COLORS AND VARIABILITY OF MAGNETIC STARS*

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ABSTRACT

An average of 5.4 U, B, V observations has been obtained at random times during a 2-year interval for 70 Ap magnetic stars. The mean colors agree with those of normal dwarfs and giants but for those that are about 0 2 spectral classes earlier (among the B8p–A2p stars). After observational inaccuracies are allowed for, it is found that all magnetic stars are slightly variable in visual light and in $B - V$ and $U - B$ colors. The mean dispersions from the mean are 0.039, 0.017, and 0 023 mag. in V, $B - V$, and $U - B$, respectively. There is no correlation between the amounts of variability in magnitude and in color, although there is a correlation between the dispersions in the two colors. There are no correlations between the photometric dispersions and the (1) magnetic-field strengths, (2) predominant sign or regularity of the magnetic-field variations, (3) spectral peculiarities, (4) mean colors, or (5) line widths.

I. INTRODUCTION

Numerous observers (see Bertaud 1959, 1960, for a bibliography) have shown that some of the peculiar A-type stars are variable in light and/or color with ranges up to about 0.1 mag. One wonders whether all such stars might be variable. Provin (1953) reported several stars to be constant in light within his high photoelectric accuracy, but this does not exclude the possibility of variations of the order of 0.01 mag. In fact, Miczaika (1950) observed six Ap stars and found all six to be variable by about that amount. The determination of the frequency of variability of Ap stars is one aim of this project.

Babcock (1958) has shown that among the Ap stars with lines narrow enough for Zeeman measurements, essentially all have detectable magnetic fields. The temporal character of the fields is either periodic or irregular. Since the determination of this character from magnetic-field measures alone involves a large amount of observing time with large telescopes, as well as a large amount of reduction time, Babcock published a plea (1960*a*) for more photoelectric measures of Ap stars, in the hope that their temporal character and periods could be determined by this easier technique. However, the photoelectric technique will not be successful in those cases in which the photometric variations are small. A photoelectric survey to find those magnetic stars that have appreciable photometric variations seemed like a reasonable first step. The completion of such a survey is a second aim of this project.

Provin (1953*b*) has shown that for about 20 Ap stars their $U - B$ and $B - V$ colors are roughly consistent with the colors of normal main-sequence stars. Deutsch (1947) pointed out that the photometry collected by Öpik from various sources indicated earlier spectral types for the Ap stars than their *Henry Draper* types. Schilt (1952) confirmed this. To see whether the colors of Ap stars are indeed normal but correspond to earlier spectral types is the third aim of this project.

To accomplish these three aims, we proceeded as follows. All the Ap stars (B8p–F0p) in Babcock's (1958) catalogue of magnetic stars were observed at random times during a 2-year interval with conventional photoelectric equipment and U, B, V filters and with the Kitt Peak 16- and 36-inch telescopes. An average of 5.4 measures per star was obtained. The only stars not observed were three visual doubles (Babcock Nos. 50, 51,

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and 63), one star that is too far south for accurate photometry (Babcock No. 86), and Babcock No. 25; HD 215441, which was not in the above catalogue but which has an unusually large magnetic field (Babcock 1960*b*), and γ Virginis N were included. At the same time and with the same equipment, stars thought to be constant in light and color were observed as controls to determine the observational photometric dispersions.

II. PHOTOMETRIC MEASURES AND COLORS

The individual photometric measures are listed in Table 1, in which the serial number comes from Babcock (1958). After comparison (below) with constant stars, we find that the larger differences in measures per star cannot be attributed to observational scatter but must be due to intrinsic variability. Therefore, reasoning that the 16- and 36-inch observations were equally good for detecting this variability, we gave equal weight in the following analysis to observations obtained with the two telescopes, despite the fact that similar observations of other stars (Abt and Golson 1962) showed their accuracies to be different. This procedure is valid as long as the ratio of 16- to 36-inch observations is the same for the magnetic as for the control stars.

The mean light and color measures are listed in Table 2 (cols. 6–8), following the number of observations, n (col. 5). The mean colors for all stars brighter than $V = 5.00$ (*dots*) and between $V = 5.00$ and $V = 6.00$ (*circles*) are plotted in Figure 1. Even after allowance for a mean luminosity increase of 1 mag. (Eggen 1957) over the zero-age main sequence (Sandage 1957), such stars are less than 160 and 250 parsecs distant, respectively, and hence relatively uneffected by interstellar reddening.

We see from Figure 1 that the magnetic stars generally lie along the main-sequence line (Johnson and Morgan 1953) except for most of the late A-type and F0p stars ($B - V = 0.1$–0.4), which, in consistency with their classifications and luminosities as giants, tend to lie below the main-sequence stars. The scatter of the earlier stars about the main-sequence line can be explained partly, but not entirely, by their intrinsic variability, i.e., the observed mean dispersion in $B - V$ alone of 0.032 mag. is larger than the expected dispersion in the mean $B - V$ colors of 0.013 mag. because of their variability and observational errors. After allowance for scatter due to variability, the remaining scatter is no larger than for normal stars. Also, the scatter is not correlated with spectral peculiarities. Thus we confirm Provin's conclusion that the $U - B$ and $B - V$ colors of Ap stars are not different from those of normal dwarfs and giants.

For most of the Ap stars, only *Henry Draper* spectral types are available. In the fourth column of Table 2 we have listed the revised types, whenever available. In Figure 2 are plotted the mean $U - B$ colors against spectral types. The stars tend to lie to the right of the main-sequence line; interstellar reddening, which might be present in a small amount among the $V = 5.00$–6.00 stars (*circles*), would move the stars downward in the diagram. We conclude, in agreement with Deutsch and Schilt, that the B8p–A2p magnetic stars have the colors of normal dwarfs about 0.2 spectral class earlier. The $B - V$ colors show the same effect.

The B8–A2 stars are classified (Morgan, Keenan, and Kellman 1942) mostly by the decreasing strength of their He I lines, either absolutely or relative to the constant strengths of the Si II and Mg II lines or increasing strengths of the Ca II and neutral metallic lines. Therefore, the He I lines in Ap stars are too weak for their colors. The tendency for the K line to be abnormally weak (Morgan, Keenan, and Kellman 1942) for their assigned types may simply be the result of their classification at later types than their colors suggest. We are unable to say whether the discrepancy shown in Figure 2 can be validly attributed to (1) simple misclassifications, due to unusual strengths of the metallic lines, or (2) a bona fide physical discrepancy between ionization and color temperatures, due, perhaps, to large electron pressures. Hunter (1939), Tai (1940), Deutsch (1947), and others have discussed the problem. In support of the misclassification explanation, the Burbidges (1955) found that the ionization temperature of α^2 CVn

