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K-LINE PHOTOMETRY OF STARS IN POPULATION I CLUSTERS

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ABSTRACT

Photoelectric photometry of the K-line of calcium has been performed for the A stars of five open clusters (Hyades, Pleiades, IC 2391, IC 2602, and NGC 6475) and one association (Orion). For NGC 6475 (M7), as we previously reported, the relation between k and $(b - y)_0$ is a unique one, implying that abundance variations of calcium (and, presumably, other metals as well) in the cluster are less than about ±25 percent star to star, and that the original interstellar cloud from which it formed was similarly homogeneous. The Hyades appear metal-rich in comparison with the other clusters, the remainder of which have calcium abundances similar to those of field stars. The Hyades are also found to exhibit less variation in calcium abundance than the field stars, but the relationship in k versus $b - y$ is not as tight as for NGC 6475. Uncertain individual reddening corrections are the most serious limitation for the interpretation of data for reddened clusters other than NGC 6475. A number of stars in these clusters appear to exhibit previously unsuspected spectral peculiarities, as revealed by K-line and *uvby*-Hβ photometry. In particular, the young cluster IC 2391 may contain more weakly metallic stars than heretofore recognized.

From discussion of the observations in these two papers, evidence supporting three constraints on the metallicity anomaly has emerged. (i) Metallicism does not appear as a discrete phenomenon in the $(dk, d[m_1])$-plane, and a relatively smooth transition between normal and metallic-line stars is suggested by the observations. (ii) Possible support for the suggestion that metallicism is moderated by mild evolution off the zero-age main sequence may be inferred from the data. (iii) Evidence is found for the existence of weak Am stars in clusters younger than the Hyades.

I. INTRODUCTION

A system of photoelectric spectrophotometry of the calcium K-line which yields a K-line-strength index, k, has been described in Paper I (Henry 1969) and Paper II (Henry and Hesser 1971), where application has been made to solar-neighborhood A stars selected from the *Bright Star Catalog* (Hoffleit 1964). In those papers, it has been shown that the k-index yields a reddening-free estimate of $b - y$ colors accurate to ±0.012 mag. Moreover, it has been found that at a given temperature the scatter in the k-index is larger than can be accounted for by photometric errors and seems to be attributable to variations in the calcium abundance of a factor of 2 or slightly less. Furthermore, the photometry, especially when combined with *uvby*-Hβ photometry, has proved to be a useful tool for the identification of stars exhibiting spectral peculiarities, especially the metallicity anomaly.

For a continued investigation and application of this photometric system, we have observed the five Population I open clusters NGC 6475, IC 2602, IC 2391, Pleiades, and Hyades, as well as the Orion association. The investigation had a number of aims. First, we wished to learn if the calcium abundance in such clusters is more homogeneous than that among field stars; second, we wished to compare metal abundances from cluster to cluster; and finally, we hoped that application of our rather sensitive technique

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to the cluster stars might reveal new metallic or otherwise peculiar stars. From such an investigation, the results that pertain to the first question should allow us to understand further the photometric system and to extract information on the clusters themselves, as well as the medium from which they formed. We hoped to learn as well if any of the clusters observed exhibit previously undetected metal-abundance anomalies. Finally, we realized that any new remarks which could be made on the often debated question of the existence of Am stars in clusters of different ages, particularly young ones, would be of value. For each of the clusters selected for this project, some previous photometric and spectrophotometric studies existed which were used in selecting our program stars. After a brief description of the observational techniques in § II, we pass directly to the results for each cluster in § III, below. Certain of the most easily described and interesting results have been briefly presented previously (Hesser and Henry 1971).

II. OBSERVATIONS

All observations were carried out simultaneously with the field-star measurements described in Paper II, with the use of the 16-inch and 36-inch telescopes of the Cerro Tololo Inter-American Observatory. The procedure for data acquisition and reduction thus need not be redescribed here; observations began in 1969 May and terminated in 1970 January. With the exception of the Hyades, the cluster stars observed ranged from 1 mag fainter than the field stars to about 4 mag fainter. As most of the observations were acquired with the 16-inch telescopes, the narrow bandpass ($\sim$8.5 Å) of the instrument meant that photon statistics began to play a major role in the errors and it was necessary to acquire a large number of observations to obtain a reliable estimate of the k-indices. In general, sky measurements were taken as often as star measurements and in two or more directions. Observations from the larger telescope were, of course, selectively aimed at the fainter stars in each cluster and data from each aperture telescope were combined by a weighting system based upon the rms scatter in the data acquired with each aperture.

Tables 1 through 6 present the results of the cluster observations in formats identical with that of Table 1 in Paper II wherever *uvby*-Hβ photometry is available, and in a much abbreviated format wherever only *UBV* photometry exists. A key follows the tables, and Papers I and II may be referred to for additional clarification. For a discussion of the use of *uvby*-Hβ photometry in the present context, the reader is specifically referred to § III of Paper II.

KEY TO TABLES 1 AND 2

Column		
1	STAR	Identification number of the star taken from the sources identified in the text; for brevity we abbreviate the latter phrase as TFSIIT in the remainder of the key.
2	V	Visual magnitude of the star TFSIIT.
3	SP	Spectral class of the star TFSIIT.
4	LUM	Luminosity class of the star TFSIIT.
5	P	Spectral peculiarity [Am (M) stars, Ap (P) stars, silicon (S) stars, broad-lined (N) stars] TFSIIT.
6	B − V	$B - V$ color TFSIIT.
7	B − Y	$b - y$ colors of the stars obtained by converting the $B - V$ colors by the mean relation found for field stars for which both colors were available; reddening corrections applied as described in the text.
8	NO	Number of observations (as defined in Paper II) of the star.
9	NN	Number of nights on which the new observations were obtained.
10	K	Final value of the K-line-strength index, k (in magnitudes).
11	ERR	The rms internal error in magnitudes of k in column (10). No error is calculated unless NO $\geq$ 4.
12	DK	Deviation of the k-index (col. [10]) from the normal value for stars of the same color. A positive dk has the sense of an overabundance of calcium.

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TABLE 1

NGC 6475

1	2	3	4	5	6	7	8	9	10	11	12
STAR	V	SP	LUM	P	B-V	B-Y	NO/	NN	K ±	ERR	DK
30	8.44	A5			0.26	0.152	10/	4	0.911	0.015	0.113
32	10.14	A7			0.27	0.159	12/	3	0.684	0.047	-0.136
33	10.35	F2			0.39	0.249	14/	4	0.934	0.068	-0.118
34	8.21	A0			0.00	0.001	10/	5	0.171	0.020	0.046
38	9.67	A5			0.23	0.129	14/	4	0.643	0.027	-0.081
40	8.85	A3			0.21	0.114	10/	3	0.530	0.024	-0.136
47	8.89	A2	V		0.12	0.064	12/	6	0.390	0.025	-0.040
48	9.10	A2	V		0.11	0.059	12/	6	0.382	0.021	-0.021
51	9.20	A3	V		0.15	0.080	11/	6	0.471	0.030	-0.034
60	9.73	A3			0.27	0.159	12/	3	0.384	0.034	-0.435
61	9.63	F8			0.40	0.256	8/	2	1.111	0.039	0.039
63	7.56	B9	V		-0.04	-0.017	10/	5	0.089	0.008	0.012
65	8.95	A2	V		0.08	0.043	10/	4	0.266	0.015	-0.060
68	8.84	A8	V		0.28	0.167	10/	4	0.667	0.017	-0.172
71	7.37	B9.5	V		-0.01	-0.004	14/	7	0.155	0.018	0.046
72	8.20	B9.5	V		-0.04	-0.017	10/	5	0.106	0.023	0.029
75	10.59	F2			0.44	0.286	16/	5	1.052	0.051	-0.097
78	9.49				0.35	0.219	18/	7	0.924	0.027	-0.051
79	8.91	A2	V		0.09	0.048	12/	6	0.287	0.021	-0.065
82	7.78	A1	V		-0.01	-0.004	12/	6	0.136	0.024	0.027
85	9.94	F0			0.24	0.137	12/	2	0.713	0.021	-0.038
86	5.96	B9	V		-0.05	-0.021	10/	5	0.092	0.007	0.023
88	6.43	A		S	-0.06	-0.025	12/	6	0.055	0.018	-0.008
89	8.56	A2			0.13	0.070	11/	5	0.317	0.024	-0.138
92	8.41	A1	V		0.02	0.011	10/	4	0.185	0.017	0.012
94	10.41	F0			0.47	0.308	12/	2	0.913	0.054	-0.294
96	8.74	A1	V		0.07	0.037	10/	5	0.265	0.015	-0.036
103	7.47	B9.5	V		0.02	0.011	10/	5	0.201	0.006	0.027
104	6.89	B9	V		-0.02	-0.008	10/	5	0.121	0.010	0.024
105	9.47	A5			0.16	0.086	12/	4	0.572	0.033	0.041
108	7.02	B9	V		-0.05	-0.021	10/	5	0.091	0.008	0.022
109	8.86	A0			0.31	0.189	10/	3	0.252	0.030	-0.646
110	6.11	B9.5	V		-0.01	-0.004	8/	4	0.148	0.015	0.038
111	9.46	A2			0.16	0.086	12/	4	0.547	0.038	0.016
120	10.08	A5			0.33	0.204	10/	2	0.743	0.044	-0.193
121	6.93	A0			-0.02	-0.008	10/	5	0.135	0.019	0.038
123	9.44	A2			0.14	0.075	12/	4	0.484	0.034	0.003
124	8.37	A0			0.01	0.005	12/	6	0.172	0.011	0.024

TABLE 2

ORION

1	2	3	4	5	6	7	8	9	10	11	12
STAR	V	SP	LUM	P	B-V	B-Y	NO/	NN	K ±	ERR	DK
2	8.78	A2			0.11	0.059	9/	2	0.611	0.012	0.208
59	8.73	A0		P	-0.04	-0.017	9/	2	0.383	0.012	0.306
135	9.71	F2	IV-V		0.34	0.211	9/	2	1.133	0.018	0.178
243	6.83	A7	IV-V		0.16	0.086	9/	2	0.765	0.011	0.234
304	9.30	A2	V		0.09	0.048	9/	2	0.406	0.018	0.053
388	8.02	A0	V		-0.01	-0.004	9/	2	0.193	0.010	0.084
454	9.65	A7	V		0.20	0.107	9/	2	0.723	0.025	0.089
472	8.87	A1	V		0.00	0.001	9/	2	0.073	0.022	-0.051
493	4.81	B0.5	V		-0.31	-0.129	3/	1	0.160		0.107
520	9.23	B9.5	V		-0.09	-0.038	9/	2	0.099	0.015	0.043
599	9.81	A0			-0.09	-0.038	9/	2	0.076	0.014	0.020
608	9.39	A0	IV		-0.02	-0.008	9/	2	0.190	0.019	0.093
734	9.57	A0	V		-0.02	-0.008	9/	2	0.195	0.018	0.098
776	9.36	A0	V		-0.02	-0.008	9/	2	0.120	0.011	0.023
796	9.44	A2	V		0.05	0.027	9/	2	0.374	0.016	0.124
806	5.25	F0			0.22	0.122	9/	2	1.060	0.031	0.364
1001	8.66	A5			0.23	0.129	9/	2	0.732	0.019	0.008
1016	9.21	A3			0.22	0.122	9/	2	0.672	0.024	-0.024

