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ASTRONOMY AND ASTROPHYSICS

Spectrophotometry of Peculiar B and A Stars

V. HD 32650, 84 Ursa Majoris, HD 149822, 19 Lyrae, 4 Cygni, HD 196178, and 108 Aquarii

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Summary. Spectrophotometry of the optical region $\lambda\lambda$3300–7100 is presented for seven magnetic Ap stars: HD 32650, 84 Ursa Majoris, HD 149822, 19 Lyrae, 4 Cygni, HD 196178, and 108 Aquarii. The energy distributions of all seven stars show definite λ4200 and λ5200 broad, continuum features as well as other more subtle deviations from the predictions of normal stellar atmospheres. The observations of HD 32650 violate the general rule for the Ap stars that the temperature found by comparing the Balmer jump regions with the predictions of normal stellar atmospheres with $\log g = 4.0$ are systematically greater than those found from fitting the slopes of the Paschen continua.

Key words: peculiar A stars – spectrophotometry – continuum features

I. Introduction

The first paper of this series (Adelman, 1979) established preliminary criteria for the detection of the λ4200 and λ5200 broad, continuum features found in many peculiar A stars in terms of photometric indices. The second, third, and fourth papers (Adelman and Pyper, 1979a, b; White et al., 1980) examined the spectrophotometry of eleven HgMn and five magnetic Ap stars. The observations showed deviations from the best fits that could be made with the predictions of fully-line blanketed solar composition model atmospheres which had effective temperatures and gravities of main sequence stars. The temperatures found for the Balmer jump regions were systematically greater than those found from fitting the slopes of the Paschen continua.

In this paper we continue the examination of optical region energy distributions. Six of the stars examined, HD 32650, HD 149822, 19 Lyrae, 4 Cygni, HD 196178, and 108 Aquarii are considered to be silicon stars while 84 Ursa Majoris is a cool Ap star. Table 1 is a journal of observations organized by star. It includes the heliocentric Julian Date at the midpoint of the observation, the observatory, and the photometric phase of each scan. A typical observation took about nine minutes. Table 2 contains published $u-b$ and $b-y$ photometry along with the references and the number of observations as well as the mean $u-b$ and $b-y$ values as synthesized from the spectrophotometry. Table 3 presents the spectrophotometric data and the average energy distribution by star along with $u-b$, $b-y$, $\Delta\iota$, $\Delta\iota^*$, Δa and $\Delta a'$ indices which are calculated as described in Adelman (1978) and in Papers I and III. The preliminary criteria of presence for the λ4200 feature are $\Delta\iota \geq 0\overset{m}{.}016$ and $\Delta\iota^* \geq 0\overset{m}{.}015$ and for the λ5200 feature, $\Delta a \geq 0\overset{m}{.}007$ (except for $b-y > 0\overset{m}{.}060$ where $\Delta a \geq 0\overset{m}{.}011$) and $\Delta a' > 0\overset{m}{.}011$.

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Table 1. Journal of observations

Star	Scan Number	Heliocentric Julian Date	Phase	Observatory
HD 32650	1	2443063.9510	0.411	Kitt Peak
	2	2443066.9260	0.472	Kitt Peak
	3	2443442.9267	0.784	Kitt Peak
84 UMa	1	2442526.7184	0.056	Kitt Peak
	2	2442527.7101	0.774	Kitt Peak
	3	2442528.7090	0.498	Kitt Peak
	4	2443230.8905	0.362	Kitt Peak
HD 149822	1	2442526.7882	0.863	Kitt Peak
	2	2442527.7924	0.551	Kitt Peak
	3	2442528.7586	0.214	Kitt Peak
	4	2443230.9448	0.493	Kitt Peak
19 Lyr	1	2443063.6439	0.122	Kitt Peak
	2	2443066.5600	0.634	Kitt Peak
	3	2443231.0153	0.309	Kitt Peak
4 Cyg	1	2443063.6518	0.228	Kitt Peak
	2	2443066.5684	0.475	Kitt Peak
	3	2443231.0248	0.949	Kitt Peak
HD 196178	1	2443063.6610	...	Kitt Peak
	2	2443066.5776	...	Kitt Peak
	3	2443441.6309	...	Kitt Peak
108 Aqr	1	2442637.9637	0.727	Palomar
	2	2442639.9580	0.262	Palomar
	3	2442640.9382	0.524	Palomar
	4	2443062.7809	0.620	Kitt Peak

Table 2. Comparison of Strömgren $u-b$ and $b-y$ colors

Star	u-b	b-y	n	Reference
HD 32650	0.809	-0.064	2	Cameron (1966)
	0.873	-0.052	2+	Johansen and Gyldenkerne (1970)
	0.837	-0.076	3	Crawford et al. (1972)
	0.803	-0.070	3	This Paper
84 UMa	1.178	-0.046	2	Cameron (1966)
	1.142	-0.063	2+	Johansen and Gyldenkerne (1970)
	1.174	-0.058	5	Crawford et al. (1972)
	1.180	-0.047	3	Warren (1973)
	1.166	-0.055	4	This Paper
HD 149822	1.109	-0.077	2	Cameron (1966)
	1.084	-0.077	9	Crawford et al. (1972)
	1.094	-0.085	4	This Paper
19 Lyr	0.982	-0.011	1	Cameron (1966)
	0.958	-0.012	2+	Johansen and Gyldenkerne (1970)
	0.964	-0.010	5	Crawford et al. (1972)
	0.957	-0.012	3	This Paper
4 Cyg	0.752	-0.053	2	Cameron (1966)
	0.748	-0.062	2+	Johansen and Gyldenkerne (1970)
	0.725	-0.058	3	Crawford et al. (1972)
	0.753	-0.052	3	Warren (1973)
	0.729	-0.056	3	This Paper
HD 196178	0.576	-0.081	1	Cameron (1966)
	0.579	-0.071	3	Crawford et al. (1973)
	0.549	-0.076	3	This Paper
108 Aqr	0.709	-0.086	2	Cameron (1966)
	0.676	-0.068	4	This Paper