TABLE 1

INDIVIDUAL PHOTOMETRIC MEASURES

Babcock No	U T Date (mo -day-year)	Telescope (inches)	V (mag)	$B-V$ (mag)	$U-B$ (mag.)
1	11–25–59	16	6 95	−0 005	+0 048
	12–16–59	16	6 91	+ 061	+ 017
	9–23–60	16	6 90	+ 078	+ 082
	12–14–60	36	6 90	+ 071	− 009
3	12– 2–59	16	6 76	+ 018	+ 062
	12–16–59	16	6 74	− 004	+ 077
	9–23–60	16	6 69	+ 024	+ 066
	12–14–60	36	6 69	+ 021	− 033
	10–11–61	16	6 69	+ 024	+ 029
4	12– 2–59	16	6 33	+ 124	− 096
	12–16–59	16	6 30	+ 081	− 123
	12–14–60	36	6 27	+ 143	− 123
	9– 5–61	16	6 30	+ 153	− 055
	10–11–61	16	6 29	+ 131	− 130
	10–15–61	16	6 29	+ 143	− 108
5	11–18–59	16	5 57	− 031	− 220
	12– 2–59	16	5 64	− .071	− 208
	12–16–59	16	5 58	− 071	− 212
	12–14–60	36	5 60	− 076	− 253
	10–11–61	16	5 55	− 044	− 263
6 .	10–15–59	16	6 63	− 052	− 106
	11–26–59	16	6 57	− .057	− .160
	12– 2–59	16	6 65	− .063	− 140
	12–16–59	16	6 43	+ .043	− 139
	12–14–60	36	6 57	− 066	− 183
	10–11–61	16	6 55	− 061	− 173
7	12–16–59	16	7 94	+ .233	+ .262
	12–14–60	36	7 94	+ 268	+ 113
	9– 5–61	16	7 93	+ 255	+ 240
	10–11–61	16	7 91	+ .279	+ 144
8	10–14–59	16	5 71	+ .206	+ .141
	10–15–59	16	5 74	+ .171	+ 127
	12–16–59	16	5 83	+ 142	+ 097
	12–14–60	36	5 87	+ .151	+ 072
	9– 5–61	16	5 85	+ .175	+ 162
	10–11–61	16	5 82	+ 171	+ 037
9	10–14–59	16	5 03	+ 037	− .211
	10–15–59	16	5 05	+ 028	− 243
	11–11–59	16	5 14	− 025	− .252
	12–16–59	16	5 11	− .011	− 199
	12–14–60	36	5 13	− 037	− 250
	10–11–61	16	5 14	− 008	− 296
11..	10–14–59	16	6 16	+ .362	+ .124
	11–11–59	16	6 23	+ 322	+ 114
	11–25–59	16	6 25	+ 255	+ 144
	11–26–59	16	6 26	+ 275	+ 138
	12–14–60	36	6 28	+ 275	+ 059
12..	11–11–59	16	6 70	+ 162	+ 161
	12–16–59	16	6 71	+ 138	+ 113
	12–14–60	36	6 78	+ 108	+ 088
	4–13–61	16	6 65	+ 103	+ 074
	10– 3–61	36	6 70	+ 120	+ 129
	10–11–61	16	6 73	+0 139	+0 103

TABLE 1—*Continued*

Babcock No	U T Date (mo -day-year)	Telescope (inches)	V (mag)	$B-V$ (mag)	$U-B$ (mag)
14	4-12-61	16	8 30	+0 119	+0 117
	10- 3-61	36	8 36	+ 131	+ 091
	10-11-61	16	8 41	+ 119	+ 083
15	10-15-59	16	5 15	− 084	− 470
	10-22-59	16	5 15	− 123	− 492
	11-11-59	16	5 22	− 126	− 471
	11-25-59	16	5 22	− 134	− 455
	4-12-61	16	5 19	− 125	− 460
17	10-14-59	16	7 30	+ 035	− 147
	10-22-59	16	7 36	+ 025	− 150
	11-25-59	16	7 25	+ 083	− 148
	3-31-60	16	7 25	+ 044	− 157
	3-12-61	16	7 22	+ 051	− 187
18	10-14-59	16	7 07	− 046	− 393
	10-22-59	16	7 13	− 066	− 408
	11-25-59	16	7 09	− 053	− 381
	3-31-60	16	7 08	− 069	− 398
	3-12-61	16	7 02	− 082	− 405
20	10-14-59	16	3 20	− 051	− 367
	10-22-59	16	3.27	− 019	− 362
	11-25-59	16	3 28	− 101	− 342
	3-31-60	16	2 97	− 150	− 387
	3-12-61	16	3 36	− 167	− 414
22	11-25-59	16	7 16	+ 119	+ 062
	3-31-60	16	7 16	+ 084	+ 052
	11-29-60	16	7 12	+ 086	+ 071
	3-12-61	16	7 10	+ 101	+ 038
	4- 7-61	36	7 16	+ 090	+ 017
24	11-25-59	16	6 29	+ 036	+ 023
	3-31-60	16	6 16	− 007	+ 015
	3-12-61	16	6 26	+ 019	− 014
	4- 7-61	36	6 25	+ 038	− 079
	4-12-61	16	6 26	+ 015	+ 046
27	3-31-60	16	7 50	+ 317	+ 060
	3-12-61	16	7 60	+ 328	+ 050
	4- 7-61	36	7 60	+ 354	+ 044
	4-12-61	16	7 61	+ 326	+ 098
	4-13-61	16	7 57	+ 371	+ 063
28	3-31-60	16	6 08	+ 160	+ 050
	3-12-61	16	5 95	+ 146	+ 047
	4- 7-61	36	6 06	+ 139	+ 028
	4-12-61	16	5 97	+ 140	+ 086
	4-13-61	16	5 96	+ 135	+ 042
29	3-31-60	16	5 74	− 061	− 096
	3-12-61	16	5 53	− 024	− 170
	4- 7-61	36	5 65	− 089	− 121
	4-12-61	16	5 62	− 090	− 109
	4-13-61	16	5 60	− 095	− 156
30	3-12-61	16	6.65	+ 090	− 001
	4- 7-61	36	6 79	+0 054	+0 045

