (1963). The dashed line is 0.75 mag above it. The Ap stars from various clusters are designated as follows: ●, NGC 2287; ○, NGC 2422; ■, NGC 2451; □, NGC 2516; ▲, NGC 3532.

three spectral types are given. These are the Ca II K-line type, the hydrogen type, and the metal type, respectively.

Figure 1 is a color-magnitude diagram for the Ap stars found in these seven clusters. The distance moduli, reddening, and sources of photometry used to prepare Figure 1 are shown in Table 2.

The results for each cluster are discussed below. Certain normal stars were excluded from membership and the reason for excluding them is given in each case. For the Ap stars the situation is more complex. Many do not appear to be members based on their position in the color-magnitude diagram. When this is true, it is pointed out, but the discussion of whether these stars really are members is postponed until later.

i) *NGC 2287*

NGC 2287 (M41) is a well-known cluster located at $\alpha = 6^h42^m7$ and $\delta = -20°38'$ (1900). It has an age of 6.5×10^7 years (Lindoff 1968). This cluster was the subject of an extensive study by Cox (1954). He obtained photoelectric *PV* photometry for 106 stars in the field of NGC 2287 and spectral types and radial velocities for 22 of the brighter stars, and performed a proper-motion study which eliminated some of the foreground stars. Cox also discovered the Ap star HD 49299, which is confirmed by the present study.

TABLE 2

DISTANCE MODULI AND REDDENING

Cluster	$V_0 - M_v$	$E(B-V)$	Source
NGC 2287....	9.3	0.06	Cox 1954
NGC 2422....	8.4	0.07	Smyth and Nandy 1962
NGC 2451....	7.6	0.04	Williams 1967*b*
NGC 2516....	8.0	0.12	Feinstein *et al.* 1973
NGC 2547....	7.9	0.03	Fernie 1959
NGC 3228....	8.5	0.03	Hogg 1963
NGC 3532....	8.2	0.01	Koelbloed 1959

In this study spectral types were determined for 34 stars in the field of NGC 2287 of which 14 are in common with Cox (1954). These spectral types are given in Table 3. A comparison of the author's spectral types with those of Cox indicates that there is a systematic difference of about 0.1 of a spectral class and no difference in luminosity class for the 14 stars in common. In the present study one marginal Si star, HD 49023, and one marginal Am star, No. 27, were also found.

Of the normal stars Nos. 86, 78, and 55 were excluded from membership because of their position in the color-magnitude diagram. HD 49299, the Ap star, lies below the main sequence and would probably not be considered a member if it were a normal star (see Fig. 1).

ii) *NGC 2422*

NGC 2422 is a galactic cluster located at $\alpha = 7^h32^m0$ and $\delta = -14°26'$ (1900). It has an age of 2×10^7 years (Lindoff 1968). Both Hoag *et al.* (1961) and Smyth and Nandy (1962) did photographic photometry calibrated by a photoelectric sequence. In the present study spectral types were determined for the 24 stars in the field of NGC 2422 listed in Table 4. One Ap star, HD 61045, was discovered. This star was independently discovered by Dworetsky (1975) who also determined spectral types for some of the brighter stars in NGC 2422. His classification was done at 42 Å mm^{-1}, however, and as a result Dworetsky points out that his types should be used with some caution. A comparison with the present author's types shows good agreement in temperature class, but Dworetsky's luminosity classes may tend to be too faint. One definite (No. 13 of Hoag *et al.* 1961) and two marginal (Nos. 9 and 10 of Hoag *et al.* 1961) Am stars were also found in the present study.

The two stars in Table 4 which are classified pec, Nos. 31 and 13 of Smyth and Nandy (1962), both have spectra which basically resemble A1 or A2 dwarfs except that the lines at $\lambda\lambda$4030 and 4045 appear to be as strong as in a late A or F0 star. They are not typical Ap or Am stars. It is possible that they are composites of some sort, but it is not clear what they might be composites of.

The only star excluded from membership was No. 14-P of Hoag *et al.* (1961) because of its spectral type and location in the color-magnitude diagram. The Ap star, HD 61045, appears to be a member although it does lie somewhat blueward of the main sequence (see Fig. 1).

iii) *NGC 2451*

NGC 2451 is a loose galactic cluster located at $\alpha = 7^h41^m8$ and $\delta = -37°44'$ (1900). It has an age of 2×10^7 years (Williams 1967*b*). Feinstein (1966) obtained *UBV* photometry for 22 of the brighter stars in the cluster field and determined spectral types and radial velocities for a few of those stars. Williams (1966; 1967*a*, *b*) obtained much more extensive *BV* photometry in the field of NGC 2451 as well as a

Table 3

Spectral Types for NGC 2287

No. Cox (1954)	HD	BD	Spectral Type
101	48983	-20 1535	A0 IV
84	49069	-20 1552	B8 V
b	49023	-20 1543	B9 IV(p Si)
1	49150	-20 1563	A0 (V)
g	48984	-20 1534	A0 (V)
2	49106	-20 1556	B9 V
61		-20 1542	B9 V
d	49025	-20 1545	A0 V
70		-20 1540	A0 (V)
c	49184	-20 1565	A0 V
30	49185	-20 1564	B9 IV
e	49022	-20 1544	B9 III
23		-20 1558	B9 V
51	49211	-20 1570	B8 V
20		-20 1554	B9 V
5		-20 1559	B9 V
63		-20 1550	B8/9 V
93	48965	-20 1532	B9 V
25		-20 1561	B9 V
6			B9 V
56	49299	-20 1573	A0p EuCrSr
80		-20 1530	A3 V
3			A0 IV
85		-20 1529	B9.5 V
14			A1 V
49		-20 1566	A3 V
39	49277	-20 1572	A0 V
86		-20 1539	A6 V
78			A3 V
54			A1 V
4			A2 V
55		-20 1571	A3 V
95			A1 V
27			A2 V(m)