Note: n = number of observations

Table 3. Continuous energy distributions ($-2.5\log F_\nu/F_{5000}$)

λ(Å)	HD 32650 1	2	3	average	84 UMa 1	2	3	4	average
3300	0.595	0.547	0.576	0.573	0.988	1.001	0.983	0.984	0.989
3390	0.588	0.561	0.584	0.578	1.001	1.006	0.987	0.984	0.994
3448	0.604	0.567	0.586	0.586	0.973	0.973	0.966	0.966	0.970
3509	0.586	0.540	0.583	0.570	0.953	0.928	0.918	0.915	0.924
3571	0.594	0.554	0.576	0.575	0.947	0.956	0.937	0.928	0.942
3636	0.574	0.540	0.574	0.563	0.909	0.905	0.891	0.907	0.903
3704	0.556	0.530	0.561	0.549	0.872	0.872	0.869	0.863	0.869
4032	−0.280	−0.306	−0.280	−0.289	−0.214	−0.217	−0.217	−0.231	−0.220
4167	−0.221	−0.255	−0.232	−0.236	−0.180	−0.186	−0.180	−0.175	−0.180
4200	−0.203	−0.235	−0.202	−0.213	−0.159	−0.151	−0.158	−0.144	−0.153
4255	−0.186	−0.221	−0.201	−0.203	−0.141	−0.156	−0.155	−0.147	−0.150
4464	−0.176	−0.186	−0.167	−0.176	−0.150	−0.160	−0.149	−0.163	−0.156
4566	−0.107	−0.138	−0.137	−0.127	−0.090	−0.107	−0.089	−0.099	−0.096
4673	...	...	−0.103	−0.105	...	...	...	−0.088	−0.088
4785	−0.070	−0.090	−0.074	−0.078	−0.071	−0.070	−0.077	−0.067	−0.071
4935	...	...	−0.030	−0.032	...	...	...	−0.033	−0.035
5000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5128	0.055	0.039	0.059	0.051	0.052	0.040	0.049	0.064	0.051
5200	0.083	0.068	0.089	0.080	...	...	...	0.112	0.108
5264	0.074	0.072	0.098	0.081	0.104	0.099	0.108	0.106	0.104
5360	0.105	0.096	0.102	0.101	0.126	0.113	0.114	0.118	0.118
5470	0.123	0.115	0.138	0.125	0.122	0.116	0.124	0.123	0.121
5556	0.142	0.131	0.153	0.142	0.151	0.135	0.141	0.153	0.145
5700	...	...	0.163	0.152	...	...	...	0.144	0.141
5840	0.198	0.202	0.217	0.206	0.178	0.149	0.164	0.166	0.164
6020	0.241	0.234	0.251	0.242	0.205	0.208	0.210	0.208	0.208
6220	0.282	0.291	0.307	0.293	0.259	0.250	0.248	0.269	0.256
6300	...	...	0.315	0.305	...	...	...	0.278	0.270
6370	0.325	0.317	0.333	0.325	0.287	0.272	0.269	0.288	0.279
6650	0.373	0.383	0.391	0.382	0.324	0.315	0.312	0.330	0.320
6800	0.399	0.404	0.423	0.409	0.352	0.334	0.337	0.355	0.344
7100	0.455	0.463	0.471	0.463	0.400	0.387	0.394	0.409	0.398
u−b	0.807	0.793	0.810	0.803	1.167	1.176	1.159	1.160	1.166
b−y	−0.057	−0.073	−0.080	−0.070	−0.058	−0.046	−0.055	−0.061	−0.055
Δ1	0.016	0.013	0.019	0.016	0.003	0.013	0.012	0.025	0.013
Δ1*	0.039	0.031	0.039	0.036	0.036	0.041	0.037	0.063	0.044
Δa	0.015	0.013	0.024	0.017	0.023	0.021	0.025	0.036	0.026
Δa'	0.023	0.022	0.033	0.026	0.053	0.059	0.066	0.058	0.059