TABLE 1—*Continued*

Babcock No	U T Date (mo -day-year)	Telescope (inches)	V (mag)	$B-V$ (mag)	$U-B$ (mag)
31	3-30-60	16	5 68	−0 043	−0 030
	3-31-60	16	5 72	− 011	000
	5-13-60	16	5 76	− 056	− 036
	3-12-61	16	5 69	+ 018	− 080
	4- 7-61	36	5 72	− 027	− 020
32	3-30-60	16	5 60	− 133	− 276
	3-31-60	16	5 71	− 100	− 230
	3-12-61	16	5 64	− 108	− 289
	4- 7-61	36	5 69	− 118	− 242
33	3- 2-61	36	5 47	− 054	− 125
	3-12-61	16	5 43	− 051	− 110
	3-23-61	16	5 44	− 060	− 113
	4- 7-61	36	5 49	− 062	− 099
	4-12-61	16	5 33	− 050	− 101
	4-13-61	16	5 43	− 050	− 144
34	3- 2-61	36	5 26	− 122	− 469
	3-12-61	16	5 24	− .119	− 462
	3-23-61	16	5 22	− 100	− 445
	4- 7-61	36	5 27	− 112	− 445
	4-12-61	16	5 24	− 113	− 388
	4-13-61	16	5 24	− 118	− 436
35	3- 2-61	36	4 93	− 047	− 138
	3-12-61	16	4 91	− 044	− 135
	3-23-61	16	4 92	− 050	− 124
	4- 5-61	36	4 99	− 083	− 115
	4-12-61	16	4 94	− 063	− 064
	4-13-61	16	4 91	− 054	− 124
36	3- 3-60	16	6 00	− 062	− 117
	3-30-60	16	5 97	− 075	− 121
	3-31-60	16	6 15	− 056	− 063
	4-30-60	36	6 06	− 065	− 106
	3-12-61	16	5 96	− 063	− 096
37	3- 3-60	16	6 09	+ 225	+ 093
	3-30-60	16	6 09	+ 189	+ 110
	3-31-60	16	6 16	+ 215	+ 138
	4-30-60	36	6 15	+ 225	+ 139
	5- 1-60	36	6 23	+ 197	+ 130
	3- 2-61	36	6 14	+ 183	+ 114
38	4-30-60	36	5 29	− 058	− 102
	5- 1-60	36	5 40	− 069	− 123
	5-13-60	16	5 27	− 056	− 130
	6-16-60	16	5 39	− 113	− 200
	3- 2-61	36	5 28	− 052	− 119
	3-23-61	16	5 27	− 059	− 110
40	3- 3-60	16	6 39	+ 068	− 005
	3-30-60	16	6 36	+ 058	+ 003
	3-31-60	16	6 50	+ 090	+ 062
	4-26-60	36	6 55	+ 049	+ 032
	4-30-60	36	6 45	+ 062	+ 032
	5-13-60	16	6 43	+ 056	+ 014
41	2-22-61	36	4 62	− 115	− 460
	3- 2-61	36	4 61	− 150	− 515
	3-23-61	16	4 63	− 050	− 495
	4-12-61	16	4 65	− 063	− 448
	4-13-61	16	4 64	− .111	− 532
	6- 3-61	36	4 66	−0 105	−0 478

TABLE 1—*Continued*

Babcock No	U T. Date (mo -day-year)	Telescope (inches)	V (mag)	$B-V$ (mag)	$U-B$ (mag)
42	2–22–61	36	2 76	+0 363	−0 039
	3– 2–61	36	2 74	+ 349	− 051
	3–23–61	16	2 74	+ 357	− 025
	4– 1–61	36	2 74	+ 363	− 048
	4– 4–61	36	2 74	+ 355	− 035
	4– 5–61	36	2 74	+ 337	− 026
	4–12–61	16	2 76	+ 361	− 022
	6– 3–61	36	2.73	+ 337	− 032
43	3– 3–60	16	6 32	− 036	− 093
	3–30–60	16	6 29	− 033	− 094
	3–31–60	16	6 38	− 026	− 041
	4–30–60	36	6 39	− 049	− 061
	5–13–60	16	6 33	− 064	− 067
	2–22–61	36	6 39	− 036	− 040
	3– 2–61	36	6 33	− 068	− 069
44	5–13–60	16	2 96	− 149	− 372
	3– 2–61	36	2 87	− 086	− 352
	4– 1–61	36	2 93	− 111	− 341
	4–12–61	16	2 92	− 117	− 263
45 .	3– 3–60	16	7 77	+ 251	+ 013
	3–30–60	16	7 82	+ 215	− 010
	3–31–60	16	7 84	+ 295	+ 089
	4– 1–60	16	7 81	+ 262	+ 056
	4–30–60	36	7 85	+ 240	+ 064
	5–13–60	16	7 80	+ 240	+ 044
	2–22–61	36	7 85	+ 252	+ 057
	3– 2–61	36	7 81	+ 267	+ 051
46...	4– 1–60	16	4 93	+ 032	− 013
	4–30–60	36	4 99	+ 027	+ 004
	5– 1–60	36	4.92	+ 020	+ 005
	5–13–60	16	4 92	+ 086	− 077
	3– 2–61	36	4 93	+ 027	− 007
47.	3– 3–60	16	9 88	+ 098	+ 062
	3–30–60	16	9 89	+ 063	+ 075
	3–31–60	16	9 94	+ 131	+ 108
	5–13–60	16	9 91	+ 080	+ 088
	2–22–61	36	9 99	+ 091	+ 081
	4– 1–61	36	9 94	+ 089	+ 057
	4– 4–61	36	9 98	+ 086	+ 077
	6– 3–61	36	9 88	+ 093	+ 086
48	3– 3–60	16	5 93	+ 011	+ 020
	3–30–60	16	5 84	− 004	− 052
	4–13–60	16	5 88	− 042	− 086
	4–30–60	36	5 93	− 036	− 059
	5–13–60	16	5 89	+ 041	− 029
49	4– 3–60	36	7 07	+ 035	− 007
	4–30–60	36	7 13	− 005	− 036
	5– 1–60	36	7 13	− 006	− 007
52	3– 3–60	16	6 37	− 147	− 316
	3–30–60	16	6 37	− 129	− 179
	4– 1–60	16	6 39	− 132	− 275
	4–13–60	16	6 36	− 204	− 223
	4–23–60	36	6 41	− 125	− 277
	5–13–60	16	6 38	− 104	− 270
	6–16–60	16	6 38	− 135	− 234
	6–22–60	16	6 35	−0 078	−0 307

TABLE 1—*Continued*

Babcock No	U T Date (mo -day-year)	Telescope (inches)	V (mag)	B−V (mag)	U−B (mag)
53	3– 3–60	16	7 45	+0 144	+0 038
	4–23–60	36	7 60	+ 125	+ 085
	5–13–60	16	7 56	+ 168	+ 069
	6–22–60	16	7 59	+ 146	+ 056
	4– 1–61	36	7 59	+ 116	+ 067
	6– 3–61	36	7 54	+ 138	+ 048
54	3– 3–60	16	7 97	+ 017	− 101
	4–23–60	36	8 09	− 044	− 115
	5–13–60	16	8 02	− 003	− 020
	6– 3–61	36	7 98	− 014	− 035
55	4–13–60	36	3 68	+ 315	+ 041
	4–23–60	36	3 68	+ 279	+ 116
	5–12–60	16	3 67	+ 287	+ 129
	6–16–60	16	3 72	+ 281	+ 175
	6–22–60	16	3 68	+ 204	+ 033
	6–23–60	16	3 71	+ 284	+ 136
	7–12–61	36	3 67	+ 245	+ 115
56	3– 3–60	16	6 67	+ 392	+ 112
	4– 5–61	36	6 71	+ .372	+ 149
	4–13–61	16	6 62	+ 382	+ 161
	4–23–61	36	6 70	+ 366	+ 135
57	4–13–60	36	4 97	− 106	− .264
	4–23–60	36	5 01	− 045	− 166
	5–13–60	16	4 97	− 033	− 196
	6–23–60	16	5 08	− 036	− 145
	7–12–61	36	4 96	− 094	− .210
58	4–13–60	36	4 51	+ 106	+ .058
	4– 4–61	36	4 45	+ 133	+ 108
	4– 5–61	36	4 46	+ 118	+ 134
	4–13–61	16	4 46	+ 138	+ 128
	4–23–61	36	4 45	+ 116	+ .113
59	4–23–60	36	5 27	− 030	+ .004
	5–13–60	16	5 21	− 006	− 010
	6–16–60	16	5 25	+ 019	+ 005
	6–23–60	16	5 25	− 017	− 107
	7–12–61	36	5 23	− 032	− 004
	6– 3–61	36	5 21	− 028	− 004
60	4–23–60	36	4 82	+ 085	+ 057
	6–23–60	16	4 81	+ 088	+ 056
	4– 1–61	36	4 82	+ 079	+ 044
	6– 3–61	36	4 78	+ 062	+ 027
	7–12–61	36	4 81	+ 072	+ 059
62 ..	4– 1–60	16	6 32	+ 021	+ 019
	5–13–60	16	6 27	+ 063	+ 043
	6–23–60	16	6 30	+ 023	+ 059
	9–27–60	16	6 26	+ 053	+ 054
	4– 4–61	36	6 34	+ 024	+ 038
	5– 4–61	36	6 32	+ 028	+ 011
64	5–13–60	16	6 47	+ 092	+ 078
	6–16–60	16	6 34	+ 107	+ 089
	6–23–60	16	6 39	+ 073	+ 081
	9–27–60	16	6 46	+ 087	+ 104
	4– 1–61	36	6 49	+ 075	+ 050
	6– 3–61	36	6 45	+ 070	+ 068
	7–12–61	36	6 48	+0 072	+0 083