Table 4

Spectral Types for NGC 2422

No. Hoag, et. al. (1961)	No. Smyth and Nandy (1962)	HD	BD	Spectral Type
2	3	61017	-14 2025	B7 III
3	5		-14 2022	B6 III
2-P		60856	-14 1994	B6 V
3-P	9	61045	-14 2029	B7p Si
6-P	22	60940	-14 2012	B8 V
6		60999	-14 2018	B9 V
7	10	60996	-14 2019	B9 V
12-P	11	60941	-14 2010	A0 IV
11-P	24	60942	-14 2014	B9 IV
13-P	25		-14 2015	A0 V
15-P	26		-14 2024	A0 V
14-P			-14 1996	A0 III
17-P	12		-14 2032	A0 V
16-P	27		-14 2005	A0 V
	29		-14 2034	A1 V
18-P	28		-14 2023	A1 V
8			-14 1993	A7 V
21-P	31		-14 2028	A2 pec
9	32			A2 V(m)
11	14		-14 2033	A1 V
12	13		-14 2040	A1 pec
10			-14 2004	A3 V(m)
13	15		-14 2008	A2mA4-A7
26-P	34			A8 V

TABLE 5

Spectral Types for NGC 2451

No. Williams (1967a)	HD	CoD	Spectral Type
203	62226	-38 3556	B5 III
182	61878	-37 3767	B7 V
267	63215	-37 3886	B8 V
246	62893	-37 3841	B8 III
277	63401	-39 3595	B8 III
251	62991	-37 3861	B4 V
209	62376	-38 3564	B8 V
256	63079	-37 3868	B9 V
131	61087	-37 3709	B9 V
218	62503	-38 3575	B9 V
239	62803	-38 3598	B9 V
248	62938	-37 3847	A0 V
228	62642	-37 3815	B9 V
202	62227	-38 3558	B9 V
250	62992	-37 3860	A3p SrEu(Cr)
186	61926	-38 3538	B7 V
161	61621	-38 3520	A0 V
249	62961	-38 3611	A0 V
211	62415	-38 3569	A7 V
47	62974	-37 3855	A2 V
266	63216	-37 3887	A0 V
244	62876	-37 3838	A3 V
36		-37 3845	A0 V
301	63737	-37 3940	F0 III/IV
285	63511	-38 3654	A3 V
141	61310	-38 3501	B9 III/IV
207	62251	-37 3795	B9p Si
214	62479	-37 3806	[A7 V]
193	62086	-38 3546	(F0 V)
14		-37 3824	A2 V
259	63116	-38 3629	(F0 IV/V)
200	62210	-39 3494	A1 V
75		-37 3884	[F0 V]
140	61288	-38 3500	A0 V
275a	63341	-38 3641	A2 V

TABLE 5--Continued

No. Williams (1967a)	HD	CoD	Spectral Type
275b	63341	-38 3641	A5 III
276	63375	-38 3644	A1 V
24		-37 3833	A1 V
16		-37 3825	A2 V
287	63529	-37 3915	A1 V
82			A1 V
5		-37 3812	A1 V
23		-37 3831	A0 IV
108		-38 3599	A8 V

TABLE 6

Spectral Types for NGC 2516

No. Cox (1955)	No. Dachs (1970)	HD	CPD	Spectral Type
B	27	65950	-60 967	B8/9 III
15	33	65987	-60 976	B9p Si
			-60 944a	B8p Si
91	26	65949	-60 966	B9 III
20	59	66259	-60 1012	B9 III
23	67	66409	-60 1022	B8/9 III
	55	66167	-60 1005	A0 V
			-60 944b	B8 III
c	34		-60 978	A0p EuCrSr
26	62	66295	-60 1015	B8/9p Si
33			-60 1001	A1 V
3			-60 949	A0 V
38	37		-60 981	A2 V (p SrCrEu)
18	52		-60 1000	A0 V
22	65		-60 1019	A2 V
94	30		-60 970	A0 IV
16	50		-60 995	A1 V
58	31		-60 971	A0 V

Table 6 Continued

No. Cox (1955)	No. Dachs (1970)	HD	CPD	Spectral Type
24		66318	-60 1017	AOp EuCrSr
47	41		-60 984	A2 V
77	48		-60 991	A0 V
8	14		-60 948	A0 V
17	57		-60 1008	A1/2 V
45	32		-60 974	A2 V
65			-60 1029	A0 V
40	17		-60 954	A1 V
112			-60 944c	A2 IV
28	60		-60 1013	A1 V
7	10		-60 942	A1 V
66	70		-60 1025	A1 V
57	24		-60 963	A2 V
101			-60 951	A2 V
52			-60 998	A7 III
34			-60 994	A3 V
46				F0 V
35			-60 996	A1 V (m)
54	51		-60 997	A3 V
60			-60 992	A8 V
42			-60 965	A3 V
84				A7 V
51			-60 1007	A8 V
21			-60 1010	A8 V
4				A7 III
67	66		-60 1021	A7 V
44			-60 972	A7 III

Table 7 Continued

No. Fernie (1959)	HD	CPD	Spectral Type
44	68478	-48 1525	B3 V
41	68451	-48 1522	B3 [V]
61	68608	-48 1543	B7 III
47	68496	-48 1528	B6 V
33	68397	-48 1514	B9 IV
5	68074	-49 1513	B8 III
38	68432	-48 1519	B8 IV
49	68494	-48 1530	A9 IV
60	68578	-48 1541	A0 IV
31	68398	-48 1512	B9 IV/V
19	68305	-48 1500	A1 V
32	68396	-48 1513	B9 IV/V
12	68274	-48 1495	B9 IV/V
4	68073	-48 1484	A2 V
43	68452	-48 1524	A1 IV
21	68325	-49 1523	A0 V
7	68114	-48 1485	A1 V
50	68495	-48 1531	A0 V
8	68115	-48 1486	A1 V
52	68516	-49 1531	A1 V
36		-48 1517	A1 V
65	68698	-48 1551	A1 V
63	68631	-48 1546	A2 V
16	68275	-48 1498	A3 V
53		-48 1533	A5 IV
15		-48 1497	A2 V
58	68559	-48 1539	F0 V
27		-48 1508	A3 IV
67	68810.	-49 1540	A0 (V)
39		-48 1520	[F2/5 V]
20		-48 1501	A9 V
46		-48 1527	A7 V