λ(Å)	HD 149822 1	2	3	4	average	19 Lyr 1	2	3	average
3300	0.895	0.893	0.896	0.907	0.895	0.772	0.814	0.782	0.789
3390	0.914	0.905	0.911	0.921	0.913	0.769	0.799	0.771	0.780
3448	0.901	0.899	0.911	0.912	0.906	0.749	0.791	0.762	0.767
3509	0.834	0.832	0.842	0.841	0.837	0.723	0.766	0.736	0.742
3571	0.849	0.846	0.889	0.871	0.864	0.721	0.757	0.737	0.738
3636	0.819	0.815	0.825	0.843	0.826	0.713	0.751	0.717	0.727
3704	0.777	0.776	0.791	0.788	0.783	0.630	0.689	0.653	0.657
4032	−0.230	−0.223	−0.213	−0.250	−0.229	−0.200	−0.183	−0.216	−0.200
4167	−0.190	−0.177	−0.183	−0.190	−0.185	−0.172	−0.152	−0.184	−0.169
4200	−0.141	−0.141	−0.135	−0.153	−0.142	−0.163	−0.130	−0.160	−0.151
4255	−0.146	−0.137	−0.139	−0.155	−0.144	−0.144	−0.126	−0.158	−0.143
4464	−0.163	−0.168	−0.158	−0.184	−0.164	−0.148	−0.127	−0.153	−0.143
4566	−0.112	−0.099	−0.106	−0.119	−0.109	−0.085	−0.077	−0.113	−0.092
4673	...	...	...	−0.095	−0.090	...	...	−0.088	−0.078
4785	−0.088	−0.075	−0.074	−0.078	−0.079	−0.060	−0.039	−0.069	−0.056
4935	...	...	...	−0.051	−0.051	...	...	−0.029	−0.019
5000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5128	0.071	0.068	0.064	0.066	0.067	0.061	0.055	0.037	0.051
5200	...	...	...	0.112	0.114	0.064	0.080	0.079	0.074
5264	0.114	0.121	0.130	0.116	0.120	0.070	0.084	0.068	0.074
5360	0.139	0.142	0.152	0.138	0.143	0.072	0.082	0.067	0.074
5470	0.132	0.136	0.140	0.142	0.138	0.084	0.106	0.091	0.094
5556	0.154	0.166	0.175	0.164	0.165	0.102	0.117	0.090	0.103
5700	...	...	...	0.136	0.132	...	...	0.104	0.113
5840	0.159	0.161	0.161	0.173	0.164	0.143	0.162	0.133	0.146
6020	0.192	0.190	0.199	0.192	0.193	0.191	0.201	0.179	0.190
6220	0.257	0.251	0.256	0.265	0.257	0.233	0.234	0.221	0.229
6300	...	...	...	0.268	0.272	...	...	0.242	0.239
6370	0.285	0.273	0.284	0.285	0.282	0.242	0.259	0.260	0.254
6650	0.311	0.306	0.311	0.317	0.311	0.286	0.291	0.294	0.290
6800	0.326	0.321	0.329	0.343	0.330	0.316	0.316	0.317	0.316
7100	0.379	0.385	0.393	0.392	0.387	0.347	0.362	0.362	0.357
u−b	1.093	1.080	1.096	1.105	1.084	0.940	0.966	0.966	0.957
b−y	−0.085	−0.078	−0.089	−0.088	−0.085	−0.007	−0.009	−0.020	−0.012
Δ1	0.018	0.016	0.012	0.026	0.018	−0.002	0.008	0.009	0.005
Δ1*	0.066	0.066	0.063	0.077	0.068	0.011	0.020	0.019	0.017
Δa	0.032	0.031	0.034	0.040	0.034	0.015	0.018	0.021	0.018
Δa'	0.084	0.082	0.092	0.074	0.083	0.023	0.017	0.031	0.024

λ(Å)	4 Cyg 1	2	3	average	HD 196178 1	2	3	average
3300	0.491	0.519	0.507	0.506	0.279	0.321	0.298	0.299
3390	0.500	0.528	0.507	0.512	0.300	0.331	0.307	0.313
3448	0.492	0.513	0.505	0.503	0.293	0.331	0.313	0.312
3509	0.488	0.509	0.495	0.497	0.290	0.331	0.305	0.309
3571	0.490	0.511	0.511	0.504	0.297	0.332	0.311	0.313
3636	0.488	0.508	0.500	0.499	0.297	0.343	0.307	0.316
3704	0.463	0.484	0.484	0.477	0.296	0.327	0.301	0.308
4032	−0.278	−0.263	−0.283	−0.275	−0.292	−0.277	−0.270	−0.280
4167	−0.232	−0.213	−0.239	−0.228	−0.251	−0.236	−0.239	−0.242
4200	−0.222	−0.201	−0.223	−0.215	−0.239	−0.208	−0.214	−0.220
4255	−0.195	−0.191	−0.212	−0.199	−0.225	−0.204	−0.203	−0.211
4464	−0.167	−0.166	−0.181	−0.171	−0.181	−0.185	−0.182	−0.183
4566	−0.184	−0.119	−0.131	−0.125	−0.145	−0.124	−0.135	−0.135
4673	...	...	−0.109	−0.105	...	...	−0.113	−0.113
4785	−0.066	−0.072	−0.071	−0.070	−0.089	−0.079	−0.083	−0.083
4935	...	...	−0.033	−0.033	....	...	−0.041	−0.041
5000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5128	0.051	0.056	0.043	0.050	0.054	0.063	0.055	0.057
5200	0.067	0.080	0.079	0.075	0.093	0.097	0.090	0.093
5264	0.071	0.069	0.076	0.072	0.075	0.080	0.090	0.082
5360	0.086	0.100	0.092	0.093	0.084	0.098	0.110	0.097
5470	0.102	0.117	0.113	0.111	0.114	0.127	0.119	0.120
5556	0.126	0.138	0.133	0.132	0.116	0.142	0.136	0.131
5700	...	...	0.152	0.152	...	...	0.162	0.157
5840	0.188	0.192	0.188	0.189	0.195	0.192	0.201	0.196
6020	0.226	0.232	0.230	0.229	0.227	0.230	0.240	0.232
6220	0.274	0.278	0.290	0.281	0.270	0.277	0.277	0.275
6300	...	...	0.307	0.296	...	...	0.284	0.280
6370	0.295	0.312	0.331	0.313	0.313	0.319	0.327	0.320
6650	0.365	0.360	0.374	0.366	0.364	0.361	0.368	0.364
6800	0.401	0.374	0.398	0.391	0.399	0.387	0.402	0.396
7100	0.437	0.450	0.453	0.447	0.439	0.440	0.444	0.441
u−b	0.714	0.738	0.736	0.729	0.544	0.560	0.544	0.549
b−y	−0.047	−0.058	−0.062	−0.056	−0.079	−0.070	−0.078	−0.076
Δ1	0.005	0.015	0.011	0.010	0.009	0.014	0.005	0.009
Δ1*	0.023	0.031	0.026	0.027	0.025	0.038	0.032	0.032
Δa	0.013	0.014	0.018	0.015	0.026	0.023	0.027	0.025
Δa'	0.011	0.012	0.021	0.015	0.028	0.028	0.037	0.031