TABLE 1—*Continued*

Babcock No	U T. Date (mo -day-year)	Telescope (inches)	V (mag)	$B-V$ (mag.)	$U-B$ (mag)
65	5–13–60	16	6 50	+0 027	−0 126
	6–16–60	16	6 41	+ 001	− 049
	6–23–60	16	6 42	+ 009	− 103
	9–27–60	16	6 53	+ 022	− 053
	4– 1–61	36	6 57	+ 009	− 111
	4– 4–61	36	6 58	+ 013	− 097
66	5–13–60	16	5 89	+ 260	+ 091
	6– 1–60	36	5 91	+ 243	+ 078
	6–16–60	16	5.83	+ 220	+ 098
	6–23–60	16	5 83	+ 286	+ 061
	7–12–61	36	5 91	+ 240	+ 094
67	6–16–60	16	5 06	− 023	− 386
	6–23–60	16	5 08	− 063	− 397
	9–27–60	16	5 14	− 071	− 379
	4– 4–61	36	5 16	− 090	− 425
	4–23–61	36	5 16	− 080	− 415
	7–12–61	36	5 14	− 072	− 404
70	6– 1–60	36	6 67	− 048	− 261
	6–16–60	16	6 48	− 042	− 232
	6–23–60	16	6 56	− 033	− 225
	7–13–60	16	6 64	000	− 168
	9–14–60	16	6 64	− 014	− 215
	9–27–60	16	6 65	− 048	− 204
	6– 3–61	36	6 64	− 040	− 240
	7–12–61	36	6 62	− 031	− 280
71	6– 3–61	36	5 30	− 064	− 224
	6– 9–61	36	5 33	− 082	− 219
	9– 5–61	16	5 30	− 067	− 212
	10–16–61	16	5.28	+ 011	− 261
72	6 –1–60	36	5 64	+ 160	± 056
	6–16–60	16	5.62	+ 190	+ 043
	9–14–60	16	5 64	+ 194	+ 105
	4–23–61	36	5 67	+ 165	+ 059
	7–12–61	36	5 64	+ 228	+ 062
	10–15–61	16	5 61	+ 234	+ 092
74	9–14–60	16	8 11	+ 276	+ 201
	9–27–60	16	8.13	+ 206	+ 227
	4–23–61	36	8 17	+ 210	+ 183
	6– 9–61	36	8 17	+ 193	+ 193
75	9–27–60	16	7 35	− 023	+ 014
	4–23–61	36	7 38	− 022	000
	6– 3–61	36	7 35	− 032	+ 013
	6– 9–61	36	7 39	− 024	+ 002
	8–27–61	16	7 36	− 038	+ 021
	10–15–61	16	7 37	− 023	+ 016
76	6– 1–60	36	6 69	− 080	− 262
	9–14–60	16	6 67	− 069	− 219
	9–27–60	16	6 62	− 066	− 218
	4–23–61	36	6 70	− 079	− 249
	6– 3–61	36	6 65	− 072	− 243
	6– 9–61	36	6 67	− 073	− 245
77	6– 1–60	36	5 21	+ 068	+ 083
	6–23–60	16	5 18	+ 041	+ 106
	7–13–60	16	5 16	+ 090	+ 116
	4–23–61	36	5 22	+ 078	+ 106
	7–12–61	36	5 20	+0 095	+0 104

TABLE 1—*Continued*

Babcock No.	U.T. Date (mo.-day-year)	Telescope (inches)	*V* (mag)	*B−V* (mag)	*U−B* (mag.)
78	10–22–59	16	4 66	+0 274	+0 114
	6– 1–60	36	4 70	+ .244	+ 101
	6–16–60	16	4 63	+ 244	+ 083
	6–23–60	16	4 58	+ 317	+ 055
79	11–26–59	16	4 81	+ .019	− 061
	9– 5–61	16	4 83	000	− 012
	10– 3–61	36	4.79	− 011	− 038
	10–15–61	16	4 87	+ 087	− 188
	11–11–61	16	4.77	000	− 175
82	10–22–59	16	8 18	− .034	− 446
	11–26–59	16	8 29	+ 022	− 419
	6–23–60	16	8 13	− 043	− 471
	10–15–61	16	8 26	− 013	− 494
	11–11–61	16	8 11	− 091	− 415
HD 215-441	9–28–60	16	8 79	+ 009	− 498
	10–21–60	16	8 78	+ 109	− 503
	9– 5–61	16	8 80	− 003	− 479
	10–15–61	16	8 83	+ 041	− 518
	11–11–61	16	8 77	− 010	− 446
83	10–22–59	16	7 96	+ 088	+ 112
	11–26–59	16	7 91	+ 081	+ 079
	9–14–60	16	7 90	+ .101	+ 085
	10–15–61	16	7 90	+ 021	+ 087
	11–11–61	16	7 81	+ 095	+ 110
84	10–15–61	16	4 90	+ 010	− 040
	10–16–61	16	4 92	+ .047	− 033
	11–11–61	16	4 87	+ 038	+ 027
	11–13–61	36	4 89	+ 035	+ 020
85	9– 5–61	16	4 39	− 088	− 335
	10– 3–61	36	4 36	− 141	− 379
	11–11–61	16	4 37	− 097	− 424
87	9–14–60	16	5 16	− 253	− 451
	12– 7–60	16	5 16	− .100	− 449
	9– 5–61	16	5 18	− 139	− 401
	10– 3–61	36	5 21	− 143	− 444
	11–11–61	16	5 16	− 208	− 415
88.	12– 2–59	16	6 35	− 049	− 366
	9–14–60	16	6 35	− 048	− 358
	12– 7–60	16	6 42	− 127	− 278
	10– 3–61	36	6 40	− 057	− 351
	10–11–61	16	6 39	− 075	− 350
	10–15–61	16	6 32	− 081	− 364
89	12– 2–59	16	6 16	+ 008	− 034
	9–14–60	16	6 14	+ 044	− 029
	12– 7–60	16	6 10	− 011	− 002
	10– 3–61	36	6 19	+ 008	− 053
	10–11–61	16	6 13	+ 049	− 054
	10–15–61	16	6 14	−0 008	−0 061