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III. RESULTS

We list for convenience in Table 7 the identifications and principal physical parameters of the clusters studied by us, with references to the relevant papers for each of the derived parameters.

a) NGC 6475 (M7)

Our principal conclusions regarding this rich southern cluster have already been described in an earlier communication (Hesser and Henry 1971); here we give the details of the measurements and restate the conclusions of the previous paper. The $B - V$ colors in Table 1 are those given by Koelbloed (1959) and have been corrected for uniform reddening of $\langle E_{B-V} \rangle = 0.04$ mag; the numbering system for identification is also that of Koelbloed. Using the relation found in Paper II between $B - V$ and $b - y$ colors for field stars, we have converted Koelbloed's $(B - V)_0$ to the $(b - y)_0$ values presented in column (7) of Table 1 for the 38 late B, A, or early F stars that were observed with the K-line photometer. Relatively few of the stars in NGC 6475 have been classified to date on the MK system (Buscombe and Kennedy 1968; Abt and Jewsbury 1969; Conti and van den Heuvel 1970), so that the HD spectral types are cited in Table 1; but we should note that for the star K-78, Abt and Jewsbury (1969) give A9 V as the classification. Abt and Jewsbury found a rotational-velocity anomaly among the stars of NGC 6475, in that the B stars are unusually slow rotators ($\langle V \sin i \rangle \leq$ 90 km s^{-1}) while the A1–A3 stars are unusually rapid rotators ($\langle V \sin i \rangle \geq 200$ km s^{-1}).

KEY TO TABLES 3, 4, 5, AND 6

Column		
1	STAR	Identification number of the star taken from the source(s) identified in the text; for brevity, we abbreviate the latter phrase as TFSIIT in the remainder of the key.
2	V	Visual magnitude of the star TFSIIT.
3	SP	Spectral class of the star TFSIIT.
4	LUM	Luminosity class, TFSIIT.
5	P	Spectral peculiarity [Am (M) stars, Ap (P) stars, silicon (S) stars, broad-lined (N) stars] TFSIIT.
6	B − V	$B - V$ color, TFSIIT.
7	M1	The m_1-metallicity index of Strömgren (1966).
8	C1	The c_1-luminosity index of Strömgren (1966).
9	NO	Number of observations (as defined in Paper II) of the star.
10	NN	Number of nights on which the observations were obtained.
11	K	Final value of the K-line-strength index k (in magnitudes).
12	ERR	The rms internal error in magnitudes of k in column (11). No error is calculated unless NO $\geq$ 4.
13	DK	The deviation of the k-index (col. [11]) from the normal value for stars of the same color. A positive value of dk has the sense of an overabundance of calcium.
14	C	Class of the star on the system of Strömgren (1966): E is an early star (B stars), I an intermediate star (A0–A3), and L is a late group star (later than A3).
15	B − Y	$b - y$ colors for the stars, with reddening corrections applied as described in the text.
16	E(B − Y)	Color excess E_{b-y} determined by the methods of Strömgren. This value has been applied to the observed $b - y$ values to obtain those in column (15).
17	BETA	The β-index of Crawford and Mander (1966) and Crawford *et al.* (1966, 1970) as measured by the authors cited in the text.
18	(M1)	The $[m_1]$ reddening-independent metallicity index of Strömgren (1966).
19	D(M1)	The deviation of the $[m_1]$-index from the value for normal, main-sequence stars. A negative value indicates high metal abundance.
20	(C1)	The $[c_1]$ reddening-independent luminosity index of Strömgren (1966).
21	DV	The $[c_1]$ of column (20), and other data, may be used to calculate dV, the number of magnitudes the star has evolved above the main sequence.
22	(U − B)	The $[u - b]$ luminosity/temperature parameter of Strömgren (1966).
23	A, D(M1)	For early (E) group stars (col. [14]), this is $d[m_1]$ calculated by an alternative method, while for the intermediate (I) group stars, it is the a temperature parameter of Strömgren.

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TABLE 3

PLEIADES

1		2	3	4	5	6	7	8	9 10	11	12	13
STAR		V	SP	LUM	P	B−V	M1	C1	NO/NN	K	ERR	DK
158	1	8.23	A7	V		0.25	0.204	0.826	19/ 7	0.777	0.023	0.122
157	2	7.90	A9	V		0.34	0.182	0.739	19/ 7	0.844	0.011	0.031
232	3	8.06	A5	V		0.20	0.197	0.908	19/ 7	0.522	0.015	0.075
344	4	8.17	A8	V		0.27	0.185	0.760	19/ 7	0.773	0.014	−0.078
531	8	8.58	A		M	0.34	0.182	0.777	19/ 7	0.573	0.021	−0.298
652	10	8.04	A3	V		0.21	0.192	0.970	19/ 7	0.448	0.006	0.010
697	11	8.60	A9	V		0.35	0.176	0.716	19/ 7	0.784	0.016	−0.084
717	12	7.18	A1	V		0.16	0.132	0.941	19/ 7	0.044	0.003	−0.031
804	14	7.85	A2	V		0.20	0.186	0.994	19/ 7	0.351	0.011	0.118
859	17	6.43	B9	V		−0.02	0.127	0.860	19/ 7	0.058	0.005	0.001
1028	20	7.35	A2	V		0.10	0.179	1.013	19/ 7	0.251	0.008	0.004
1084	21	8.11	A0	V		0.36	0.128	1.075	19/ 7	0.219	0.012	−0.130
1266	22	8.28	A9	V		0.36	0.173	0.748	19/ 7	0.820	0.019	0.007
1234	23	6.82	B9.5	V		0.02	0.122	0.917	19/ 7	0.063	0.005	−0.002
1284	24	8.37	A9	V		0.30	0.186	0.714	19/ 7	0.825	0.023	−0.013
1384	26	7.66	A4	V		0.21	0.183	0.910	19/ 7	0.474	0.010	−0.073
1397	29	7.26	A2	V		0.05	0.162	0.945	3/ 1	0.082		−0.005
1380	30	6.99	A1	V		0.03	0.166	1.009	19/ 7	0.168	0.005	0.063
1431	31	6.81	A0	V		0.06	0.164	0.930	19/ 7	0.125	0.006	−0.060
1425	32	7.77	A3	V		0.15	0.194	0.942	21/ 8	0.448	0.012	−0.105
1762	33	8.27	A9	V		0.36	0.161	0.686	10/ 4	0.852	0.016	−0.081
1876	35	6.95	A1	V		0.12	0.177	0.952	11/ 5	0.308	0.005	−0.008
1993	36	8.37	A8	V		0.29	0.201	0.768	19/ 7	0.769	0.019	0.007
2195	39	8.12	A7	V		0.22	0.201	0.861	19/ 7	0.674	0.014	−0.045
2220	40	7.52	A2	V		0.10	0.177	1.018	13/ 5	0.265	0.007	0.002
2263	41	6.60	B9.5	V		−0.03	0.147	0.904	13/ 5	0.089	0.005	0.004
2289	42	7.97	A3	V		0.18	0.208	0.921	13/ 5	0.529	0.016	0.080
2425	43	6.17	B9	V		−0.05	0.117	0.843	19/ 7	0.069	0.003	0.014
2415	44	8.10	A7	V		0.22	0.218	0.855	10/ 4	0.790	0.006	0.194
2488	45	7.54	A2	V		0.08	0.193	0.981	10/ 4	0.268	0.007	−0.002
2507	46	6.74	A0	V		0.06	0.129	0.887	16/ 6	0.075	0.010	0.012
2866	47	6.93	A2	V		0.09	0.150	0.926	10/ 4	0.212	0.004	0.134

		14	15	16	17	18	19	20	21	22	23
STAR		C	B−Y	E(B−Y)	BETA	(M1)	D(M1)	(C1)	DV	(U−B)	A,D(M1)
158	1	L	0.112	0.037	2.839	0.231	−0.02	0.796	0.00	1.258	
157	2	L	0.157	0.056	2.790	0.220	−0.01	0.696	0.00	1.137	
232	3	L	0.068	0.050	2.882	0.218	−0.01	0.884	0.00	1.321	
344	4	L	0.171	0.001	2.772	0.216	−0.001	0.726	0.20	1.157	
531	8	L	0.179		2.794	0.221	−0.01	0.733		1.176	
652	10	L	0.066	0.060	2.875	0.215	−0.008	0.945	0.27	1.374	
697	11	L	0.178	0.049	2.765	0.217	−0.01	0.671	0.19	1.104	
717	12	E	−0.018	0.134	2.869	0.153	−0.004	0.918	0.06	1.224	0.004
804	14	I	0.023	0.093	2.892	0.207	0.046	0.971	0.22	1.385	0.159
859	17	E	−0.029	0.029	2.823	0.127	−0.004	0.860	0.15	1.114	0.013
1028	20	I	0.026	0.032	2.907	0.189	0.027	1.001	0.14	1.380	0.081
1084	21	I	0.048	0.199	2.909	0.172	0.166	1.026	0.25	1.371	0.331
1266	22	L	0.157	0.072	2.788	0.214	−0.00	0.702	0.06	1.131	
1234	23	E	−0.023	0.054	2.849	0.128	0.010	0.911	0.04	1.166	0.022
1284	24	L	0.166	0.020	2.783	0.219	−0.01	0.677	0.00	1.116	
1384	26	L	0.089	0.036	2.856	0.206	0.00	0.885	0.06	1.296	
1397	29	E	−0.012	0.060	2.891	0.171	−0.009	0.935	0.05	1.277	−0.006
1380	30	E	−0.006	0.019	2.899	0.168	−0.002	1.006	0.06	1.343	−0.000
1431	31	I	0.013	0.027	2.879	0.171	0.022	0.922	0.15	1.264	0.036
1425	32	L	0.090	0.009	2.862	0.210	−0.00	0.924	0.14	1.344	
1762	33	L	0.203	0.031	2.736	0.203	0.01	0.639	0.40	1.045	
1876	35	I	0.041	0.030	2.875	0.190	0.025	0.938	0.31	1.317	0.087
1993	36	L	0.140	0.035	2.811	0.233	−0.02	0.733	0.00	1.198	
2195	39	L	0.128	0.008	2.826	0.224	−0.01	0.835	0.02	1.283	
2220	40	I	0.030	0.025	2.894	0.187	0.021	1.007	0.40	1.381	0.077
2263	41	E	−0.013	0.007	2.852	0.145	−0.005	0.907	0.08	1.196	0.006
2289	42	L	0.068	0.025	2.880	0.225	−0.018	0.902	0.00	1.352	
2425	43	E	−0.032	0.020	2.794	0.115	−0.002	0.845	0.42	1.075	0.015
2415	44	L	0.099	0.017	2.852	0.239	−0.021	0.832	0.00	1.310	
2488	45	I	0.031	0.002	2.905	0.199	0.002	0.975	0.02	1.372	0.043
2507	46	E	−0.025	0.076	2.844	0.138	−0.003	0.877	0.03	1.153	0.010
2866	47	E	−0.016	0.080	2.867	0.162	−0.013	0.913	0.08	1.236	−0.005