Table 8

Spectral Types for NGC 3228

No. Hogg (1963)	HD	CoD	Spectral Type
6	89915	-51 4693	A0 V
19	90086	-50 5097	B6 V
5	89900	-51 4691	A0 IV
10	89956	-51 4701	B8 V
4	89901	-51 4690	B9 (IV)
3	89856	-51 4685	(B9 III)
13	89937	-51 4699	B9 V
12	89938	-51 4698	B8 V
8		-51 4695	B9 V
9			A2 III/IV
11		-51 4697	B9 IV/V
20		-51 4686	A1 V
16		-51 4702	A3mA5-A7

Table 9

Spectral Types for NGC 3532

No. Koelbloed (1959)	HD	CPD	Spectral Type
163	96564	-58 3120	A0 IV
231	96898	-58 3186	[F0/2 III]
14	96059	-58 2995	A0 (IV)
62	96227	-58 3037	A0 IV
29	96137	-58 3005	B9 IV
52	96213	-58 3028	A0 IV
63	96245	-57 4208	A0 IV
189	96653	-58 3144	A0 V
82	96305	-58 3056	A0 IV
132	96472	-57 4257	A0 IV
108	96387	-58 3073	A1 V
152	96522	-57 4272	A0 V
101		-58 3069	A1 V

Table 9 Continued

No. Koelbloed (1959)	HD	CPD	Spectral Type
154		-58 3110	A2 V
7	96011	-57 4156	A0 V
243	96944	-58 3198	A0 V
220	96809	-58 3174	A0 V
117		-58 3081	A1 V
114	96413	-57 4247	A0 V
80	96306	-58 3053	A0 V
150		-58 3107	A1 V
69	96260	-58 3043	A0 V
8	96012	-58 2987	B9/A0 III
86		-58 3058	A0 V
70		-58 3044	A1 V
164	96565	-58 3123	A0 IV
116		-58 3080	A1 V
75		-58 3053	A0 V
184		-58 3139	A2 V
85		-58 3057	A2 V
175		-58 3133	A1 V
45	96192	-58 3020	A1 V
123			A2 V
217	96773	-58 3170	A1 V
148		-58 3106	A1 V
185		-58 3138	A1 V
107	96386	-57 4239	A2 V
103		-58 3071	A1 V
36	96157	-58 3011	A2 V
206	96729	-58 3157	B9 III(p Si)
67		-58 3041	A2 V
126		-58 3089	A2 V
215	96774	-58 3168	A2 V
234		-58 3188	A1 IV
34	96138	-58 3006	A2 V
47	96211	-57 4199	A2 V
242		-58 3197	[B2]
223	96825	-58 3177	A2 V

Table 9 Continued

No. Koelbloed (1959)	HD	CPD	Spectral Type
110	96389	-58 3076	A2 V
26	96120	-57 4183	A3mA6-A8/9
42		-58 3015	A2/3 V
159		-57 4274	A3 V
119		-57 4251	A2 V
139		-58 3100	A4 V
94		-58 3063	A2 V
192		-58 3146	A5 V
138		-58 3101	A2mA4/5-A7
81		-57 4223	A4 V
167		-57 4282	FO IV
160		-57 4275	A9 V
226		-58 3180	AOp Si
78		-57 4223	[F2 V]
155		-58 3111	A5 V
54		-57 4203	A2mA6/7-A9
93		-57 4223	A5 V
28		-58 3004	A5 III
72		-58 3045	A7 V
88		-57 4228	A5 V
214		-58 3167	A5 V
10		-57 4167	A7 V
201		-58 3154	A8 IV

proper-motion study intended to eliminate foreground objects.

In this study spectral types were determined for the 44 stars given in Table 5. Only stars which were proper-motion members according to Williams (1967*b*) were included in the program. Two definite Ap stars, HD 62992 and HD 62251, were found. The Si star reported by Feinstein (1966), HD 62712, is probably not a member of the cluster based on its radial velocity (Feinstein 1966) and its proper motion (Williams 1967*b*). Furthermore, it did not appear to be a Si star on a Michigan 10° Blue Survey Plate.

The question of membership is complicated in this cluster. The lower end of the main sequence is still badly contaminated with field stars in spite of the proper-motion study by Williams (1967*b*). HD 61310 and HD 63341 were excluded because of their spectral types. HD 63737 was excluded because of its spectral type and location in the color-magnitude diagram. HD 62415, 62974, 62086, 63116, 63529 and Nos. 82, 5, and 23 were all excluded because of their location in the color-magnitude diagram. Neither of the Ap stars, HD 62992 and HD 62251, appears to be a member based on their location in the color-magnitude diagram (see Fig. 1).

iv) *NGC 2516*

NGC 2516 is a very interesting galactic cluster located at $\alpha = 7^h56^m.7$ and $\delta = -60°36'$ (1900). It has an age of 7.1×10^7 years (Lindoff 1968). This cluster has been the subject of a number of recent spectroscopic investigations. Evans *et al.* (1961) first pointed out the presence of an Ap star in this cluster. Abt and Morgan (1969) using plates of 125 Å mm^{-1} and 39 Å mm^{-1} for each star gave MK spectral types for 26 probable members and found three Si stars, one Mn star, one Hg star, and two additional marginal Hg or Mn stars. Abt *et al.* (1969) gave MK-like spectral types for five more stars based on 39 Å mm^{-1} spectra. Dachs (1972) using spectra of 20 Å mm^{-1} found three new Ap stars described as Si, Si λ4200, and Ti–Si. The present author obtained spectral types for the 45 stars in the field of NGC 2516 shown in Table 6 of which 34 apparently had not been previously investigated. Included in this sample were all the stars reported to be peculiar by the above workers. The present author was unable to confirm from his plates either the Mn star, star B, or the Hg star, No. 91, found by Abt and Morgan (1969) or the Si λ4200 star, CPD $-60°944$b, reported by Dachs (1972). Since the Mn and Hg stars were probably found at the higher dispersion (39 Å mm^{-1}) used by Abt and Morgan (1969), it is probably not too surprising that they could not be detected in this study. The fact that the author could not confirm that CPD $-60°944$b is a Si λ4200 star is rather puzzling in light of the large equivalent width (480 mÅ) quoted for this line by Dachs (1972). The author has two plates of this star, one somewhat overexposed, and the star appears normal on both plates. The author considered this star as normal. One marginal Ap star and one marginal Am star were also found in the present study.