TABLE 2

MEAN PHOTOMETRY AND DISPERSIONS

Babcock No (1)	HD (2)	Name (3)	Spectral Type (4)	n (5)	Magnitudes ⟨V⟩ (6)	⟨B−V⟩ (7)	⟨U−B⟩ (8)	σ(V) (9)	σ(B−V) (10)	σ(U−B) (11)
1...	2453	...	A2p	4	6.92	+0.051	+0 034	0 024	0 038	0 039
3...	8441	...	A2p	5	6 71	+ 017	+ 040	034	012	045
4..	9996	HR 465	A0p	6	6 30	+ .129	− 106	020	026	028
5 ...	10221	43 Cas	A0p	5	5 59	− .059	− 231	034	020	025
6 ..	10783	...	A2p	6	6 57	− 057	− 150	077	008	028
7 .	11187	...	A0p	4	7 93	+ .259	+ 189	014	020	072
8 ..	15144	HR 710	A4p	6	5 80	+ .169	+ 106	064	022	046
9.	18296	21 Per	A0p	6	5 10	− 003	− 242	048	029	034
11 ..	20210	HR 976	A7[1]	5	6 24	+ .298	+ 116	046	043	034
12 .	22374	9 Tau	A2p	6	6 71	+ .128	+ 111	042	022	031
14 .	25354	...	A0p	3	8 36	+ .123	+ 097	055	007	018
15 .	25823	41 Tau	A0p	5	5 19	− 118	− 470	035	020	014
17 .	30466	...	A0p	5	7 28	+ .048	− 158	055	022	017
18 .	32633		B9p	5	7 08	− 063	− 397	041	014	011
20	33904	μ Lep	B9p	5	3 41	− .098	− 374	084	063	027
22 .	42616	...	A2p	5	7 14	+ .096	+ 048	028	014	021
24 .	49976	HR 2534	A0p	5	6 24	+ .020	− 002	049	018	048
27 ..	56495	...	A3p	5	7 58	+ .339	+ 063	045	022	021
28 .	65339	53 Cam	A2p	5	6 00	+ .144	+ 051	061	010	022
29 .	68351	15 Cnc	A0p	5	5 63	− 072	− 130	076	030	031
30	71866	...	A0p	2	6 72	+ 072	+ 022	...	...	...
31 .	72968	3 Hya	A2p	5	5 71	− 024	− 033	031	029	030
32 .	74521	49 Cnc	A0p	4	5.66	− .115	− 259	050	014	028
33 .	77350	ν Cnc	B9p	6	5.43	− .054	− 115	055	005	014
34	78316	κ Cnc	B8p	6	5.24	− 114	− 441	017	008	029
35	89822	HR 4072	A0p	6	4 93	− 057	− 117	030	014	027
36	90569	45 Leo	A2p	5	6 03	− .064	− 101	078	007	027
37 .	98088	HR 4369	gF0p	6	6 14	+ 207	+ 120	052	019	018
38	108662	17 Com A	A0p	6	5 32	− .068	− 131	061	023	035
40	110066	HR 4816	A4p	6	6 45	+ 064	+ 023	075	014	024
41	110073	HR 4817	B8p	6	4 64	− 099	− 488	020	037	032
42	110379	γ Vir N	F0V	8	2 74	+ 353	− 035	015	011	011
43	111133	HR 4854	A4p	7	6 35	− 045	− 066	039	016	022
44	112413	α^2 CVn	A0p	4	2 92	− .116	− 332	037	026	048
45	115708	...	A2p	8	7 82	+ 253	+ 045	045	023	031
46 .	118022	78 Vir	A2p	5	4 94	+ 038	− 018	030	027	034
47 .	...	BD+46° 1913	Ap	8	9 93	+ 091	+ 079	043	019	016
48	125248	HR 5355	A0p	5	5 89	− .006	− 041	037	034	040
49	126515	...	A2p	3	7 11	+ 008	− 017	034	023	017
52	133029	HR 5597	A0p	8	6 38	− 132	− 260	018	036	046
53	134793		A3p	6	7 56	+ 139	+ 060	056	018	017
54	135297	...	A0p	4	8 02	− .011	− 068	054	025	047
55	137909	β CrB	F0p	7	3 69	+ 271	+ 106	020	036	052
56 .	137949	33 Lib	F0p	4	6.68	+ 378	+ 139	041	011	021
57	143807	ι CrB	A0p	5	5 00	− 045	− 196	050	029	046
58 . .	148898	ω Oph	A7p	5	4 47	+ 122	+ 108	025	013	030
59 ...	151525	45 Her	A0p	6	5 24	− .016	− 004	024	020	008
60 ..	152107	52 Her	A4p	5	4 81	+ 079	+ 049	016	010	013
62	153882	HR 6326	A4p	6	6 30	+ 035	+ 037	031	018	019
64	171586	...	A2p	7	6 44	+ 082	+ 079	051	014	017
65 .	173650	HR 7058	A0p	6	6 50	+ 013	− 090	072	010	032
66. .	176232	10 Aql	A4p	5	5 87	+ 250	+ 084	041	025	015
67	179761	21 Aql	B8	6	5 12	− 066	− 401	042	023	017
70	184905	...	A0p	8	6 61	− .032	− 228	062	017	034
71...	187474	HR 7552	A0p	4	5 30	− 050	− 229	021	042	.022
72...	188041	HR 7575	A5p	6	5 64	+ 195	+ 069	:021	031	024
74....	191742	...	A7p	4	8 14	+0 221	+0 201	0 030	0 037	0 019

[1] Osawa (1959) classified HD 20210 as Am.

TABLE 2—*Continued*

Babcock No (1)	HD (2)	Name (3)	Spectral Type (4)	*n* (5)	Magnitudes ⟨*V*⟩ (6)	⟨*B*−*V*⟩ (7)	⟨*U*−*B*⟩ (8)	σ(*V*) (9)	σ(*B*−*V*) (10)	σ(*U*−*B*) (11)
75	192678		A4p	6	7 37	−0 027	+0 011	0 016	0 007	0 008
76	192913	. . .	A0p	6	6 67	− 073	− 239	029	005	017
77	196502	73 Dra	A2p	5	5 19	+ 074	+ 103	024	021	012
78	201601	γ Equ	A7p	4	4 64	+ 270	+ 088	051	035	026
79	203006	θ^1 Mic	A2p	5	4 81	+ 019	− 095	038	040	081
82	215038		A0p	5	8 19	− 032	− 449	.078	.031	034
. .	215441		A0	5	8 79	+ 029	− 489	025	049	.028
83	216533	. .	A2p	5	7 90	+ 077	+ 095	053	032	015
84	220825	κ Psc	A2p	4	4 89	+ 032	− 006	021	016	035
85	221507	β Scl	B9p	3	4 37	− 107	− 379	016	028	045
87	223640	108 Aqr	A0p	5	5 17	− 169	− 432	022	061	038
88	224801	HR 9080	A0p	6	6 37	− 073	− 344	037	030	033
89	4778	HR 234	A0p	6	6 14	+0 015	−0.039	0 030	0 026	0 022