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TABLE 4

IC 2391

1	2	3	4	5	6	7	8	9	10	11	12	13
STAR	V	SP	LUM	P	B-V	M1	C1	NO/	NN	K ±	ERR	DK
74195	3.63	B3	III		-0.18	0.093	0.344	7/	4	0.077	0.008	0.023
74560	4.88	B3	V		-0.17	0.093	0.337	6/	4	0.039	0.014	-0.014
74146	5.23	B5	V		-0.14	0.122	0.396	4/	4	0.071	0.004	0.017
74071	5.50	B6	V		-0.15	0.112	0.427	7/	4	0.068	0.021	0.013
74535	5.54	B9.5	III		-0.16	0.143	0.428	2/	1	0.041		-0.013
74196	5.59	B5	V		-0.14	0.104	0.515	6/	4	0.053	0.008	-0.001
73952	6.47	B8	V		-0.10	0.124	0.698	6/	4	0.058	0.018	0.003
74169	7.26	A0	IV	P	-0.04	0.212	0.830	7/	4	0.059	0.018	0.004
74275	7.31	A0	V		-0.01	0.166	0.931	7/	4	0.097	0.021	0.005
74516	7.40	A0	V		0.00	0.184	0.986	7/	4	0.146	0.016	0.039
74955	7.59	A1	V		0.07	0.211	0.958	9/	4	0.283	0.031	0.022
74678	7.70	A1	V		0.07	0.196	0.984	7/	4	0.225	0.018	-0.031
74762	7.77	A5	V		0.19	0.213	0.937	12/	5	0.716	0.032	0.187
73681	7.86	A2	V		0.09	0.219	0.960	7/	4	0.203	0.014	-0.034
74665	8.14	A3		M	0.20	0.185	0.924	12/	5	0.530	0.005	-0.170
74145	8.56	A7	V		0.21	0.208	0.772	12/	5	0.819	0.036	0.056
74117	9.10	F2	V		0.36	0.164	0.561	12/	5	1.003	0.054	-0.032
74340	9.86	F6	V		0.48	0.143	0.379	14/	5	1.222	0.041	-0.016
74009	8.76	F2			0.41	0.183	0.525	9/	4	0.886	0.035	-0.227
74044	8.52	A3			0.22	0.216	0.838	10/	5	0.512	0.009	-0.136
74582	9.62	F5			0.38	0.174	0.763	10/	4	1.002	0.101	0.045
75066	9.31	F5			0.39	0.206	0.723	6/	3	1.355	0.076	0.370
75202	7.73	A3			0.19	0.212	0.937	7/	4	0.410	0.085	-0.171
75466	6.34	B9			-0.10	0.138	0.718	5/	3	0.084	0.030	0.028

	14	15	16	17	18	19	20	21	22	23
STAR	C	B-Y	E(B-Y)	BETA	(M1)	D(M1)	(C1)	DV	(U-B)	A,D(M1)
74195	E	-0.098	0.023	2.666	0.079	0.003	0.359	0.72	0.518	0.003
74560	E	-0.099	0.028	2.688	0.080	0.010	0.351	0.17	0.512	0.010
74146	E	-0.084	0.011	2.713	0.109	-0.011	0.411	0.23	0.628	-0.010
74071	E	-0.082	0.012	2.717	0.099	-0.000	0.441	0.21	0.640	0.001
74535	E	-0.085	-0.015	2.723	0.128	-0.026	0.445	0.38	0.700	-0.025
74196	E	-0.069	0.015	2.710	0.094	0.004	0.526	0.67	0.714	0.004
73952	E	-0.040	0.006	2.778	0.117	-0.008	0.706	0.26	0.940	0.007
74169	L	-0.042		2.855	0.204	0.01	0.838		1.247	
74275	E	-0.010	0.004	2.896	0.164	0.000	0.933	0.02	1.261	0.002
74516	I	-0.005	-0.009	2.911	0.183	-0.008	0.987	0.00	1.353	-0.008
74955	I	0.029	-0.030	2.900	0.216	-0.015	0.952	0.00	1.385	0.043
74678	I	0.028	-0.019	2.887	0.201	-0.010	0.978	0.35	1.380	0.041
74762	L	0.085	0.014	2.857	0.231	-0.020	0.917	0.20	1.379	
73681	I	0.024	-0.034	2.918	0.223	-0.017	0.955	0.00	1.402	0.039
74665	L	0.123		2.834	0.207	0.009	0.899		1.314	
74145	L	0.140	-0.011	2.801	0.233	-0.014	0.744	0.00	1.210	
74117	L	0.242	0.001	2.703	0.208	0.00	0.513	0.09	0.928	
74340	L	0.320	0.006	2.635	0.201	0.01	0.315	0.00	0.716	
74009	L	0.272	-0.004	2.664	0.232	-0.02	0.471	0.37	0.935	
74044	L	0.110	-0.003	2.838	0.236	-0.03	0.816	0.00	1.288	
74582	L	0.212	0.085	2.708	0.227		0.704	1.48	1.159	
75066	L	0.222	0.017	2.704	0.249		0.675	1.11	1.173	
75202	L	0.096	0.009	2.856	0.229	-0.018	0.918	0.17	1.376	
75466	E	-0.055	-0.014	2.776	0.128	-0.020	0.729	0.42	0.985	-0.005

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TABLE 5

IC 2602

1	2	3	4	5	6	7	8	9	10	11	12	13
STAR	V	SP	LUM	P	B-V	M1	C1	NO/	NN	K ±	ERR	DK
91906	7.42	A0			0.00	0.177	1.005	10/	3	0.170	0.020	-0.029
307860	8.23	A0			0.17	0.109	0.913	4/	1	-0.024	0.015	-0.088
92385	6.75	B9	V		-0.09	0.132	0.735	6/	3	0.035	0.018	-0.021
92467	6.99	B9	IV		-0.07	0.150	0.842	6/	3	0.104	0.018	0.041
92478	7.58	A0	IV		0.01	0.188	0.970	6/	3	0.202	0.032	0.032
92535	8.27	A3	V		0.18	0.194	0.877	8/	3	0.594	0.028	-0.037
92536	6.34	B8	IV		-0.09	0.123	0.708	6/	3	0.049	0.006	-0.007
92664	5.52	B9		P	-0.17	0.116	0.382	6/	3	0.034	0.009	-0.020
92715	6.83	B9.5	V		-0.04	0.130	0.885	6/	3	0.087	0.010	0.024
92783	6.74	B8	V		-0.06	0.117	0.838	6/	3	0.047	0.017	-0.009
92837	7.18	B9	V		-0.03	0.155	0.956	6/	3	0.049	0.018	-0.036
92896	7.32	A5	IV		0.15	0.193	0.838	6/	3	0.548	0.025	-0.141
92938	4.81	B3	V		-0.17	0.093	0.390	6/	3	0.085	0.010	0.031
92966	7.28	B9.5	V		-0.03	0.154	0.929	6/	3	0.065	0.020	-0.013
92989	7.60	A1	IV		0.00	0.180	0.982	6/	3	0.166	0.021	0.061
93012	9.25	A2			0.17	0.101	1.237	12/	3	0.378	0.028	0.323
93030	2.77	B0	V		-0.29	0.063	-0.078	6/	3	0.050	0.017	-0.003
93098	7.61	A0	V		0.00	0.180	0.993	6/	3	0.157	0.041	0.048
93163	5.78	B3	V		-0.18	0.055	0.334	6/	3	0.085	0.013	0.031
93194	4.83	B5	V		-0.18	0.083	0.369	6/	3	0.057	0.008	0.003
93209	9.42	A4	IV		0.12	0.140	1.095	6/	3	0.573	0.028	0.335
93424	8.14	A4	IV		0.11	0.190	0.944	6/	3	0.454	0.016	0.041
93517	7.86	A2	V		0.05	0.200	0.972	6/	3	0.375	0.025	0.088
93540	5.36	B6	V		-0.14	0.099	0.483	6/	3	0.075	0.009	0.021
93549	5.26	B7	IV		-0.14	0.106	0.464	6/	3	0.048	0.017	-0.007
93607	4.87	B4	V		-0.18	0.081	0.304	6/	3	0.071	0.013	0.018
93648	7.86	A2	V		0.07	0.180	1.029	6/	3	0.293	0.021	0.077
93714	6.56	B2	IV		-0.21	0.045	0.234	6/	3	0.085	0.011	0.031
93738	6.48	A0	V		-0.06	0.148	0.848	6/	3	0.115	0.010	0.053
93796	10.30	G2	IV		0.60	0.159	0.339	18/	3	1.344	0.065	-0.055
*	9.97	F8	V		0.54	0.141	0.360	9/	2	1.261	0.095	-0.096
94174	7.76	A0			0.06	0.193	0.946	5/	3	0.228	0.015	-0.033