On the basis of the photometry and spectral types CPD $-60°944$b and stars Nos. 52, 4, and 44 were excluded from membership. All the confirmed Ap stars in this cluster would appear to be members on the basis of the usual criteria (see Fig. 1).

v) *NGC 2547*

NGC 2547 is a rather poor galactic cluster located at $\alpha = 8^h7^m\!.7$ and $\delta = -48°58'$ (1900). It has an age of 7.4×10^7 years (Lindoff 1968). Fernie (1959) obtained photoelectric U_cBV photometry for stars in the field of NGC 2547, and Fernie (1960) performed a proper-motion study of the brighter stars in the field.

In the present study spectral types were determined for 32 apparent members in the field of NGC 2547 shown in Table 7. No peculiar stars were found. HD 68494 and No. 39 were excluded from membership because of their position in the color-magnitude diagram.

vi) *NGC 3228*

NGC 3228 is an inconspicuous galactic cluster located at $\alpha = 10^h17^m\!.6$ and $\delta = -51°13'$ (1900). It has an age of 4×10^7 years (Lindoff 1968). It was the subject of a photoelectric *UBV* study by Hogg (1963).

In the present study spectral types were determined for 13 members or probable members found by Hogg (1963). These are given in Table 8. One Am star, No. 16, was found. HD 89856 and No. 9 were excluded from membership because of their spectral types.

vii) *NGC 3532*

NGC 3532 is a very rich open cluster located in the η Carinae region at $\alpha = 11^h2^m\!.2$ and $\delta = -58°8'$ (1900). It has an age of 2×10^8 years (Lindoff 1968). Koelbloed (1959) gave photoelectric and photographic *BV* photometry for stars in the field of NGC 3532 as well as relative proper motions. Only stars of the most probable membership class based on this proper-motion study were included in the present study.

In this study spectral types were determined for the 71 stars listed in Table 9. Additional spectral types were taken from Houk and Cowley (1975) for HD 96285, 96651, 96714, 96772, 96896, 96490, and 96897. This last star was classified as an Ap star by Houk and Cowley (1975). In the present study one Ap star, No. 226, one marginal Ap star, No. 206, and three Am stars, Nos. 26, 138, and 54, were found.

Among the normal stars Nos. 231, 8, and 242 were excluded from membership because of their spectral types and position in the color-magnitude diagram; No. 234 was excluded because of its position in the color-magnitude diagram; and No. 28 was excluded because of its spectral type. Neither of the definite Ap stars appears to be a member based on its location in the color-magnitude diagram (see Fig. 1).

III. FREQUENCY OF Ap STARS

a) Comparison of the Frequency in the Field and Galactic Clusters

Before we can discuss the frequency of Ap stars we must decide upon a reference population of normal stars out of which they arise. It is generally agreed that Ap stars are dwarfs (luminosity classes IV or V) and that they occupy an effective temperature range from about 15,000 K to 8000 K (Preston 1974). This corresponds approximately to a range of spectral types from B5 to A5. Thus, for our reference population, we will adopt the stars of luminosity classes IV and V and temperature class between B5 and A5.

To obtain one estimate of the frequency of Ap stars in the field, spectral types were taken from Cowley *et al.* (1969), Cowley (1972), Cowley and Fraquelli (1974), and Lesh (1968) for the stars contained in the Yale Catalogue of Bright Stars (Hoffleit 1964) and north of $-20°$ (the Bright Star sample). In this sample we find a total of 1182 normal dwarfs between B5 and A5, 100 Ap stars, and 13 marginal Ap stars. If we define the frequency of Ap stars, f_p, as

$$f_p = N_p/(N_p + N_n + N_p')\,, \tag{1}$$

where N_p is the number of Ap stars, N_n is the number of normal B5 to A5 dwarfs, and N_p' is the number of marginal Ap stars, then the frequency of Ap stars in this sample is 0.077.

One can obtain a second estimate of the frequency of Ap stars in the field from Houk and Cowley (1975). If we include only the quality 1 classifications, we find 3383 normal B5 to A5 dwarfs, 259 Ap stars, and 36 marginal Ap stars. This is a frequency of 0.070.

TABLE 10

Summary of Ap Stars Found

Cluster	B5–A5	Ap	Ap?	A5–A9	Am	Am?
NGC 2287...	27	1	1	0	0	1
NGC 2422...	13	1	0	2	1	2
NGC 2451...	24	2	0	2	0	0
NGC 2516...	45	5	1	5	0	1
NGC 2547...	23	0	0	3	0	0
NGC 3228...	10	0	0	0	1	0
NGC 3532...	61	2	1	9	3	0
Total.....	203	11	3	21	5	4

Table 10 summarizes the results for the seven clusters studied in the present work. In Table 10 all Ap stars were considered to be members of their respective clusters, although, as stated earlier, many do not appear to be. This question will be considered in more detail later. In Table 10 the author's results were combined with those of Abt and Morgan (1969) and Abt *et al.* (1969) for NGC 2516. In this sample we find the frequency of Ap stars is 0.051. This is lower than that found in the two field samples above, but not significantly, considering the small sample size.

In order to reduce the problem of the small number of clusters sampled, a compilation of reliable spectroscopic data for galactic clusters was made from the literature. It is summarized in Table 11. In preparing this table the question of membership in the clusters was generally left up to the original authors with a few exceptions. In this larger sample of cluster stars we find 744 B5 to A5 dwarfs, 36 Ap stars, and three marginal Ap stars. This is a frequency of 0.046, very