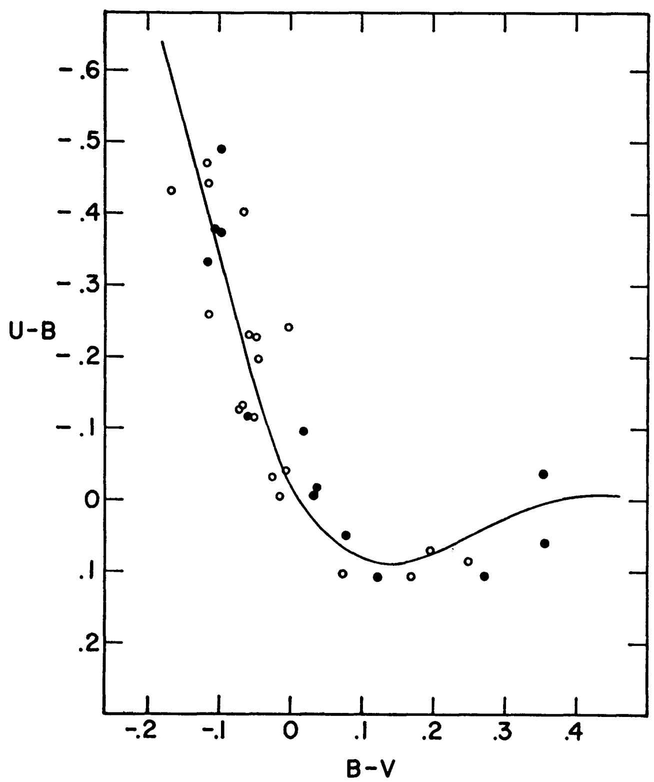

FIG 1.—The color-color diagram for Ap magnetic stars brighter than $V = 5.00$ (*dots*) and with V between 5.00 and 6 00 mag (*circles*). The line represents the relation for main-sequence stars that are primarily non-zero-age (Johnson and Morgan 1953).

(classified A0p) is about 1000° higher (0.12 spectral classes) than the A0 IV standard, γ Gem.

III. VARIABILITY

The dispersions in visual magnitude, V, were computed for each star from

$$\sigma(V) = \left[\frac{\Sigma(V-\bar{V})^2}{n-1}\right]^{1/2}, \qquad (1)$$

where the bar indicates the mean value and n is the number of measures; similar equations were used for $\sigma(B-V)$ and $\sigma(U-B)$. The individual dispersions are listed in the last three columns of Table 2. The distributions of these dispersions are plotted in Figures 3–5 (labeled "observed").

An estimate of the accuracy of these dispersions may be obtained from the comparison with other observers given in Table 3. The numbers of observations are given in parentheses. The fact that the present dispersions are 0.01–0.02 mag. larger than those by Provin and Stibbs is undoubtedly due to their use of nearby comparison stars. If we had employed the same more accurate technique, the dispersions for both magnetic and constant stars would have been reduced slightly, but we doubt that the principal results would be effected. McCuskey's measures were photographic. After these qualifications, the general agreement in Table 3 is heartening; in view of the small number of measures per star in the present study, errors in dispersions by factors of 2 or more should be expected for some stars.

The constant stars used for controls were as follows: (1) 42 stars in the Cassiopeia-Taurus stream, of which 21 have $V = 2.91$–4.99 and 21 have $V = 5.00$–6.72; (2) 34 north

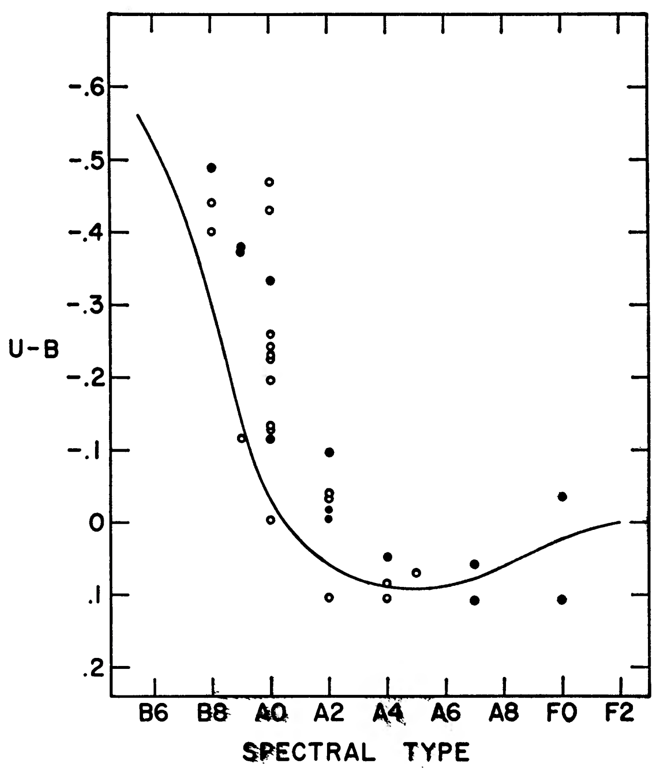

FIG. 2.—The mean $U-B$ colors of magnetic stars are plotted against their spectral types for stars brighter than $V = 5.00$ (*dots*) and with V between 5.00 and 6.00 mag. (*circles*). The line represents the mean relation for normal dwarfs (Johnson and Morgan 1953).

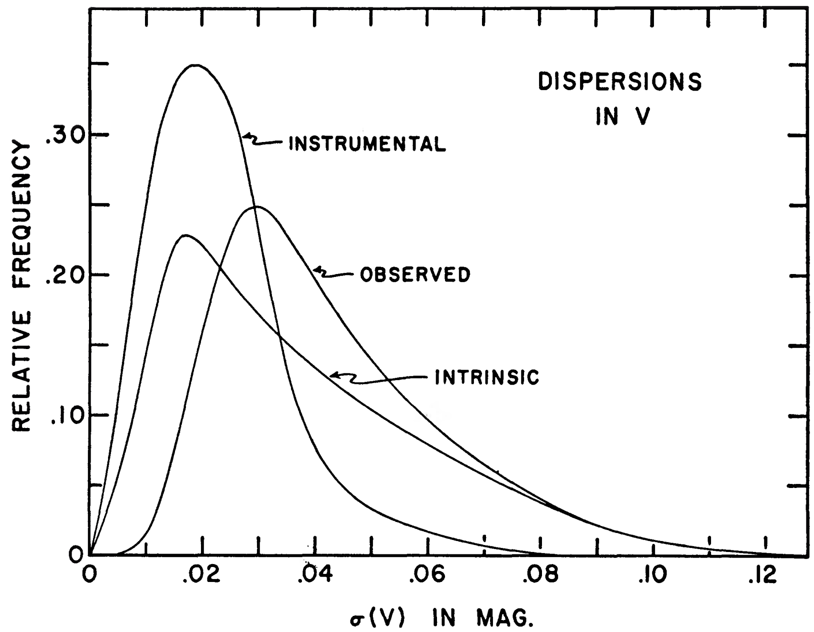

FIG. 3.—The distribution (labeled "observed") of dispersions about their mean visual magnitudes is given for 70 magnetic stars. The curve marked "instrumental" indicates the expected distribution of dispersions, due to observational inaccuracies, for constant stars. The curve marked "intrinsic" gives the deduced distribution of dispersions due to intrinsic variability.