Table 3 (continued)

λ(Å)	108 Aqr 1	2	3	4	average
3300	0.456	0.462	0.412	0.429	0.448
3390	0.455	0.466	0.457	0.438	0.454
3448	0.450	0.482	0.446	0.440	0.454
3509	0.460	0.449	0.448	0.432	0.446
3571	0.450	0.464	0.448	0.424	0.446
3636	0.447	0.471	0.444	0.432	0.448
3704	0.447	0.463	0.429	0.423	0.440
4032	−0.281	−0.263	−0.263	−0.298	−0.276
4167	−0.231	−0.217	−0.243	−0.242	−0.233
4200	−0.215	−0.201	−0.198	−0.224	−0.210
4255	−0.210	−0.197	−0.195	−0.210	−0.203
4464	−0.190	−0.176	−0.164	−0.179	−0.177
4566	−0.114	−0.123	−0.106	−0.132	−0.119
4785	−0.080	−0.077	−0.078	−0.092	−0.082
5000	0.000	0.000	0.000	0.000	0.000
5128	0.071	0.055	0.056	0.041	0.056
5200	...	...	...	0.090	0.096
5264	0.101	0.085	0.102	0.090	0.094
5360	0.107	0.097	0.104	0.096	0.101
5470	0.123	0.121	0.129	0.120	0.123
5556	0.138	0.140	0.140	0.135	0.138
5840	0.198	0.197	0.192	0.181	0.192
6020	0.256	0.238	0.236	0.241	0.243
6220	0.291	0.292	0.279	0.282	0.286
6370	0.342	0.338	0.336	0.326	0.336
6650	0.374	0.364	0.365	0.370	0.368
6800	0.417	0.395	0.389	0.393	0.398
7100	0.461	0.447	0.439	0.465	0.453
u−b	0.679	0.693	0.658	0.672	0.676
b−y	−0.068	−0.066	−0.064	−0.076	−0.068
Δ1	0.020	0.016	0.008	0.016	0.015
Δ1*	0.040	0.037	0.019	0.037	0.033
Δa	0.027	0.016	0.023	0.026	0.023
Δa'	0.047	0.030	0.049	0.051	0.044

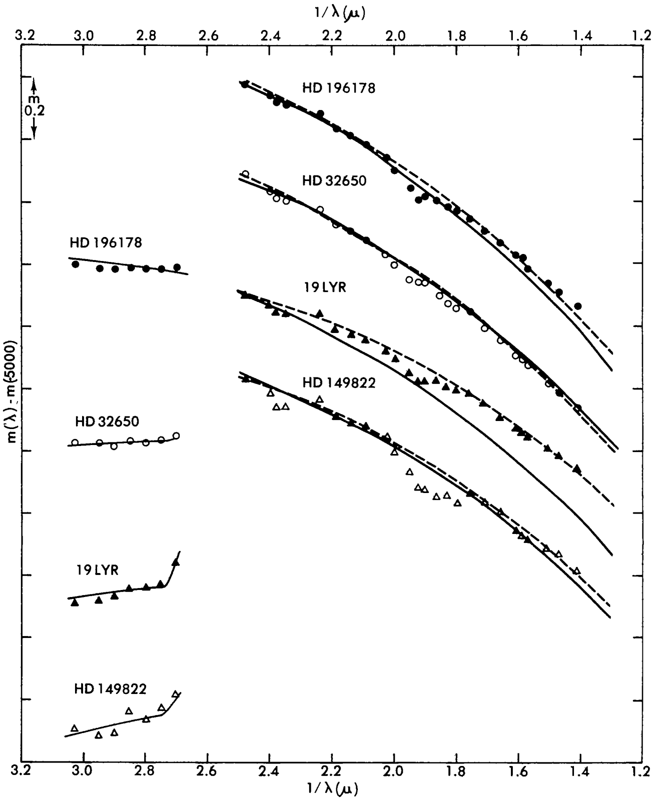

Fig. 1. The observed energy distributions of four magnetic Ap stars, HD 196178 (closed circles), HD 32650 (open circles), 19 Lyr (closed triangles), and HD 149822 (open triangles), compared with the predictions of $\log g = 4.0$ solar composition model atmospheres that best match the Balmer jump (solid lines) and Paschen continuum (dotted lines) regions. The Balmer jumps of the latter models and the predictions in the region of the Balmer confluence are not shown. The effective temperatures of the models are: HD 196178, BJ, 14,750 °K and PC, 13,000 °K; HD 32650, BJ, 12,500 °K and PC, 13,500 °K; 19 Lyr, BJ, 11,875 °K and PC, 9500 °K; and HD 149822, BJ, 10,950 °K and PC, 10,000 °K

Figures 1 and 2 show the average energy distributions of the seven stars and compare them with the predictions of fully-line blanketed solar composition $\log g = 4.0$ model atmospheres. Although the Ap stars are more heavily blanketed than normal stars and consequently have a somewhat different atmospheric structure, it is useful to make this comparison as one obtains some idea of how great the differences are as well as some estimate of the effective temperature. The second order bandwidths are 25 Å for the Palomar observations and 30 Å for those made at Kitt Peak with the first order bandwidths twice as large. For each star effective temperature estimates are given only for the average distribution as values for individual scans usually are close to that for the average.