	14	15	16	17	18	19	20	21	22	23
STAR	C	B-Y	E(B-Y)	BETA	(M1)	D(M1)	(C1)	DV	(U-B)	A,D(M1)
91906	I	0.016	0.000	2.891	0.180	0.000	1.002	0.42	1.362	0.022
307860	E	-0.024	0.184	2.781	0.138	-0.029	0.881	0.72	1.157	-0.012
92385	E	-0.036	0.005	2.806	0.126	-0.011	0.742	0.09	0.993	0.008
92467	E	-0.025	0.048	2.851	0.154	-0.015	0.837	0.00	1.146	-0.004
92478	I	0.010	0.006	2.929	0.190	0.005	0.968	0.00	1.348	0.011
92535	L	0.107	0.014	2.839	0.216	-0.01	0.853	0.03	1.284	
92536	E	-0.045	0.014	2.798	0.117	-0.004	0.714	0.05	0.949	0.013
92664	E	-0.103		2.700	0.101	-0.007	0.398		0.601	-0.007
92715	E	-0.026	0.021	2.838	0.129	0.002	0.886	0.03	1.144	0.017
92783	E	-0.033	0.020	2.805	0.115	0.001	0.841	0.27	1.070	0.019
92837	E	-0.013	0.011	2.879	0.155	0.000	0.956	0.07	1.266	0.006
92896	L	0.120	0.007	2.835	0.215	-0.00	0.814	0.00	1.243	
92938	E	-0.093	0.039	2.687	0.083	0.006	0.401	0.48	0.567	0.007
92966	E	-0.016	0.015	2.895	0.154	0.010	0.929	0.01	1.237	0.012
92989	I	-0.006	0.014	2.933	0.181	0.011	0.980	0.00	1.343	0.008
93012	I	-0.038	0.276	2.816	0.144	0.138	1.189	2.81	1.477	0.338
93030	E	-0.115		2.603	0.046		-.059	3.07	0.033	0.011
93098	E	-0.004	0.021	2.918	0.183	-0.006	0.990	0.02	1.356	-0.009
93163	E	-0.105	0.163	2.670	0.065	0.018	0.322	0.33	0.453	0.018
93194	E	-0.097	0.047	2.676	0.074	0.012	0.379	0.53	0.527	0.012
93209	I	0.024	0.189	2.802	0.178	0.094	1.052	2.23	1.409	0.292
93424	L	0.061	0.030	2.886	0.206	0.00	0.926	0.00	1.339	
93517	I	0.034	0.017	2.922	0.209	0.014	0.962	0.00	1.380	0.072
93540	E	-0.075	0.045	2.726	0.094	0.008	0.489	0.21	0.676	0.010
93549	E	-0.076	0.053	2.728	0.102	0.001	0.469	0.16	0.672	0.003
93607	E	-0.104	0.052	2.683	0.072	0.016	0.314	0.05	0.458	0.016
93648	I	0.020	0.044	2.892	0.192	0.022	1.016	0.49	1.399	0.092
93714	E	-0.116	0.192	2.646	0.059	0.015	0.219	0.46	0.336	0.016
93738	E	-0.026	0.030	2.818	0.149	-0.028	0.847	0.26	1.145	-0.010
93796	L	0.382		2.570	0.149	0.06	0.847		1.145	
*	L	0.366	0.015	2.577	0.210	0.00	0.284	0.32	0.703	
94174	I	0.029	0.017	2.912	0.201	0.014	0.937	0.00	1.339	0.058

* BRAES (1962) NO 57 = WHITEOAK (1961) NO 33 B

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TABLE 6

HYADES

1 STAR		2 V	3 SP	4 LUM	5 P	6 B−V	7 M1	8 C1	9 10 NO/NN	11 K	12 ± ERR	13 DK
27397	30	5.59	F0	V		0.28	0.198	0.770	12/ 4	1.299	0.019	0.451
27429	32	6.11	F2	V		0.37	0.171	0.588	15/ 5	1.024	0.014	−0.006
27459	33	5.26	A9	V		0.22	0.208	0.868	15/ 5	0.919	0.007	0.207
27628	38	5.72	A		M	0.32	0.204	0.719	12/ 4	0.486	0.009	−0.430
27749	45	5.64	A		M	0.30	0.237	0.738	15/ 5	0.210	0.007	−0.664
27819	47	4.80	A7.5	V		0.16	0.210	0.981	15/ 5	0.717	0.006	0.208
27934	54	4.22	A7	V		0.14	0.200	1.054	15/ 5	0.670	0.006	0.213
27962	56	4.30	A3	V		0.05	0.191	1.046	18/ 6	0.230	0.004	0.007
27991	57	6.46	F7	V		0.49	0.181	0.390	3/ 1	1.268		0.045
28024	60	4.29	A8	V	N	0.27	0.175	0.947	15/ 5	0.894	0.004	0.059
28226	67	5.72	A		M	0.27	0.213	0.770	15/ 5	0.551	0.008	−0.281
28294	68	5.90	F0	V		0.32	0.170	0.701	15/ 5	0.967	0.010	0.025
28319	72	3.41	A7	IV	N	0.18	0.202	1.013	15/ 5	0.865	0.005	0.265
28355	74	5.03	A6		N	0.23	0.225	0.912	6/ 2	0.565	0.021	−0.099
28527	82	4.78	A6	V	N	0.17	0.217	0.965	15/ 5	0.617	0.015	0.074
28546	83	5.48	A		M	0.26	0.233	0.795	15/ 5	0.579	0.008	−0.190
28556	84	5.40	F0	V	N	0.26	0.201	0.814	9/ 3	1.015	0.007	0.210
28677	89	6.02	F2	V	N	0.34	0.175	0.658	15/ 5	1.018	0.009	0.053
28910	95	4.66	A8	V	N	0.24	0.205	0.823	15/ 5	0.796	0.008	0.021
29375	103	5.79	F0	V		0.31	0.188	0.740	15/ 5	0.936	0.013	0.033
29388	104	4.27	A6	V	N	0.12	0.197	1.048	15/ 5	0.621	0.010	0.178
29488	108	4.68	A5	V	N	0.16	0.193	1.014	18/ 6	0.657	0.007	0.114
30210	112	5.37	A		M	0.19	0.253	0.955	6/ 2	0.355	0.007	−0.202
33254	130	5.43	A		M	0.24	0.245	0.840	6/ 2	0.276	0.015	−0.479

STAR		14 C	15 B−Y	16 E(B−Y)	17 BETA	18 (M1)	19 D(M1)	20 (C1)	21 DV	22 (U−B)	23 A,D(M1)
27397	30	L	0.170	−0.004	2.767	0.229	−0.015	0.736	0.26	1.193	
27429	32	L	0.240	−0.008	2.693	0.214	−0.00	0.540	0.28	0.968	
27459	33	L	0.126	−0.003	2.812	0.231	−0.016	0.843	0.24	1.304	
27628	38	L	0.196		2.757	0.239	−0.029	0.680		1.158	
27749	45	L	0.180		2.783	0.269	−0.054	0.702		1.241	
27819	47	L	0.081	0.001	2.857	0.225	−0.018	0.965	0.48	1.414	
27934	54	L	0.070	0.005	2.864	0.213	−0.00	1.040	0.93	1.465	
27962	56	I	0.021	−0.023	2.889	0.195	−0.012	1.042	0.69	1.431	0.041
27991	57	L	0.314	0.009	2.644	0.238	−0.03	0.327	0.00	0.802	
28024	60	L	0.165	0.001	2.753	0.205		0.914	1.57	1.323	
28226	67	L	0.164		2.775	0.243	−0.027	0.737		1.222	
28294	68	L	0.206	0.009	2.747	0.207	0.00	0.660	0.13	1.074	
28319	72	L	0.100	0.002	2.830	0.220	−0.01	0.993	0.98	1.433	
28355	74	L	0.114	0.007	2.831	0.246	−0.035	0.889	0.40	1.380	
28527	82	L	0.088	0.006	2.856	0.233	−0.026	0.947	0.45	1.413	
28546	83	L	0.142		2.809	0.259	−0.043	0.767		1.284	
28556	84	L	0.154	0.007	2.797	0.229	−0.012	0.783	0.09	1.241	
28677	89	L	0.215	−0.000	2.725	0.214	−0.00	0.615	0.31	1.042	
28910	95	L	0.144	−0.002	2.797	0.231	−0.015	0.794	0.17	1.256	
29375	103	L	0.191	0.007	2.754	0.222	−0.013	0.702	0.45	1.147	
29388	104	L	0.067	0.007	2.870	0.209	0.00	1.035	0.84	1.453	
29488	108	L	0.088	0.010	2.852	0.209	−0.002	0.996	0.84	1.414	
30210	112	L	0.091		2.844	0.269	−0.067	0.937		1.476	
33254	130	L	0.138		2.820	0.270	−0.059	0.812		1.352	

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TABLE 7

CLUSTERS FOR WHICH K-LINE PHOTOMETRY HAS BEEN PERFORMED

Object	α(1950)	δ(1950)	l^{II}	b^{II}	$(m-M)_0$ (mag)	$\langle E_{B-V}\rangle$ (mag)	Age ($\times 10^6$ years)
NGC 6475......	$17^h50^m.7$	−34°48′	356°	− 4°	6.84 (1)	+0.040 (1)	70 (1); 250 (9)
Orion..........	05 33.0	−05 21	209	−19	8.37 (2)	+0.060 (2)	3 (2)
Pleiades........	03 43.9	+23 58	167	−23	5.52 (3)	+0.040 (3)	150 (3)
IC 2391........	08 41.2	−52 45	270	−07	5.90 (4)	0.000 (4)	30 (4)
IC 2602........	10 41.0	−64 08	290	−05	5.90 (5)	+0.035 (5)	4 (5)
Hyades........	04 16.7	+15 31	180	−22	3.0 (6)	0.000 (7)	850 (8)

REFERENCES: (1) Koelbloed (1959); (2) Walker (1969); (3) Mitchell and Johnson (1957); (4) Perry and Hill (1969); (5) Hill and Perry (1969); (6) Wayman *et al.* (1965); (7) Johnson and Knuckles (1955); (8) van den Heuvel (1969); (9) Conti and van den Heuvel (1970).

From comparison of the display of k versus $(b - y)_0$ in Figure 1 with similar diagrams in Papers I and II for field stars and with the results for the other clusters to be discussed below, we readily note the uniquely tight relationship exhibited by this cluster. Except for the two highly deviant stars, Koelbloed numbers 60 and 109, which we have suggested (Hesser and Henry 1971) may be previously unrecognized Am stars, there are at most four stars (Koelbloed numbers 30, 61, 89, and 94) which fall outside the boundary of the photometric errors in the k-index for the majority of the stars. It would seem that by the use of only a mean reddening for the cluster we should have maximized the errors along the $(b - y)_0$ axis and that very accurate reddening corrections might compress the relationship even further.

Additional comparison may be made in Figure 1 between our data and the two similar curves, the latter being theoretically calculated k-indices for solar and twice solar abundance; these theoretical relations and their limitations are discussed in Paper I. From the lack of scatter in the observed relation for NGC 6475 we conclude that the abundance, star to star, of calcium in NGC 6475 varies by less than about ± 25 percent. A final comparison may be made in Figure 1 to the mean field-star relation adopted in Papers I and II (the third curve in the figure), and this comparison indicates that the average abundance of calcium (and, presumably, other metals) is the same in NGC 6475 as in the field stars. The difference in slope between the NGC 6475 stars and the mean relation for field stars may, in part, be attributable to the $(B - V)_0$ to $(b - y)_0$ conversion employed. As we pointed out earlier (Hesser and Henry 1971), if we adopt 40 pc (Spitzer 1968) as the diameter of a typical cloud from which a cluster like NGC 6475 is formed, then it appears that such a distance scale represents the region over which the interstellar gas may be significantly more homogeneous than when examined over larger regions of the Galaxy (as sampled, for instance, in our field-star measurements).