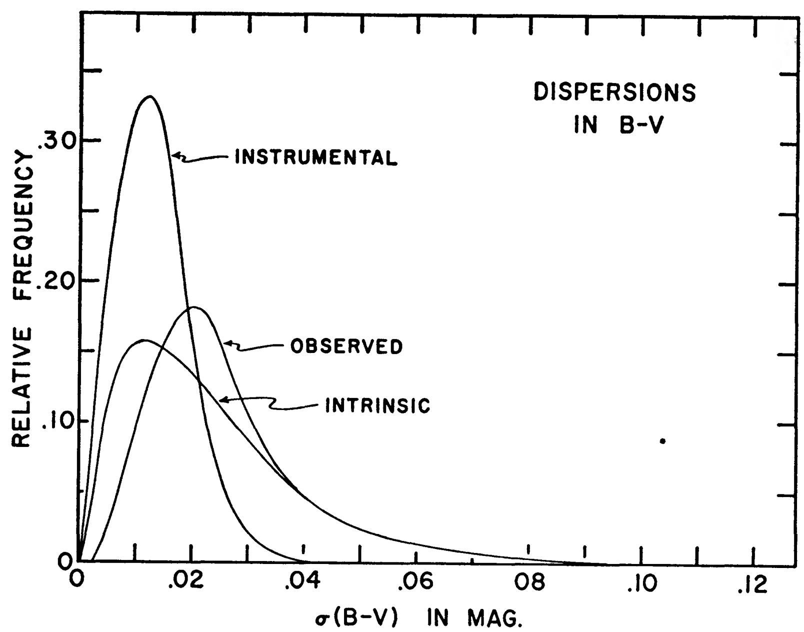

FIG. 4.—The meaning of three curves is the same as in Fig. 3, except that here all the dispersions per star are in $B - V$.

equatorial polar stars (Abt and Golson 1962), of which 25 have $V = 7.95$–8.99 and 9 have $V = 9.00$–10.95. All these stars were measured about three times during the same time interval as were the magnetic stars and with the same equipment; in each case the 36-inch telescope was used one-fourth to half the time and the 16-inch the remainder. Dispersions were computed in the same manner as for the magnetic stars. It was found that the mean dispersions in magnitude and colors increased rapidly by a factor of 2 between $V \doteq 6.0$ and $V = 9.0$; above and below this range they were rather constant. The distribution of dispersions for stars of the same mean magnitudes as the magnetic stars are shown in Figures 3–5 and are marked "instrumental," indicating that these are the distributions expected, because of observational inaccuracies, if the magnetic stars were all constant.

It is seen that the observed photometric dispersions for the magnetic stars are con-

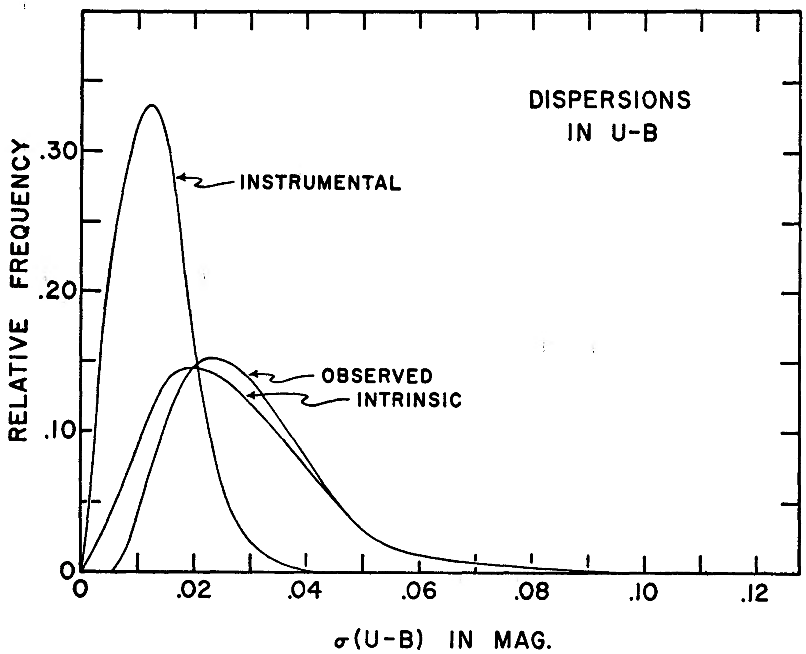

FIG. 5.—The meaning of the three curves is the same as in Fig. 3, except that here all the dispersions per star are in $U - B$.

TABLE 3

COMPARISON WITH DISPERSIONS BY OTHER OBSERVERS

Bab-cock No.	Source	Result (mag)	Present Result (mag)
44 . .	Provin (1953*b*)	{σ(*Y*) =0 017 (9) {σ(*B*−*Y*)= 008 (9)	σ(*V*) =0 037 (4) σ(*B*−*V*)= 026 (4)
48	Stibbs (1950)	σ(*B*) = 018 (405)	σ(*V*) = 037 (5)
77	McCuskey (1934)	σ(*B*) = 061 (59)	σ(*V*) = 024 (5)
77 .	Provin (1953*a*)	{σ(*Y*) = 012 (13) {σ(*B*−*Y*)= 011 (13)	σ(*V*) = 024 (5) σ(*B*−*V*)= 021 (5)
88	Provin (1953*b*)	{σ(*Y*) = 017 (28) {σ(*B*−*Y*)=0 008 (28)	σ(*V*) = 037 (6) σ(*B*−*V*)=0 030 (6)

siderably greater than those expected for constant stars. The problem, then, is to determine the distributions of intrinsic dispersions which, when combined with the observed instrumental distributions, will duplicate the observed distributions of dispersions. We have already implicitly assumed that the observed and instrumental scatter per star can be described by a Gaussian distribution. Let us furthermore assume that the intrinsic variability of a typical star can also be described by a Gaussian distribution of deviations from a mean magnitude or color. If $O(\sigma_0)$, $I(\sigma_i)$, and $R(\sigma_r)$ are, successively, the observed, instrumental, and intrinsic distributions of dispersions, then, from the fact that Gaussian distributions combine as the squares of their dispersions,

$$O(\sigma_0) = \int_0^\infty R[(\sigma_0^2 - \sigma_i^2)^{1/2}]\, I(\sigma_i)\, d\sigma_i . \qquad (2)$$

Performing the integrations numerically, we obtain the intrinsic distributions of dispersions in Figures 3–5. The distributions in Figure 3 are normalized to unit area for $\Delta\sigma = 0.01$ mag.; those in Figures 4 and 5 for $\Delta\sigma = 0.005$ mag.

The distributions on Figures 3–5 show four results. (1) All the intrinsic distributions pass through the origin, indicating that there are no magnetic stars that are constant in V magnitude or $B - V$ and $U - B$ colors. This is the direct result of the lack of any magnetic stars with observed dispersions less than 0.014, 0.005, and 0.008 mag. in V, $B - V$, and $U - B$, respectively, whereas these were frequent among the constant stars. (2) The most frequent intrinsic dispersions (maxima of the curves) in V, $B - V$, and $U - B$ are 0.018, 0.012, and 0.020 mag., respectively. (3) The mean intrinsic dispersions in V, $B - V$, and $U - B$ are 0.039, 0.017, and 0.023 mag., respectively. (4) For stars with observed dispersions in V, $B - V$, and $U - B$ greater than about 0.06, 0.03, and 0.03 mag., respectively, we can assume that these observed dispersions are nearly equal to the intrinsic dispersions. Obviously, for a single star with moderate or small dispersions, we do not know the relative amounts of variability and instrumental inaccuracies. The stars with dispersions greater than the above amounts are the ones that are mostly likely to yield light and color variations that exceed the instrumental errors by significant amounts.