II. HD 32650

The suspected magnetic star HD 32650 (HR 1643) has broad lines, $w = 0.5$: (Babcock, 1958). Winzer (1974) found it is a large amplitude single wave variable with $U, B,$ and V magnitudes all changing in phase according to the emphemeris

$$\mathrm{JD}\,(U_{\max}) = 2441252.91 + 0.7325\,E\,.$$

The approximate amplitudes are $0^m\!.10$ in U, $0^m\!.06$ in B, and $0^m\!.05$ in V. Abt and Snowden (1973) noted that their radial velocity measurements and those previously published show a marginally significant scatter and that a period of $7^d\!.993$ would fit their results, but not the older values.

Three scans of HD 32650 were obtained at Kitt Peak National Observatory in 1976 and 1977. The published and synthesized $b-y$ values agree well while the synthesized $u-b$ values agree moderately well with that of Cameron (1966) and less well with that of Crawford et al. (1972), but disagree with that of Johansen and Gyldenkerne (1970) whose value appears anomalous. The Δa and $\Delta a'$ values suggest that the λ 5200 broad, continuum feature is definitely present and probably variable while the $\Delta\iota$ and $\Delta\iota^*$ values indicate that the λ 4200 feature is present with the λ 4200 and λ 4255 magnitudes having equal values. These results are confirmed by examination of the average energy distribution (Fig. 1, Table 3).

Scans 1 and 2 were observed close to minimum light and scan 3 half-way between maximum and minimum if the ephemeris is reliable. Winzer (1974)'s UBV results show fairly smooth light curves with some superimposed structure. The $u-b$ and $b-y$ colors for the scans are consistent with Winzer's results if their phases are good to 0.1 of the period. Structure in the light curves probably accounts for most of the differences in $b-y$ for similar $u-b$ values as between scans 1 and 3.

Comparison of the synthesized $u-b$ color of the average energy distribution with those of Kurucz's (1979) fully line blanketed model atmospheres with solar compositions and $\log g = 4.0$ as given by Relyea and Kurucz (1978) suggests an effective temperature of 12,575 °K. Figure 1 compares the average fluxes with the predictions of a 12,500 °K, $\log g = 4.0$ Kurucz model for which the global fit is fairly good. If we increase the temperature to 12,550 °K, the fit would be slightly improved. But to obtain the best fit to the Paschen continuum requires a 13,500 °K, $\log g = 4.0$ model. The values for the individual scans are close to these results. Very small changes in the slope of the Paschen continuum result in much larger changes in the temperature of the model required to obtain the best fit.

That the Paschen continuum temperature is greater than the Balmer jump (global fit) temperature both for the average and the individual scans is contrary to the results for the stars studied in previous papers and for the other stars of this paper. From the character of the variability it is possible that at light maximum, the temperature of the model which fits the Balmer jump region may be greater than that which fits the Paschen continuum. This suggestion needs to be confirmed by additional measurements.

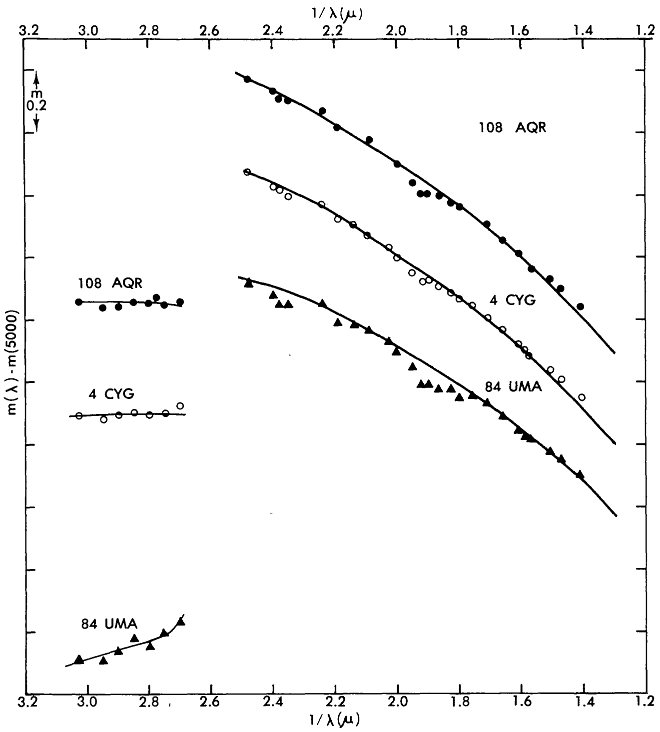

Fig. 2. The observed energy distributions of three magnetic Ap stars, 108 Aqr (closed circles), 4 Cyg (open circles), and 84 UMa (closed triangles), as compared with the predictions of $\log g = 4.0$ solar composition model atmospheres. The figure is similar to Fig. 1 except that only the Balmer jump region model fits are shown. The effective temperatures of the models are: 108 Aqr, 13,500 °K; 4 Cyg, 13,000 °K; and 84 UMa, 10,600 °K

III. 84 Ursa Majoris

Abt and Snowden (1973) reported that 84 Ursa Majoris (HD 120198 = HR 5187) apparently has a constant radial velocity, but that among all the sets of values which have been published there is more scatter than one might expect. Babcock (1958) noted that this star has broad lines, $w = 1$; so much so that he could not measure them for the Zeeman effect, but Durrant (1970) claimed $v \sin i = 20\,\mathrm{km\,s^{-1}}$. Winzer (1974) found that it was a low amplitude single wave variable with U, B, and V approximately in phase. His ephemeris is

$$\mathrm{JD}\,(U_{\max}) = 2441444.80 + 1.3799\,E\,.$$

The U amplitude is approximately $0^m\!.03$, B slightly larger than $0^m\!.02$, and V $0^m\!.015$.