TABLE 11

Compilation of Cluster Spectroscopy

Cluster	B5–A5	Ap	A5–A9	Am	Reference
Orion Ic...........	59	0	14	5	Sharpless 1952; Smith 1972; Morgan and Loden 1966
Upp Sco...........	57	7	5	1	Garrison 1967
Sco-Cen............	82	0	0	0	Morris 1961
NGC 2244.........	4	0	0	0	Morgan *et al.* 1965
NGC 2362..........	7	0	0	0	Johnson and Morgan 1953
NGC 7160..........	6	0	4	1	Conti and van den Heuvel 1970
NGC 6067..........	7	0	0	0	Thackeray *et al.* 1962
α Per...............	28	1	10	1	Morgan *et al.* 1971
Pleiades............	30	0	12	0	Mendoza 1956; Abt *et al.* 1965
NGC 2422..........	13	1	2	1	This paper
NGC 2451..........	24	2	2	0	This paper
NGC 2264..........	10	0	0	0	Morgan *et al.* 1965
IC 2391............	11	1	3	1	Perry and Bond 1969
NGC 7243..........	23	1	1	1	Hill and Barnes 1971
IC 2602............	20	1	1	0	Houk and Cowley 1975
Young group total	381	14	54	11	
NGC 6087..........	18	0	0	0	Feast 1957
NGC 2547..........	23	0	3	0	This paper
NGC 2516..........	45	5	5	0	This paper; Abt and Morgan 1969; Abt *et al.* 1969
IC 4665............	25	0	0	0	Abt and Chaffee 1967
NGC 6475..........	24	2	6	2	Abt and Jewsbury 1969; Conti and van den Heuvel 1970
NGC 3114..........	16	2	0	0	Frye *et al.* 1970
IC 4725............	34	0	0	0	Feast 1957
NGC 2287..........	27	1	0	0	This paper
NGC 3228..........	10	0	0	1	This paper
Praesepe...........	6	0	14	9	Bidelman 1956
Ursa Major.........	42	6	6	5	Roman 1949
NGC 7092..........	15	0	3	1	Weaver 1953; Meadows 1961
NGC 1039..........	11	2	0	0	Ianna 1970
Coma..............	4	2	4	5	Kraft 1965
NGC 3532..........	61	2	9	3	This paper
Hyades.............	2	0	9	4	Morgan and Hiltner 1965
Old group total....	363	22	59	30	
Grand total.........	744	36	113	41	

similar to the result using only the seven clusters in the present study.

One can statistically compare the frequency of Ap stars in clusters and the field by constructing a simple two by two contingency table and performing a standard χ^2 test. Such a table comparing the clusters with the Bright Star sample has a χ^2 of 7.48, which implies that one can state at the 99.4 percent confidence level that the apparent frequency of Ap stars is lower in galactic clusters than in the field.

A contingency table comparing the clusters with the field sample from Houk and Cowley (1975) has a χ^2 of 6.03, which implies that one can conclude that the apparent frequency of Ap stars in clusters is low at the 98.6 percent confidence level. Thus it would appear that the apparent frequency of Ap stars in galactic clusters may be low compared with that in the field, confirming the results of Young and Martin (1973).

The work of Leckrone (1973) suggests that an appropriate reference population for the Ap stars might be the B8 to A5 dwarfs. If we were to adopt this reference population, the frequency in the Bright Star sample would be 0.087 and in the sample from Houk and Cowley (1975) would be 0.074 compared with 0.055 in the cluster sample in Table 11. A χ^2 test on contingency tables comparing these two field samples with the cluster sample yields a χ^2 of 5.6 and 2.6, respectively. These correspond to confidence levels of 98.2 percent and 89.6 percent. If we were to move the limits of the reference population still later in spectral type—say, to A0 to A5—then the difference in frequencies would be even smaller, and the significance of the discrepancy would disappear. There are, however, good reasons for preferring the B5 to A5 reference population. Preston (1974) argues from several lines that the effective temperatures of Ap stars extend as high as 15,000 K which corresponds to B5. Megessier (1974) showed that the hot Ap stars, like those studied by Leckrone (1973), have space motions like the normal B5 to B8 dwarfs rather than the B9 to A3 dwarfs. Even Leckrone (1973) found an effective temperature of 14,500 K for HR 1732 which corresponds to about B6. Thus, while it is possible to reduce or even eliminate the deficiency of Ap stars in clusters by adopting a later reference population, it does not seem realistic to use even B8 to A5 much less A0 to A5 as a reference population.

One might question the validity of comparing a volume limited sample such as the cluster sample used here with an apparent magnitude limited sample such as the Bright Star sample or Houk and Cowley (1975). This comparison, however, is completely valid as long as the reference population and the Ap stars have the same distribution in absolute magnitude about the same mean absolute magnitude. As far as is known this is true (Eggen 1967).

b) *Discussion of Systematic Effects*

Before concluding that Ap stars are deficient in galactic clusters, we should consider the systematic effects that may have caused this result. The most obvious possibilities are a difference in the detectability of Ap stars at the slightly different dispersions used in the different studies considered or a difference between spectroscopists in what they consider to be an Ap star. Both of these problems are very difficult to treat. The first problem is certainly very serious for Hg–Mn stars, and for this reason they were excluded from the present study. Since the Hg line at λ3984 is not detectable at any dispersion in normal stars, it is easy to see why one finds progressively more Hg–Mn stars as one goes to higher dispersion. For the Si stars, on the other hand, $\lambda\lambda$4128–4130 is visible at classification dispersion in normal stars. The same is true for the Sr λ4077 line near the cool end of the range occupied by the Sr stars. Thus, for the types of Ap stars considered here, the slightly different dispersions used by different authors should not make a significant difference in the detectability of Ap stars.

The question of the personal equation of different spectroscopists is very difficult to deal with. Cowley *et al.* (1969) were especially interested in peculiar stars and probably looked very hard for them. It might not be surprising then if they found a higher frequency than other spectroscopists. However, both the present study and that of Young and Martin (1973) were undertaken specifically to look for Ap stars, and they were no more successful in finding Ap stars in clusters than other workers. This author has also examined a selection of the Ap stars found by Cowley *et al.* (1969) including all the marginal cases on the original plates used for that project. The present author can see no difference between his definition of an Ap star and that used by Cowley *et al.* This author also worked very closely with Houk during his classifications and can see no significant difference between his definition of an Ap star and that used in Houk and Cowley (1975).

Another possible systematic effect arises if the frequency of Ap stars is not constant across the B5 to A5 temperature range. The data on the frequency of Ap stars as a function of $B - V$ color given by Preston (1974) would indicate that the frequency is higher near B5 than at A5. Figure 2 shows the normalized relative distribution of the normal stars with spectral type in the three samples compared here. What this shows is that there are more normal stars near B5 and fewer normal stars near A5 in the cluster sample than in either of the field samples. If the frequency of Ap stars is really higher near B5, then we would expect to find more, not fewer, Ap stars in the cluster sample than in the two field samples. Thus we can reject this as an explanation of the apparent deficiency of Ap stars in clusters.