If, then, all Ap magnetic stars are slightly variable in visual light and colors, a number of questions naturally arise. The fundamental question—namely, the cause of the variability—is part of the larger problem of the source and nature of the magnetic fields and the cause of the variability in all observed quantities; this question must await a more penetrating physical analysis than is given in this paper. Other questions follow.

(1) *What is the spectral dependence of the variability?* This cannot be answered satisfactorily from the present material because the photometric reductions were made to determine V, $B - V$, and $U - B$; in deriving B and U, all the errors in V, $B - V$, and $U - B$ will be combined.

(2) *Is there a correlation between large variations in visual light and in color?* For 11 stars with large dispersions in visual light [$\sigma(V) \geq 0.06$ mag.], the dispersions in the two colors [$\langle\sigma(B - V)\rangle = 0.021$, $\langle\sigma(U - B)\rangle = 0.031$ mag.] do not average more than for all the stars measured (0.025 and 0.030 mag., respectively). Also, for stars with large dispersions in color [$\sigma(B - V) \geq 0.035$, $\sigma(U - B) \geq 0.035$ mag.], the average dispersion in visual magnitude is again normal. Stars picked for large dispersions in one color tend to have large dispersions in the other color, i.e., those 13 stars with $\sigma(B - V) \geq 0.035$ mag. have $\langle\sigma(U - B)\rangle = 0.043$ mag., compared with an average of 0.030 mag. for all 70 stars, and those 18 stars with $\sigma(U - B) \geq 0.035$ mag. have $\langle\sigma(B - V)\rangle = 0.037$ mag., compared with an average of 0.025 mag. for all the stars. We conclude that a large variability in visual light is not correlated with a large variability in colors but that variabilities in the two colors tend to be correlated.

(3) *Is the variability in light or color correlated with the magnetic-field strengths?* That

such a correlation is weak or non-existent is apparent when we note that the star (HD 215441) with by far the largest magnetic field (Babcock 1960*b*) has photometric dispersions that are average. The mean absolute magnetic fields of the 32 stars for which Babcock (1958) has published five or more measures show no correlation with the dispersions in magnitude or colors; for instance, a least-squares solution gives the trivial dependence

$$\sigma(V) = 0.0530 - 0.0016\langle |H_e| \rangle \quad (3)$$

for H_e in kilogauss, with a correlation coefficient of only +0.031. There is no marked tendency for large or small photometric dispersions to be correlated with (*a*) the predominant sign of the magnetic field, (*b*) the occurrence of regularity or irregularity in the magnetic field variation, or (*c*) the presence of a cross-over effect.

(4) *Are there any correlations between the photometric dispersions and other characteristics?* The stars with large dispersions in magnitude or color have average colors and line widths; they do not possess distinct spectral peculiarities or spectral types.

Additional photometric observations of magnetic stars are not planned at the present time.

We should like to thank Dr. David L. Crawford for helpful discussions and for the use of his measures of the Cassiopeia-Taurus stars prior to publication.

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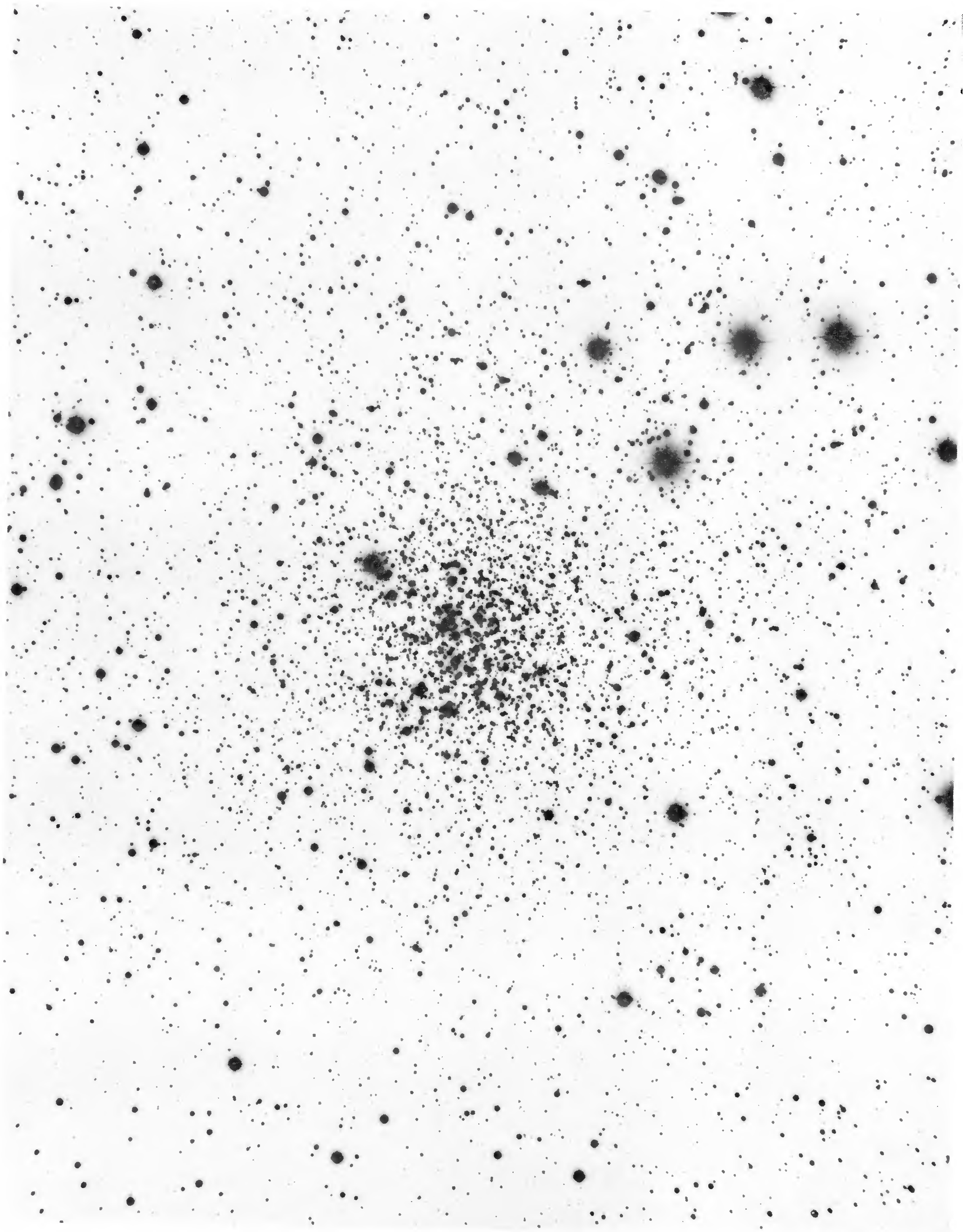

Fig. 1.—Red-sensitive photograph of NGC 2158