On the question raised above concerning the apparent metallic character of stars K-60 and K-109, we should remark that Conti and van den Heuvel (1970) recently found star K-109 to be Am, as they did star K-114, which we unfortunately did not observe. On a weakly exposed 100 Å mm^{-1} spectrogram of star K-60, they noted no metallic peculiarities and classified it A9 V. Our assignment of K-60 and K-109 as Am stars rests upon the assumption that they are not metal-poor or heavily reddened stars; it would be extremely useful to have Strömgren photometry to combine with our K-line material to eliminate these possibilities.

b) Orion

Results of our observations of 17 stars of spectral types between B9 and F2 in the vicinity of the Orion Nebula are presented in Table 2, where they are identified by their

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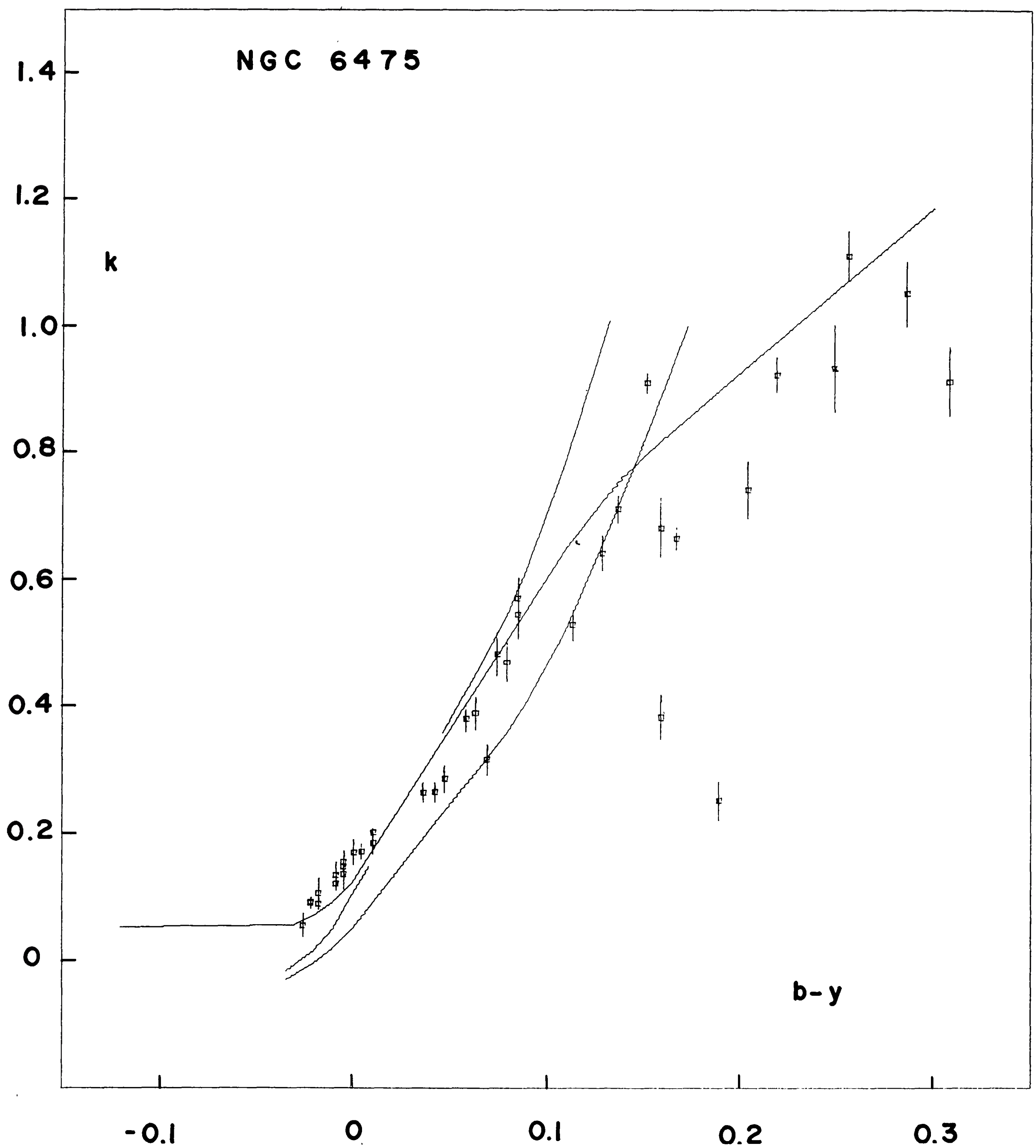

FIG. 1.—The $[k, (b-y)_0]$-diagram for NGC 6475. The two nearly parallel curves are theoretical relations for solar and twice-solar calcium abundance, while the other curve is the mean observed relation for field stars as determined in Paper II. As discussed in the text, the stars of this cluster exhibit an abundance range of only ± 25 percent, which is to be compared with the factor-of-2 range observed for solar-neighborhood field stars. The two strongly deviant stars, as described in the text, are probably Am stars.

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Brun (1935) numbers. Comparison data are taken from the combined *UBV* and spectroscopic study of Walker (1969), who found that the reddening was nearly uniform over the region and equal to 0.060 mag in E_{B-V}. We have applied that reddening to his colors for presentation in column (6) of Table 2 of $(B - V)_0$ colors, except where Walker noted an individual reddening correction, which we adopted in preference to the average value. Although Walker particularly noted the difficulties of making accurate measurements when contention with the emission nebulosity is necessary, he states that for stars of $V < 10.0$ the photometric errors are about ± 0.01 mag in V and $B - V$. One star measured in the course of our program, Brun 806, is a foreground star (Walker 1969), and it exhibits a strong K-line for its color. Only one star (Brun 734) in our list appeared to suffer heavily from nebular contamination in the k-index measurements, and for that star we made sky measurements with particular care in adjacent locations in several directions and averaged the results. It should also be recorded that, because of an instrument malfunction which took place during the two nights the Orion data were acquired and which was discovered after observing had ceased in 1970 January, and also because of the small number of standards taken due to weather conditions, the transformation errors in k may be somewhat larger, systematically, than for all other data acquired. This uncertainty is unfortunate, as it is not clear (although it seems unlikely) whether the errors would be large enough to account completely for the apparent overabundance of calcium exhibited in Figure 2, the plot of k versus $(b - y)_0$. In view of the difficulty of determining reddening corrections in the Orion region (Mendez 1967; Johnson 1968; Walker 1969) coupled with the possible transformation errors in k itself, we are reluctant to state definitely that the K-line photometry indicates an overabundance of calcium in the stars of the Orion association. The scatter at a given temperature appears to be about equal to that of the field stars, but the poor number of stars available for measurement and the uncertain reddening corrections may be masking an otherwise smooth relationship. An intermediate-band photometric study of the Orion association would be extremely interesting for comparison with this photometry and with that of Walker (1969).

c) *Pleiades*

Data were acquired for 32 stars of spectral classes B9–A9, thus making the Pleiades second only to NGC 6475 in the number of stars measured during our cluster program. We have employed unpublished *uvby*-Hβ photometry kindly supplied to us by D. L. Crawford in Table 3, while the spectral classification information was taken from the work of Mendoza V. (1956). In column (1) of Table 3 we present both the Hertzsprung (1947) and the Abt *et al.* (1965) numbers for identification. We have made individual reddening corrections wherever the value of E_{b-y} calculated according to the scheme of Strömgren (1966, 1967) exceeded 0.010 mag. Where a reddening could not be calculated, we applied the average value cited in Table 7.

In Figure 3 a plot of k versus $(b - y)_0$ is given for comparison with the similar diagrams for the other clusters and field stars, while Figure 4 graphically displays the difference from normal at a given temperature of the k-index, dk, and the difference from normal of the metallicity $[m_1]$-index, $d[m_1]$. Negative values of dk and $d[m_1]$ are indicative of low calcium and high metal abundance, respectively. (For further explanation of this diagram, the reader is referred to the discussion in Paper II, especially concerning Fig. 1 of that paper.) The star Hz 531 falls in Figure 4 in the Am-star region C defined in Figure 1 of Paper II, and its position confirms the tentative classification of it by Mendoza V. (1956) as an Am star. Several other stars barely fall outside the normal star region in Figure 4 into the region D of Figure 1, Paper II, of weak Am stars and perhaps should be reexamined spectroscopically or photometrically. On the other hand, A-44 tends to look slightly metal-rich in Figure 4, while A-14 and A-21, which are

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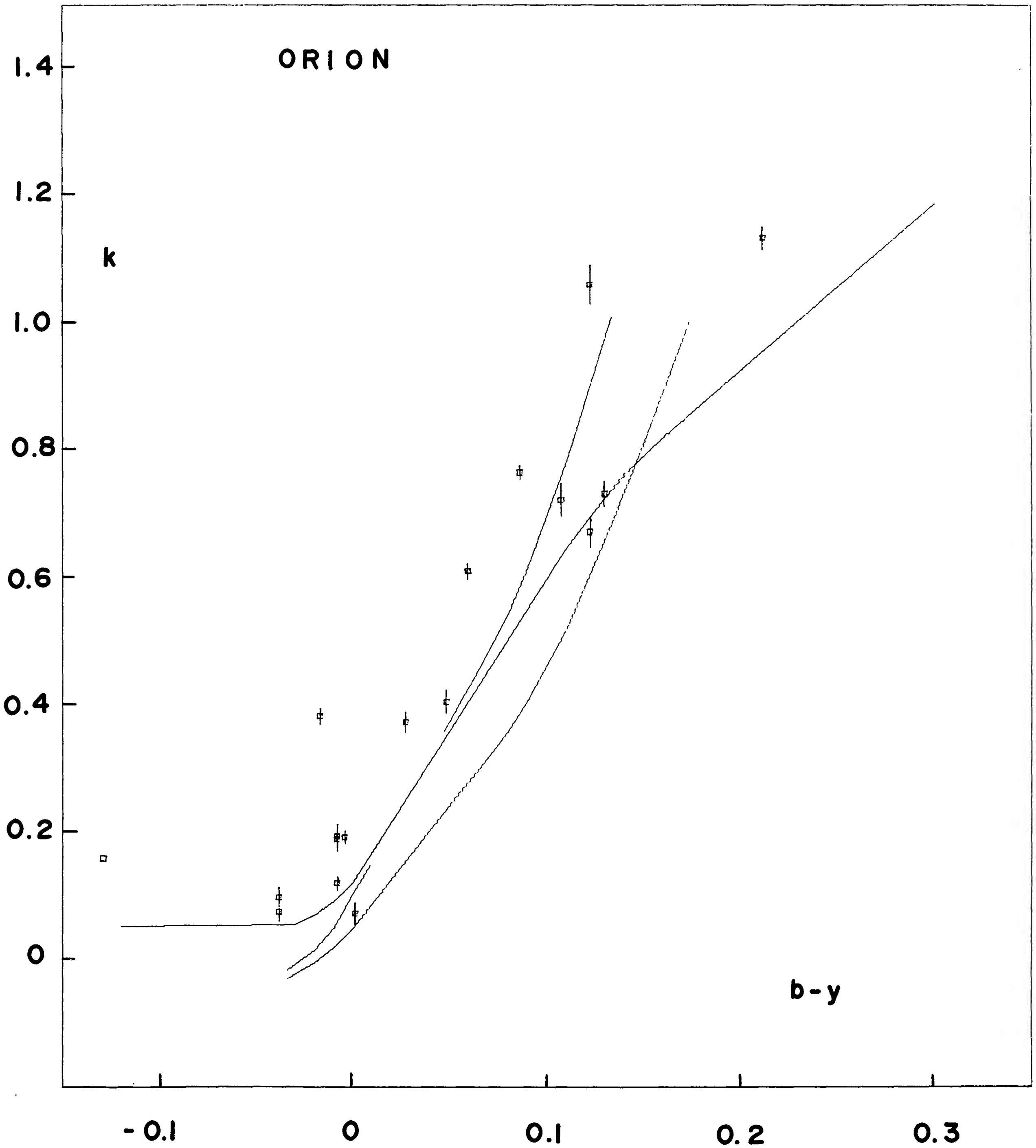

FIG. 2.—The [k, $(b - y)_0$]-diagram for the Orion association. The apparent systematic overabundance of calcium may be a combination of inadequate reddening corrections and small transformation errors in k itself, as explained in the text. For both this and the preceding diagram the $(B - V)$ colors were transformed to $(b - y)$ colors by using a relation derived from field-star observations for which both colors were available.