It was pointed out above that about half of the Ap stars found in the fields of the seven clusters studied in this paper do not appear to be members of those clusters based on their position in the color-magnitude diagram. If these stars are excluded from membership in those clusters, the frequency in those seven clusters will be even lower and would be statistically lower than the field frequency in spite of the small size of the sample. It has generally been assumed that since some Ap stars in clusters occupy normal positions in the color-magnitude diagram, they all must. If this is not true, then it is possible that a good number of Ap stars have been missed in clusters. As explained above

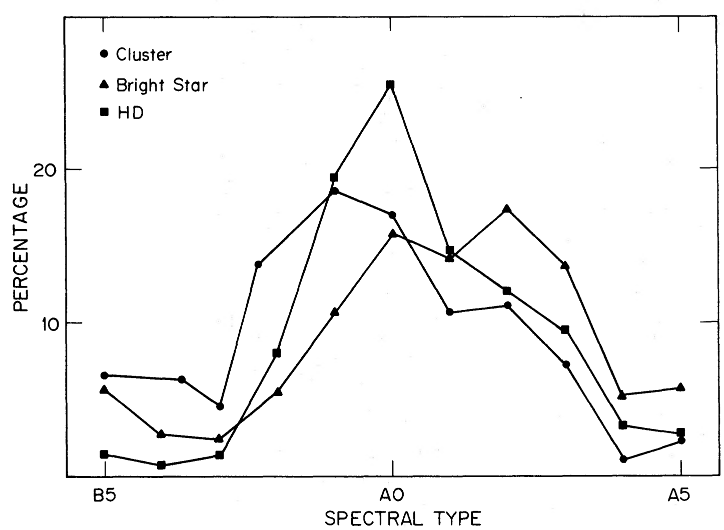

FIG. 2.—The relative distribution of the normal stars with spectral type in the cluster sample and the two field samples. The curves have been normalized so that the area under them is the same. The sample labeled HD is from Houk and Cowley (1975).

this author tried to avoid this prejudice when making up his observing program. In spite of this he did not observe HD 96897 in NGC 3532, even though it was on his observing list, because it seemed (and still does) much too far above the main sequence to be a member. It was called to the author's attention by Houk, and the spectral type was taken from Houk and Cowley (1975). In general no attempt was made by the authors listed in Table 11 to allow for the possibility of this effect, and, for example, Perry and Bond (1969) excluded one definite and one marginal Ap star from membership in IC 2391 purely on the basis of their location in the color-magnitude diagram. These two Si stars are located in the color-magnitude diagram in a position very similar to that of the Si stars in NGC 2451 and NGC 3532. In some cases the color-magnitude diagram was examined by the authors listed in Table 11 to select stars for spectroscopic observation (see, for example, Conti and van den Heuvel 1970). In this case Ap stars that occupied abnormal positions in the color-magnitude diagram would never have been observed. Thus this is a possible source of systematic error that could account for all or part of the apparent deficiency. A possible reason why some Ap stars might occupy abnormal positions in the color-magnitude diagram will be discussed below.

Another source of systematic error of which the author was not fully aware until after his observing run is concerned with the location of Ap stars in the clusters as projected on the sky. It was noted while preparing observing charts that most of the known Ap stars in NGC 2516 lay around the apparent edge of the cluster and only one was located in the central concentration. A similar effect was noted in the rotational velocities by Abt *et al.* (1969) in that the fast rotators (the normal stars) tended to be concentrated toward the center of the cluster. It was pointed out by Abt (1970) that this effect also occurs in the rotational velocities of some other clusters, although not all. As explained in § II*a*, this author, as well as many others, biased his observing programs toward the apparent center of the clusters. If Ap stars really do occur preferentially near the edge of some clusters, then this could also account for all or part of the apparent deficiency. However, the present author is not sure this effect is real, since it is only based on a small number of stars in a single cluster.

If all these systematic effects could be taken into account, they *might* fully explain the apparent deficiency of Ap stars in galactic clusters. On the other hand, these systematic effects might not be important, and the deficiency of Ap stars in clusters could be a clue to the unknown formation process of Ap stars. The present author in his study of seven southern galactic clusters found nearly the same frequency of Ap stars as that found in the larger sample of galactic clusters in spite of the fact that he allowed for Ap stars occurring in peculiar positions in the color-magnitude diagram. This suggests that this systematic effect may not be important, although statistically it could just have been bad luck which caused the author to find the same frequency.

TABLE 12

FREQUENCY OF HOT AND COOL AP STARS

Reference Population	Field Frequency	Cluster Frequency
	Hot Ap Stars	
B5–B8........	0.214	0.073
B5–B9........	0.142	0.047
B5–A0........	0.105	0.035
	Cool Ap Stars	
B9–A5........	0.045	0.034
A0–A5........	0.051	0.045
A1–A5........	0.064	0.067

c) *Frequency as a Function of Type of Ap Stars*

Ap stars can be roughly divided into two temperature classes based on which lines are enhanced in their spectra (Preston 1974). The "hot" group are those usually called Si λ4200, Si, or Si-Cr stars. The "cool" group usually have enhanced Sr, Cr, and/or Eu. While this division into types depends on dispersion and other factors, it can be used as a rough guide to the temperature of Ap stars. Young and Martin (1973) suggested that it was the cool Ap stars that were deficient in clusters. To test this one must first decide where to divide the reference population for the two groups. Table 12 compares the frequency of hot and cool Ap stars in the Bright Star sample and the combined cluster sample for three possible reference populations. From this table one can see that surprisingly it is the hot Ap stars which appear to be deficient in clusters. The information on the breakdown of the Ap stars by type for the Houk and Cowley (1975) catalog was not available to the author at the time of this paper. It is planned, however, that it will be published at a later time.

d) *Frequency as a Function of Age*

Both Havnes and Conti (1971) and Strittmatter and Norris (1971) have suggested time scales between 10^7 and 10^9 years for magnetic braking in Ap stars. From this one might expect a higher frequency of Ap stars in older galactic clusters. In fact this could be invoked as an explanation of the deficiency of Ap stars in clusters, since the average age of the cluster stars in this study is probably less than that of field stars.