Four scans of 84 UMa were obtained at Kitt Peak National Observatory in 1975 and 1977. The synthesized $b-y$ values are in good accord with the published values (Table 2) while the synthesized $u-b$ values are only in fair accord. But this might be because the $u-b$ amplitude is greater than that for $b-y$. The $u-b$ value of Johansen and Gyldenkerne (1970) appears discordant. The $\Delta\iota$ and $\Delta\iota^*$ values and those for Δa and $\Delta a'$ suggest modest λ4200 and λ5200 broad, continuum features. The average energy distribution (Fig. 2, Table 3) shows that the λ4200 feature is due to a large extent to the λ4464 value being substantially above the run of the other values. The λ5200 feature although not as deep as in some other Ap stars is quite broad, on the order of 1000 Å. The λ5556 value lies below the trend of the λ5200 feature profile and suggests that the profile might have a secondary minimum.

The λ4200 feature is probably variable as suggested by the $\Delta\iota$ and $\Delta\iota^*$ values. Examination of the individual scans shows this is not due solely to a change in the λ4464 value. The variability of the λ5200 broad, continuum feature is also possible. The λ3509 value is brighter than the mean smooth Balmer continuum.

If we use the average $u-b$ value and proceed as for HD 32650, then we estimate a temperature of 10,625 °K for 84 UMa. To fit the Balmer jump region requires a 10,600 °K model while for the Paschen continuum a 10,125 °K model is a reasonable compromise. For all models the λ4464 value is too bright and cannot be fit simultaneously with the shorted wavelength Paschen continuum values.

IV. HD 149822

Babcock (1958) found that HD 149822 (HR 6176) had lines too broad, $w=1$:, to be measurable for the Zeeman effect. Abt and Snowden (1973) found this star had a constant radial velocity although they could not exclude an eccentric small amplitude variation. Temperature estimates include 12,900 °K (Searle and Sargent, 1964), 14,800 °K (Mihalas and Henshaw, 1966), 10,700 °K (Sargent et al., 1969), and 10,500 °K (Wolff, 1967; based on spectrophotometry of $\lambda\lambda$ 5260–8800).

Winzer (1974) found that HD 149822 is a photometric variable with epochs of U light maxima described by

$$\mathrm{JD}\,(U_{\max})=2441459.05+1.4590\,E\,.$$

The U, B, and V curves may be in phase with the U amplitude about $0\overset{m}{.}03$, that for B $0\overset{m}{.}02$, and that for V $0\overset{m}{.}01$. Near phase 0.4 there may be a secondary maximum.

Four scans of HD 149822 were obtained at Kitt Peak National Observatory in 1975 and 1977. The synthesized $u-b$ and $b-y$ values are in fair to excellent agreement with published values (Table 2). The Δa and $\Delta a'$ values indicate a strong λ5200 broad, continuum feature while the $\Delta\iota$ and $\Delta\iota^*$ values a strong λ4200 feature with the λ4200 and λ4255 values about equal. The average energy distribution confirms these deductions (Table 3, Fig. 1). The λ4464 value is brighter than the mean trend to values about on which the λ4167 value lies. As for 84 UMa, the λ5556 value lies below the trend of the profile of the λ5200 feature and suggests that this feature has a secondary minimum. Further the λ3509 value is above the trend of the Balmer continuum. The λ6220, λ6300, and λ6370 values are about $0\overset{m}{.}02$ below the trend of the Paschen continuum and suggest that a weak λ6300 feature may be present.

The $u-b$ and $b-y$ colors of the four scans may be consistent with Winzer (1974)'s results. The index values suggest that both the λ4200 and λ5200 features might be variable. Slight scan to scan differences bear this out. Similar differences are seen near λ6300.

If we proceed as for the previous two stars and use the average $u-b$ value to estimate a temperature, then we find 10,975 °K. Models with about this temperature can only approximately fit the Balmer jump region due to differences in the shapes of the energy distributions. A 10,950 °K model does as well as any. The Paschen continuum also is not easy to fit, with a 10,000 °K model a reasonable compromise. The λ4464 value is too bright as are to a lesser extent the longest two wavelength values.

V. 19 Lyrae

Winzer (1974) found that 19 Lyrae (HR 7283 = HD 179527) is a photometric variable whose behavior can be described by the ephemeris

$$\mathrm{JD}\,(U_{\max})=2442449.99+1.1608\,E\,.$$

The amplitude in U is about $0\overset{m}{.}04$, in B $0\overset{m}{.}03$, and in V $0\overset{m}{.}02$. The U, B, and V variations may be in phase. But the light curves of 19 Lyr are based on only 9 sets of observations taken over a period of 19 nights. The curves are asymmetric with light minimum near phase 0.3 in U and B and that of V is ill defined as the minimum is flat bottomed, but is between phases 0.2 and 0.7. The period is not necessarily well determined and needs to be checked. Further, Winzer notes that the observed scatter seems a little large and that the comparison star might be slightly variable. Abt and Snowden (1973) find no evidence for radial velocity variability in their and previously published results.