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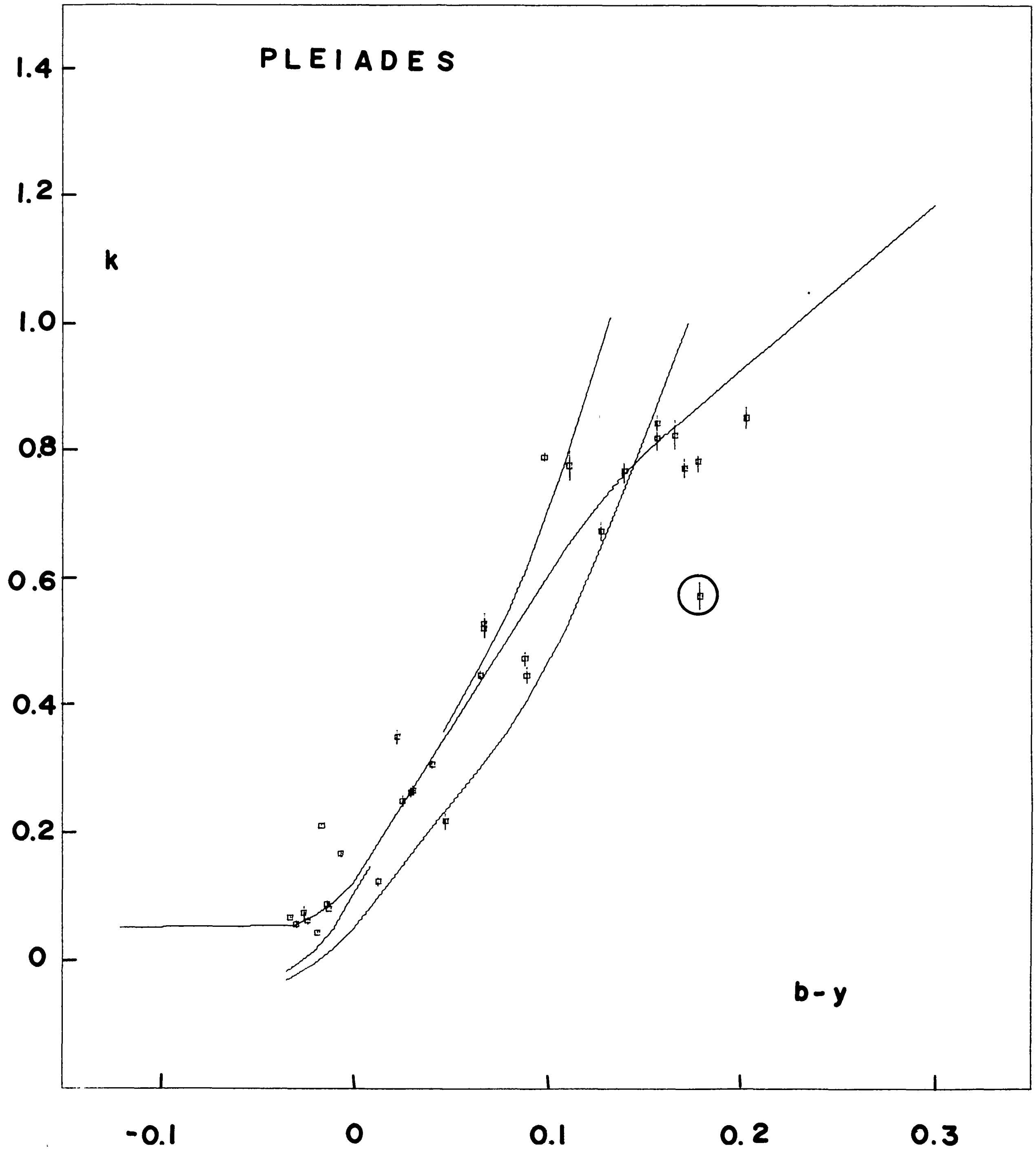

FIG. 3.—The $[k, (b-y)_0]$-diagram for the Pleiades. The colors are from unpublished *uvby*-Hβ photometry by Crawford and his associates. Star Hz 531 was classified as "Am?" by Mendoza V., and is identified by the heavy circle.

classified "intermediate" in the Strömgren system and which have very large (and uncertain [Strömgren 1966]) reddening corrections, appear to have peculiar $d[m_1]$-values. From the appearance of the data presented in Figures 3 and 4 we conclude that the stars measured exhibit a scatter no greater than that of the field stars and that the calcium abundance is equal to that of the field stars, if the reddening corrections are accurate.

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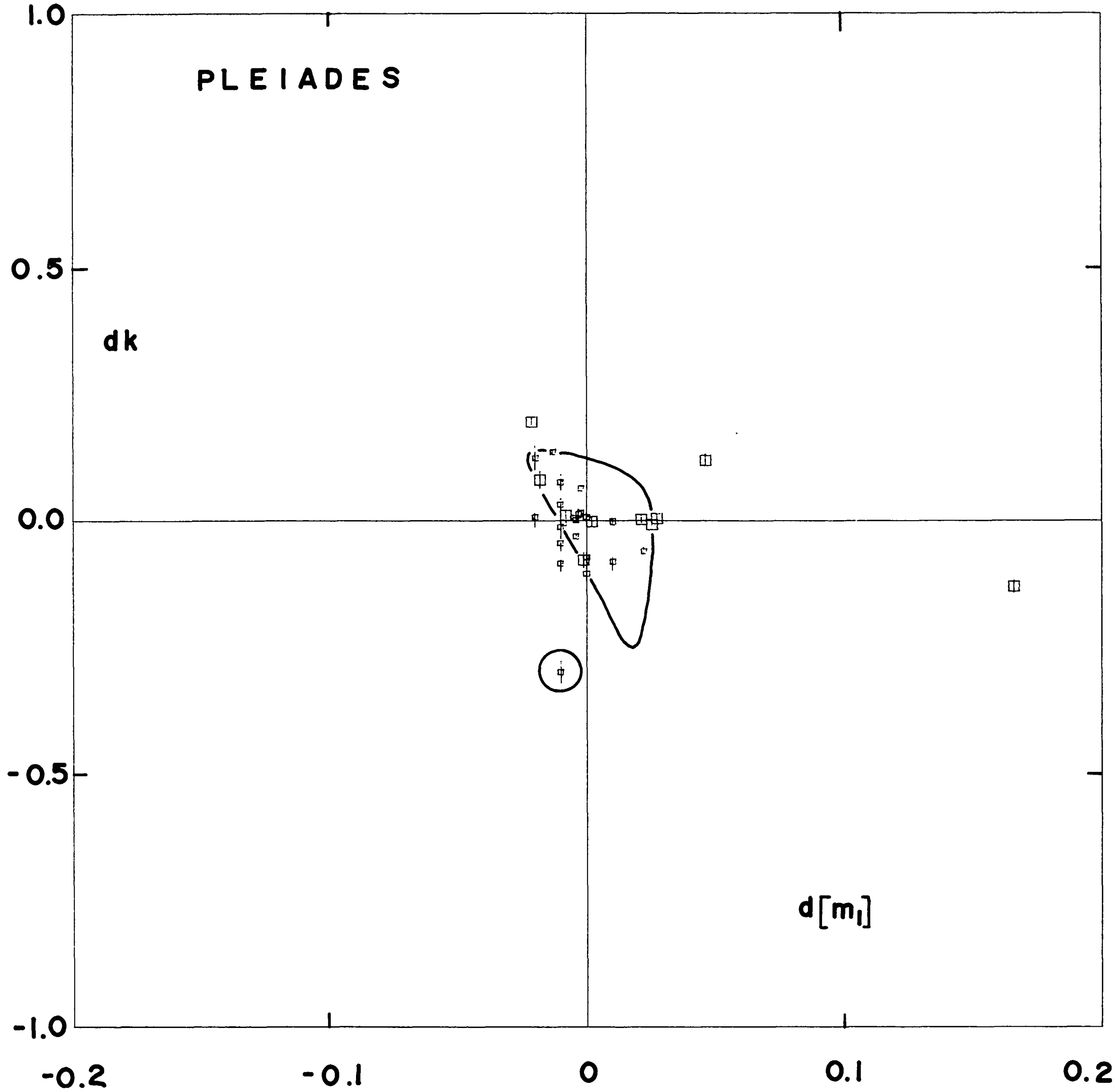

FIG. 4.—The (dk, $d[m_1]$)-diagram for the Pleiades, which may be compared with similar figures of Paper II and this paper. Negative values of dk and $d[m_1]$ represent a weak K-line and strong metals, respectively. The solid triangular border near the origin delineates the region occupied by normal field A stars. Upon comparison with Figs. 1 and 10 of Paper II we readily note the presence of the metallicity anomaly in star Hz 531, the circled datum. The remainder of the stars falling outside the normal region are discussed in the text.

With respect to the conclusion concerning star-to-star calcium-abundance variations, it is clear that errors in the (large) reddening corrections calculated and given in column (16) of Table 3 may be leading to distortion of an otherwise dispersionless relationship.

As we noted in our earlier communication (Hesser and Henry 1971), we observed only one of the three stars stated to be Am by Conti (1967), HD 23631, which we found to be of normal K-line strength; the measurements may, however, have been vitiated by a nearby star that could not be completely excluded from the entrance aperture.