To test this the cluster sample in Table 11 is divided into young and old groups. To do this the age determinations by Lindoff (1968) were used whenever available, since they were the largest consistent collection of age determinations. The division between the young and old groups comes at about an age of 3×10^7 years on the scale of Lindoff (1968). In the young group there are 381 B5–A5 normal stars and 14 Ap stars, which is a frequency of 0.035. In the old group there are 363 B5–A5 normal stars and 22 Ap stars which is a frequency of 0.057. The frequency, then, is higher in the older clusters. However, a χ^2

test comparing the old group with the young group gives a χ^2 of 1.6 which corresponds to about the 80 percent confidence level. Thus this result cannot be considered statistically significant.

If one further divides the two age groups into the hot and cool groups, one gets the results shown in Table 13 using B5–B9 as the reference population for the hot group and A0–A5 for the cool group. As can be seen, it is the frequency of Ap stars in the hot group that increases with age. A χ^2 test comparing just the hot Ap stars in the young and old group gives a χ^2 of 2.46 which is the 88.3 percent confidence level. This result, then, is still not statistically significant. For the cool Ap stars, on the other hand, there is no evidence for a deficiency in either the young or old groups and no evidence for any change in the frequency with age. One should be cautious, though, in taking these results at face value, since after subdividing the data into four groups, one is dealing with the statistics of small numbers.

IV. FREQUENCY OF Am STARS

a) Comparison of the Frequency in the Field and Galactic Clusters

Before we can discuss the frequency of Am stars we must again decide on a reference population of normal stars. Am stars are dwarfs (luminosity classes IV or V), and the temperature domain they occupy is approximately 8500 K to 7000 K (Preston 1974). This roughly corresponds to a range of spectral types from A3 to F1. This was the reference population used by Smith (1971). Preston (1974) used A3 to A9 while Abt and Moyd (1973) used A5 to A9. Since the results below are not seriously affected by which range one chooses, we will discuss all the results using a reference population of A5 to A9 stars with luminosity classes IV or V.

We can use the same two field star samples to obtain estimates of the frequency of Am stars in the field. In the Bright Star sample we find 182 normal A5 to A9 dwarfs, 94 Am stars, and 56 marginal Am stars. If we define the frequency of Am stars, f_m, analogously to the definition for f_p given in equation (1), we get f_m = 0.28 for this sample. For the sample of quality 1 classifications from Houk and Cowley (1975) we get 670 A5 to A9 dwarfs, 253 Am stars, and 24 marginal Am stars. This gives a frequency of 0.27 which is in good agreement with the Bright Star sample.

The sample from only the seven clusters studied by the author is obviously too small to contribute a significant result as can be seen in Table 10. However, the combined cluster sample in Table 11 contains 113 normal A5 to A9 dwarfs and 41 Am stars. This is a frequency of 0.26. The agreement between this frequency and that in the two cluster samples is excellent. Overall there is no deficiency of Am stars in galactic clusters.

b) Frequency as a Function of Age

It was suggested by Jaschek and Jaschek (1967) that the frequency of Am stars tended to increase with age. At the time, however, the number known was too small to draw any statistically significant conclusion. Smith (1972) discovered Am stars in the very young association Orion Ic and argued this trend was just a chance coincidence.

Using the division of our sample into young and old groups in Table 11, we find 54 normal A5 to A9 dwarfs and 11 Am stars in the young group. This is a frequency of 0.17. In the old group we find 59 normal A5 to A9 dwarfs and 30 Am stars, which is a frequency of 0.34. A χ^2 test comparing the young and old groups gives a χ^2 of 4.6 which corresponds to the 96.5 percent confidence level. Thus the frequency of Am stars does appear to increase with age, but unlike the Ap stars this increase is at least marginally statistically significant. This marginal significance and the fact that the seven clusters studied here continue to support the previously noted trend both argue that this increase in frequency with age is not entirely due to chance.

Myron Smith has informed the author that one of the five Am stars he found in Orion Ic would probably not be detected at classification dispersion. This would increase the statistical significance of the increase in frequency with age.

V. DISCUSSION

a) Ap Stars

The apparent deficiency of Ap stars suggested by Young and Martin (1973) is confirmed by the present study, but the author could see no evidence that those Ap stars found in clusters were milder than those found in the field. It may be possible to explain this apparent deficiency in terms of the systematic effects discussed above, although this remains to be shown. One of these systematic effects arises because some, but by no means all, Ap stars occur in peculiar positions in the color-magnitude diagram; we should then consider what might cause this. Hartoog (1975) considered and rejected changes in the interior He abundance, magnetic pressure, and the slow rotation of the Ap stars as acceptable explanations of this problem. The best explanation appears to be that flux redistribution caused by the surface abundance peculiarities changes the photometric colors of some Ap stars. Recent space ultraviolet observations have shown that greatly increased ultraviolet opacity in the Ap stars changes the atmospheric structure and redistributes flux into the visible region of the spectrum (Molnar 1973; Leckrone 1973). In cases where the abundances vary over the surface of the star (Pyper 1969), the flux distribution has been observed to vary with the abundances (Molnar 1973, 1975; Leckrone 1974).

Leckrone, Fowler, and Adelman (1974) performed exploratory calculations to investigate the effects of flux redistribution in the spectrum variable Ap stars. They calculated emergent fluxes for a series of flux-constant model atmospheres with enhanced metal-line opacities. The author used their published fluxes to estimate how flux redistribution might affect the position of an Ap star in the color-magnitude diagram.