Three scans of 19 Lyr were obtained at Kitt Peak National Observatory in 1976 and 1977. The published and synthesized $u-b$ and $b-y$ values agree reasonably well. The Δa and $\Delta a'$ values are larger than the preliminary criteria of presence and thus the λ5200 broad, continuum feature is expected, but the $\Delta\iota$ values are smaller than the corresponding criterion while the $\Delta\iota^*$ values are close to it and hence the λ4200 feature is expected to be weak. The average energy distribution (Fig. 1) indeed shows a strong λ5200 feature with a constant magnitude region or shelf in the energy distribution with the suggestion of broad wings and an asymmetry in the longward direction. The λ4200 and λ4255 values are depressed slightly relative to the mean continuum with the λ4464 value above it.

If Winzer's (1974) ephemeris is correct, scan 1 is halfway between light maximum and light minimum, scan 3 occurs close to light minimum while scan 2 occurs halfway between light minimum and light maximum. The variation of $u-b$ and $b-y$ for the spectrophotometry is consistent with the UBV photometry for the ephemeris used. Examination of the individual scans (Table 3) and the values of the feature indices suggest that the λ4200 feature is definitely variable while the λ5200 feature may be.

An effective temperature of 11,675 °K is estimated by comparison of the synthesized $u-b$ value of the average distribution as was done for the previous three stars of this paper. Figure 1 shows that the Balmer jump is fit by a 11,875 °K, $\log g=4.0$ model although the slopes of both the Balmer and Paschen continua are wrong. The slope of the Balmer continuum is fit by an 11,000 °K, $\log g=4.0$ model and that of the Paschen continuum requires a 9500 °K, $\log g=4.0$ model. This suggests that 19 Lyr might be slightly reddened. As $V=5\overset{m}{.}91$, $U-B=-0\overset{m}{.}32$ and $B-V=-0\overset{m}{.}05$ (Winzer, 1974), the Q method gives $E(B-V)=0\overset{m}{.}04$ which is probably an overstimate as the λ5200 feature slightly affects the V magnitude. Thus no corrections have been applied.

VI. 4 Cygni

Babcock (1958) described 4 Cygni (HD 183506 = HR 7395) as a suspected magnetic star whose spectrum contains Si II lines and few others with a line width of $w=0.4$:. Abt and Snowden (1973) find a period of $35^{\mathrm{d}}02$: for this protable single-lined spectroscopic binary. But additional measurements are needed to assure the reality of the binary motion. Jugaku and Sargent (1968) obtained spectrophotometry of $\lambda\lambda$ 3390–5852 and deduced $T_{\mathrm{eff}}=13{,}600$ °K, $\log g=4.2$. Adelman (1977) noted that this data indicated a probable λ 5200 feature. Durrant (1970) measured the Hα profile and used the star's colors to find $T_{\mathrm{eff}}=12{,}600$ °K, $\log g=3.75$.

Winzer's (1974) *UBV* photometry showed that 4 Cyg is a low amplitude variable with a somewhat undertain period. His ephemeris for the variation is

$$\mathrm{JD}\,(U_{\max})=2441451.03+0.68674\,E\,.$$

U has a maximum amplitude of $0^{\mathrm{m}}02$. B may vary in phase with U with a $0^{\mathrm{m}}01$ amplitude while V has an amplitude of less than $0^{\mathrm{m}}01$.

Three scans of 4 Cyg were obtained at Kitt Peak National Observatory in 1976 and 1977. The published and synthesized $b-y$ values are in good agreement while the $u-b$ values in only fair agreement (Table 1). The $\Delta\iota^*$, Δa, and $\Delta a'$ values are larger than the criteria of presence while the $\Delta\iota$ values are smaller. They suggest that both the λ 4200 and λ 5200 broad, continuum features are weakly present. This is confirmed by examination of the average energy distribution (Fig. 2) and the spectrophotometric data (Table 3). The point at λ 4464 is brighter than the trend of the shortward part of the Paschen continuum λ 4032 through λ 4255 which results in a definite result based on $\Delta\iota^*$. That the λ 5200 value is fainter than the trend of adjacent values suggests a core is present in the λ 5200 broad, continuum feature, which has modest strength, and perhaps broad, weak wings which extend shortward to about λ 4935 and longward to about λ 5470.

If Winzer's (1974) ephemeris is correct, then scan 3 was made close to U maximum, scan 2 close to U minimum, and scan 1 between U maximum and U minimum. That scans 2 and 3 have almost identical $u-b$ and $b-y$ colors suggests that the phase might be slightly off which is not surprising as these observations occurred 4 yr after Winzer's photometry. Intercomparison of the scans shows that there are subtle differences among them.

An effective temperature of 13,075 °K is estimated as for the previous stars in this paper from $u-b$ colors. Figure 2 shows that the observations fit reasonably well the predictions of a 13,000 °K, $\log g=4.0$ model atmosphere. A λ 4200 feature is suggested and the longward portion of the Paschen continuum is brighter than the model's predictions. A best match for the Paschen continuum is found with a 12,500 °K, $\log g=4.0$ model.

VII. HD 196178

Babcock (1958) included HD 196178 (HR 7870) in his list of stars which have broad lines and are not measurable for the Zeeman effect as $w=1.5$. The Ca II K line is not seen while the Si II lines are shallow and broad. Winzer (1974) found that HD 196178 is a possible small amplitude photometric variable while Abt and Snowden (1973) noted that it was not a radial velocity variable.