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HD 23964 ("Am?" according to Conti [1967]) we also found to be normal in the (dk, $d[m_1]$)-plane. It is important to remark that both of these stars were isolated by Conti via his Sc II/Sr II line-ratio technique and thus may be of the type of metallic-line star with normal K-line strength.

d) IC 2391

Only 11 stars classed as A stars were available for measurement, although we did observe a number of additional stars of both earlier and later spectral class. In Table 4 we have used the *UBV* and *uvby*-Hβ photometry of Perry and Hill (1969) for the stars, which have been identified with their HD numbers. The MK spectral classes are also taken from Perry and Hill, although the majority were derived by Buscombe (1965). No general reddening has been assumed, but wherever the value of E_{b-y} in column (16) of Table 4 exceeds 0.010 mag, it has been applied to the color to yield the value of $(b - y)_0$ in column (15). Figures 5 and 6 display the [k, $(b - y)_0$]- and (dk, $d[m_1]$)-diagrams for this cluster. With the exception of the few early A stars for which the star-to-star scatter is about equal to or slightly less than that of the field stars, the low number of A stars measured prevents a decision on the uniformity of calcium abundance from star to star; the present data suggest, at least, that the calcium abundance of IC 2391 is similar to that of field A stars. It is important to note that Perry and Bond (1969) have performed a supplementary spectroscopic survey of IC 2391, in which classifications of several stars are altered from those given in Table 4. They classify HD 74044 as A7 V, HD 74582 as F3 III, HD 75066 as F2 III, and HD 75202 as A5 V (spectroscopic binary?); in addition, they suggest that HD 74340 may be a spectroscopic binary. On the basis of a luminosity criterion, they suggest that HD 74535, 74169, 74582, and 75066 are nonmembers, and on the basis of a proper-motion criterion they eliminate HD 74762 from membership. The net effect of the deletions is to reduce the number of stars lying above the mean relation for IC 2391 in Figure 5 and to lend more credence to the conclusion that the calcium abundance in the cluster is equal to that of the field A stars.

There is a suggestion in Figure 6 that several of the stars possess metallic character, e.g., HD 75202, 74044, and 74009,[1] while one star, HD 74762 (a spectroscopic binary according to Buscombe 1965 and a nonmember according to Perry and Bond 1969), tends to fall in the metal-rich region of Figure 6. Furthermore, the circled star in Figure 5, HD 74665, is an A3m star (Buscombe 1965), yet it falls within the border of the normal-star region in Figure 6; however, as found in Paper II, this is not a unique experience. In view of the controversy over the question of whether a very young cluster may be expected to have Am stars (Jaschek and Jaschek 1959; Abt *et al.* 1965; Conti and van den Heuvel 1970), the need for further spectroscopy of the photometrically peculiar stars in Figure 6 is clearly indicated.

e) IC 2602

This cluster suffers from interstellar reddening of average amount, $\langle E_{B-V}\rangle = 0.035$ mag, according to Hill and Perry's (1969) *UBV*, *uvby*-Hβ analysis. MK spectral classifications are available from the work of Whiteoak (1961). For presentation of the data in Table 5 we have used the HD or HDE numbers for identification. Wherever possible the reddening was calculated and applied to the observed colors; where necessary, the average value cited in Table 7 was applied. In general, only stars earlier than A5 were available for measurement with the K-line photometer, as seen in the plot of k versus $(b - y)_0$ in Figure 7.[2] Two stars, HD 93209 and HD 93714, have been judged by Hill

[1] Our measurement of the F2 star HD 74009 may have been influenced by a nearby faint star which was difficult to exclude from the entrance slit.

[2] Although perhaps only a fortuitous coincidence, it is worth noting that the very late stars HD 93796 (G2 IV) and Braes 57 (F8 V) both fall on a linear extension of the observed normal field star k versus $(b - y)_0$ relation for earlier spectral types.

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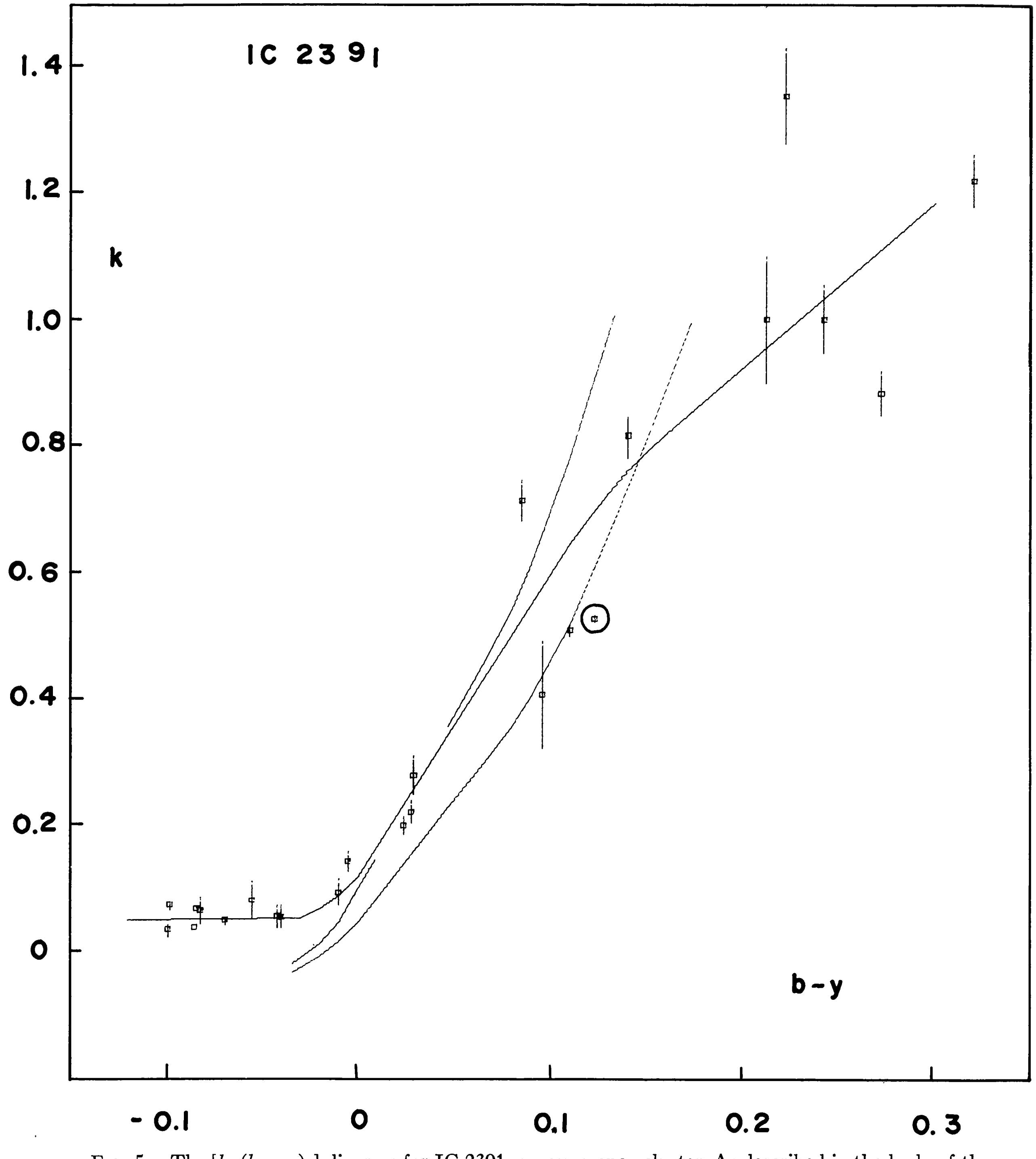

FIG. 5.—The $[k, (b - y)_0]$-diagram for IC 2391, a young open cluster. As described in the body of the paper, a number of stars in this and the following diagram appear to be weak Am, or otherwise peculiar stars.

and Perry to be nonmembers on the basis of their positions in (V_0, M_V)-diagrams. HD 93209, membership notwithstanding, and HD 93012 (also cited by Hill and Perry to be photometrically peculiar) fall in the strong K-line, weak-metals region of the $(dk, d[m_1])$-diagram, Figure 8; however, they are both of "intermediate" class with large reddening corrections. The other outstanding stars in Figure 8 are HDE 307860

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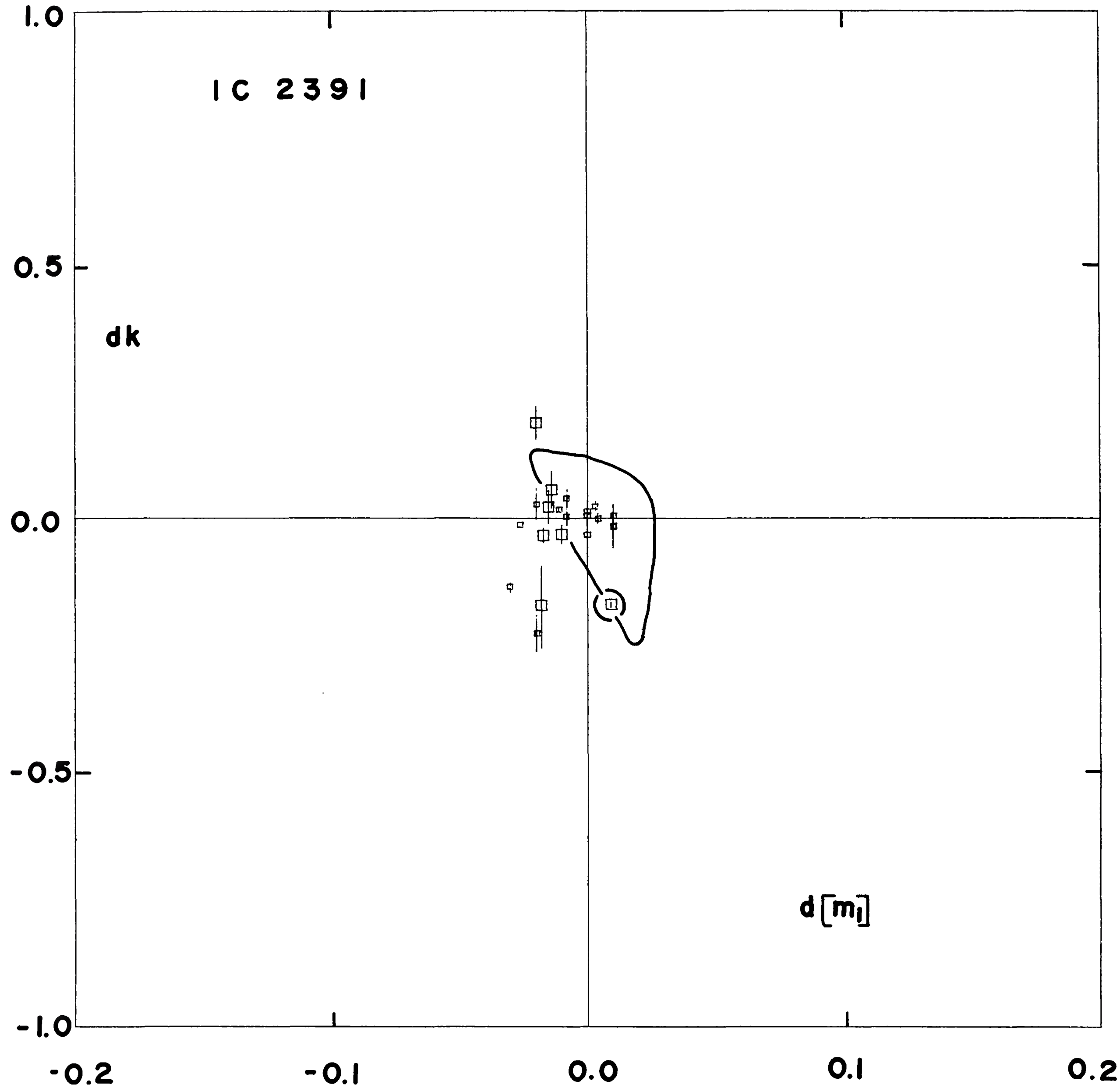

FIG. 6.—The (dk, $d[m_1]$)-diagram for IC 2391. The known Am star, HD 74665, is circled; it clearly has a weak K-line, but the metals in general do not mimic the usual behavior of the metallic stars. Three other stars appear from this diagram as candidates for weak Am stars; if confirmed, the presence of four such stars makes this young cluster a particularly important one in discussions of the metallicity anomaly as a function of stellar age. The single star outside the normal-star region in the second quadrant, HD 74762, is believed to be a foreground star.