TABLE 13

FREQUENCY OF HOT AND COOL AP STARS IN THE YOUNG AND OLD CLUSTER GROUPS

	HOT AP STARS			COOL AP STARS		
	B5–B9	Hot Ap	f_p (hot)	A0–A5	Cool Ap	f_p (cool)
Young clusters........	242	8	0.032	139	6	0.041
Old clusters...........	127	10	0.073	236	12	0.048

The results are shown in Figure 3. To obtain these results the author used the flux in the 4865 Å and 5486 Å bands given by Leckrone, Fowler, and Adelman (1974) as the B and V fluxes, respectively. The stars were then transferred to the color-magnitude diagram by assuming $B - V$ colors of -0.03, -0.06, and -0.09 for the normal 11,000 K, 12,000 K, and 13,090 K models, respectively, and by assuming an absolute visual magnitude that would place the normal models on the main sequence. Also shown in Figure 3 is the location of the Ap stars which lie below the main sequence from NGC 2287, NGC 2451, and NGC 3532. The detailed shape of the paths shown in Figure 3 should not be taken seriously, but we can see that the effect does carry a star into the correct region of the color-magnitude diagram to explain many of the Ap stars which lie below the main sequence. Thus this effect appears to be promising as an explanation of the peculiar positions in the color-magnitude diagram of those Ap stars which appear to lie below or to the left of the normal stars.

One might ask why all Ap stars do not lie below the main sequence. The calculations of Leckrone, Fowler,

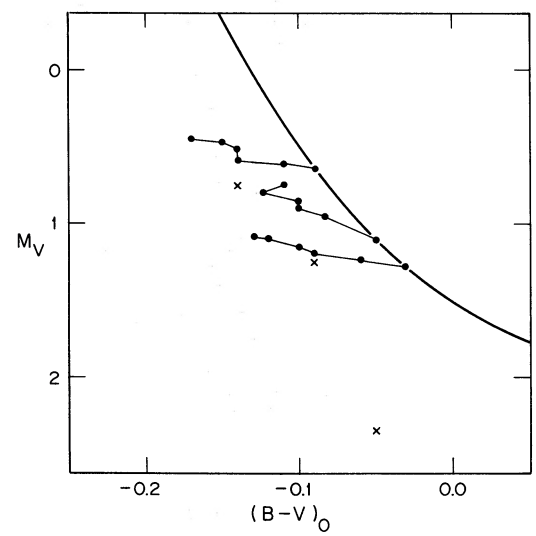

FIG. 3.—Color-magnitude diagram showing the effect of increased metal-line opacities in the calculations of Leckrone *et al.* (1974). *Heavy solid line*, zero-age main sequence. Dots connected by lines are models with the same effective temperature, but varying metal-line opacities. The point on the zero-age main sequence is with normal opacities. The other points have metal opacities enhanced by factors of 5, 20, 50, 100, and 200. The crosses show the location of Ap stars in NGC 2287, NGC 2451, and NGC 3532.

and Adelman (1974) were an attempt to explain the color variations of the spectrum-variable Ap stars. Most of these stars do behave as their calculations predict, getting bluest at the phase of maximum abundance enhancement. However, there are notable exceptions. Preston (1971) points out that three spectrum variables, α^2 CNv, HR 465, and HD 221568, are reddest at the phase of maximum element enhancement. Clearly, the flux redistribution phenomenon is far more complex than the exploratory calculations of Leckrone, Fowler, and Adelman (1974) indicate. In light of these observed photometric properties of the spectrum-variable Ap stars it might even be reasonable to expect Ap stars both above and below the main sequence due to this effect. It remains to be seen whether one can explain Ap stars as far above the main sequence as those found in NGC 3532 and NGC 2451 by this mechanism.

The results concerning the frequency of Ap stars as a function of type and age are more puzzling to interpret. It is possible to understand an increase in the frequency of Ap stars with age in terms of several models which suggest long time scales for magnetic braking (Havnes and Conti 1971; Strittmatter and Norris 1971). However, it is not possible to understand why only the hotter Ap stars would be affected. The reader should be cautioned again, however, that the result on the frequency of Ap stars with cluster age is not statistically significant. The best that could be said is that the present data are not incompatible with theories which predict an increasing frequency of Ap stars with age. It should also be pointed out that of the six cool Ap stars in the young group, the membership of four of them in their clusters could be questioned. Three of these are in the Upper Scorpius association. Garrison (1967) found four cool Ap stars in the Upper Scorpius region. The author has determined radial velocities for two of them. One is badly discordant with the brighter B stars, and the other is marginally discordant. The one with the badly discordant velocity was not considered a member in the present study, but the one with the marginal discordant velocity was included. Details of this work are being prepared for publication. Because of severe nonuniform reddening, it is impossible to draw any conclusions concerning membership for these stars from photometry so one could question the membership of all these cool Ap stars in the Upper Scorpius Region. Also the cool Ap star in NGC 2451 lies well above the main sequence, and its membership in the cluster is questionable. Thus, of the six cool Ap stars in the young group, the membership of four of them might be questioned. By contrast, in the old group, of the 12 cool Ap stars only the one in NGC 3532 is of questionable membership. In light of these considerations it seems best to wait for future clarification of these problems before drawing any conclusions concerning the cool Ap stars.

b) *Am Stars*

The agreement of the Am star frequency in the clusters and the two field samples is amazingly good and therefore perhaps makes the discrepancy for the Ap stars more believable. The interesting result is the considerable variation in the frequency with age which is statistically marginally significant even though the numbers of stars involved are relatively small.

The present theories of Am stars (Watson 1970; Smith 1971) invoke diffusion processes to explain the Am stars. The time scale for the development of the Am characteristics by this process is less than 10^7 years (Vauclair, Vauclair, and Pamjatnikh 1974) as is implied by the existence of Am stars in Ori Ic. It would not seem possible to explain the increase in frequency with age as being associated with the time scale for diffusion. However, before the diffusion processes can begin to act, the star must be slowly rotating. It is generally believed that many Am stars are slow rotators because they are in close binary systems (Abt 1961). Either the angular momentum which ordinarily would have gone into stellar rotation went into orbital angular momentum or tidal interaction has acted to brake the rotation. It may be possible to interpret this increase in frequency then as being associated with tidal braking on a time scale of about 10^8 years. After the star is slowly rotating, then the Am characteristics can develop on the short diffusion time scale. Those Am stars which are found in very young clusters such as Orion Ic can be explained as stars which were intrinsically very slow rotators when they formed or very close systems where tidal interaction is much more efficient than the average in braking the system. The present theory of tidal braking predicts a much longer time scale than that suggested here. However, since the theory also fails to predict the observed tendency toward synchronous rotation in A-type close binary systems, the present author does not consider this a serious problem (for a review see Plavec 1970).

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