Three scans of HD 196178 were obtained at Kitt Peak National Observatory in 1976 and 1977. The synthesized and published $b-y$ values are in good agreement while the published $u-b$ values are greater than the synthesized ones. This is consistent due to the small number of observations involved with HD 196178 being a low amplitude photometric variable. The Δa and $\Delta a'$ values suggest that the λ5200 broad, continuum feature is definitely present while the $\Delta\iota^*$ values are greater than and the $\Delta\iota$ values less than the criterion for the λ 4200 feature. Examination of the average energy distribution (Fig. 1, Table 3) confirm these observations. The λ4200 and λ4255 values seem depressed relative to the mean continuum. The λ5200 feature has a moderate strength core as the λ 5200 point is depressed and broad shallow wings are definitely indicated. Examination of individual scans show apparent differences in both the λ 4200 and λ 5200 regions.

An effective temperature of 14,650 °K is estimated in the manner of previous stars from the $u-b$ color. Figure 1 shows that the Balmer jump region is fit fairly well by the fluxes of a 14,750 °K, $\log g=4.0$ model while the Paschen continuum by those of a 13,000 °K, $\log g=4.0$ model.

VIII. 108 Aquarii

From visual inspection of Zeeman spectrograms Babcock (1958) discovered the varying magnetic field of the Ap star 108 Aquarii (HD 223640 = HR 9031). However, most lines are shallow and weak with sufficient broadening ($w=0.8$:) as to make Zeeman measurements extremely difficult. Abt and Snowden (1973) found that the systematic radial velocity was constant over a period of four months. Megessier (1975) constructed an oblique rotator model which showed that the abundance maxima of the iron peak elements are near the magnetic equator. The very strong Si II lines are apparently non-variable.

Morrison and Wolff (1971) obtained *uvby* measurements of 108 Aqr. They found the variability can be described by

$$\mathrm{JD}\,(\text{maximum light})=2440900.800+3.73\,E\,.$$

The four filter magnitudes varied in phase with each other and had similarly shaped curves. The approximate amplitudes are for u $0^{\mathrm{m}}08$, v $0^{\mathrm{m}}07$, b $0^{\mathrm{m}}06$, and y $0^{\mathrm{m}}05$.

Estimates of effective temperature and gravity include 15,250 °K (Searle and Sargent, 1964), 18,700 °K, $\log g=4.0$ (Mihalas and Henshaw, 1966), 12,000 °K, $\log g=3.0$ (Wolff, 1967), 13,250 °K (Sargent et al., 1969), and 14,000 °K (Megessier, 1975). Spectrophotometry of $\lambda\lambda$ 4032–8800 was published by Wolff (1967) and of $\lambda\lambda$ 3390–5556 by Hyland (1967). Adelman (1975, 1977) noted that the λ 5200 feature was definitely present while the one at λ 4200 might be present in Wolff's data.

Three scans of 108 Aqr were obtained at Palomar Observatory in 1975 and one at Kitt Peak National Observatory in 1976. The synthesized $b-y$ values agree well with Cameron's (1966) average value, but the synthesized $u-b$ values are on the average $0^{\mathrm{m}}03$ bluer. The Δa and $\Delta a'$ values suggest that the λ 5200 broad, continuum feature is definitely present and possibly variable while the $\Delta\iota$ and $\Delta\iota^*$ values suggest a marginal to weak λ 4200 feature which may also be variable. The average energy distribution confirms these observations (Fig. 2, Table 3). The λ 4200 value is slightly depressed relative to the λ 4167 and λ 4255 values with the λ 4464 value brighter than the trend of values. The λ 5200 feature has a constant magnitude region and the suggestion of broad wings as for 19 Lyr.

Due to the five year period between the photometry and spectrophotometry and the $0^{\mathrm{d}}03$ quoted uncertainty in the period, it is unclear how the two data sets are phased relative to one another. If the ephemeris is correct, then scan 1 occurs halfway between minimum and maximum light, scan 2 halfway between maximum and minimum light, scan 3 close to minimum light and scan 4 at light minimum. But we expect the star to be slightly redder in $u-b$ at minimum light than at maximum which suggests that the phase is shifted by about one-half of a period. The $b-y$

values are no help in this matter. Additional *uvby* photometry is needed.

By comparison of the average synthesized $u-b$ color with that of Kurucz's (1979) model atmospheres as given by Relyea and Kurucz (1978), an effective temperature of 13,500 °K is estimated. Figure 2 shows that a 13,5000 °K, $\log g = 4.0$ model nicely fits the Balmer jump region but to fit the Paschen continuum a slightly cooler model with 13,000 °K, $\log g = 4.0$ is needed.

IX. Overview

In this paper we have examined the optical region spectrophotometry of seven magnetic Ap stars. The $u-b$ colors usually give reasonable estimates for normal stellar model atmospheres with $\log g = 4.0$ fits to the Balmer jump region. But this model does not necessarily fit the Paschen continuum as well. To fit this region for 11 of the 12 magnetic Ap stars studied in Papers III and IV and this paper requires that one use a cooler model. HD 32650, the exception to this rule, should be studied further. The possibility of its having an undetected binary companion must be thoroughly examined.

All seven stars studied in this paper have definite λ 4200 and λ 5200 broad, continuum features for which there is often evidence of variability. Additional observations are usually needed to confirm feature variability as well as to improve the photometric period. The profiles of the λ 5200 features are different from star to star. They range from modest depressions in the continuum to those with sharp cores and extensive broad wings and those with constant magnitude regions in their energy distributions and the suggestion of broad wings. Some stars show evidence for secondary minimum. We may be dealing with a complicated phenomenon.

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