(photometrically peculiar according to Hill and Perry), HD 93738, and HD 93796 (G2 IV, for which we have no basis of comparison). From the appearance of those stars remaining as bona fide members and without peculiarities, it is seen that the scatter in abundance variation of calcium for IC 2602 is similar to that of the field stars, when the reddening corrections of column (16) are applied to the observed colors, while the abundance itself is equal to that of the field stars. According to Hill and Perry, IC 2602 is a particularly interesting cluster in that the nuclear and contraction age estimates

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numbers from van Bueren (1952) and the *Henry Draper Catalog*. In Figure 9, the $[k, (b-y)_0]$-diagram, and Figure 10, the $(d[m_1], dk)$-diagram, the Am stars are circled. We readily note that the star VB 74, classified A6N in Hoffleit (1964), exhibits Am character, as was found earlier by Crawford and Perry (1966); unfortunately we did not observe the other star (VB 107) that Crawford and Perry also found to be a "fringe"

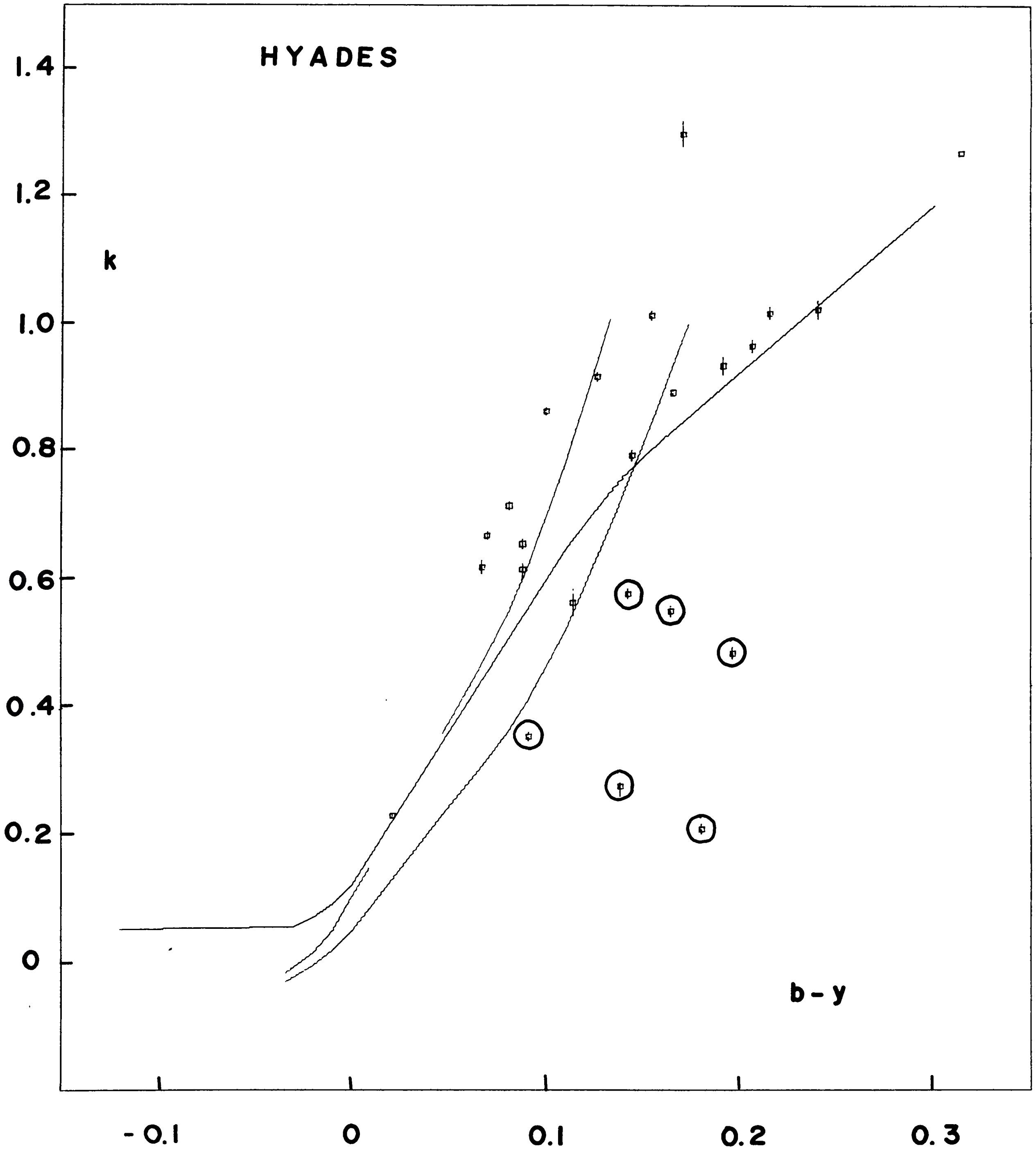

FIG. 9.—The $[k, (b-y)_0]$-diagram for the Hyades. The known Am stars are circled. The well-known tendency for the metals to be overabundant in this cluster shows clearly in comparison of the K-line strengths with the field-star relation.

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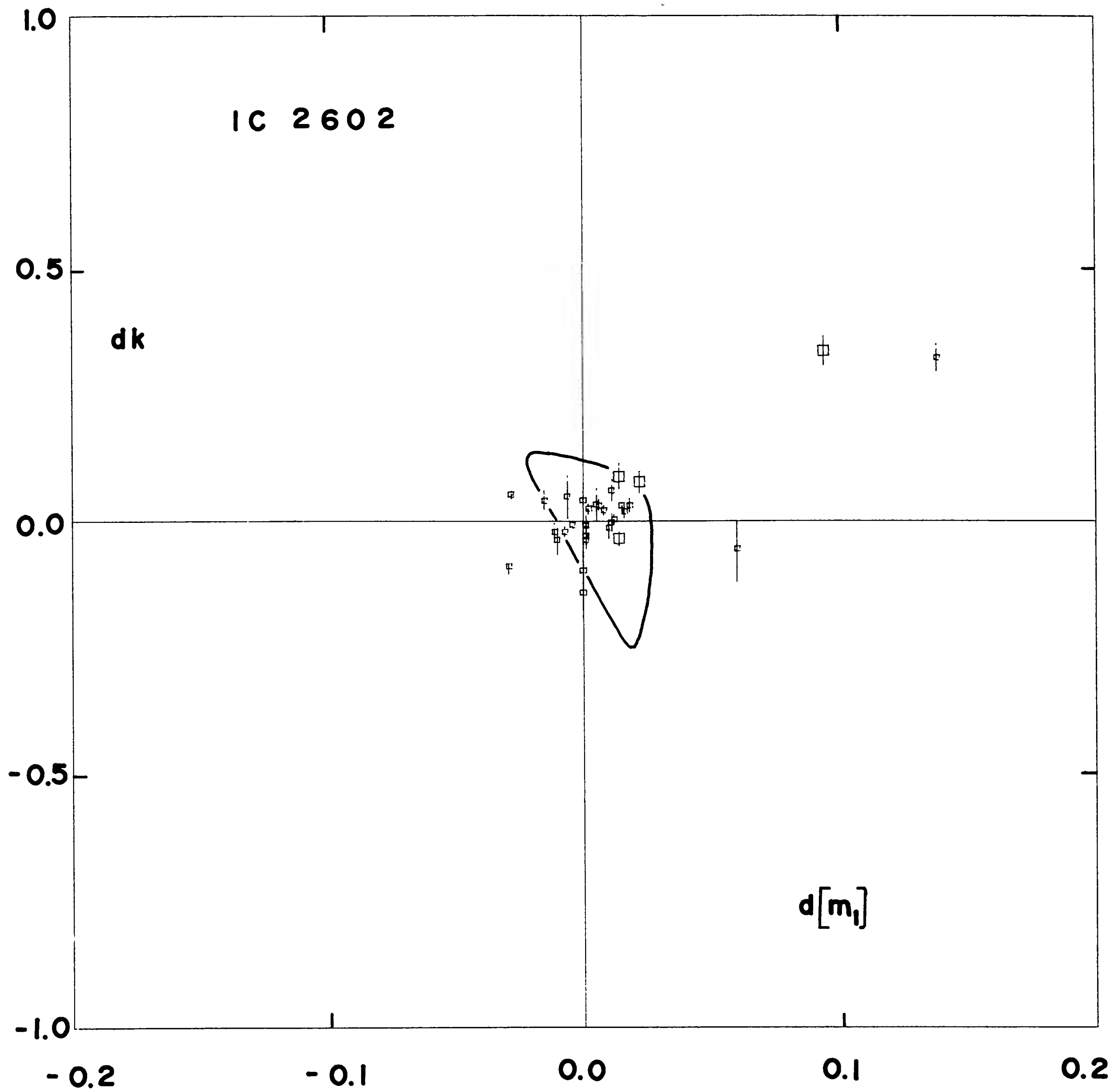

FIG. 8.—The (dk, $d[m_1]$)-diagram for IC 2602. In the first quadrant the two stars with uncertain reddening corrections appear far away from the origin, while the G2 IV star, a spectral type which is far later than for any of our comparison data, falls in the fourth quadrant away from the origin.

indicate that star formation was not coeval in this cluster; thus it is interesting to note the very normal appearance of the cluster stars in the (dk, $d[m_1]$)-diagram, which suggests that the age differences are not photometrically apparent in our system.

f) Hyades

Seventeen A stars, all but one later than A5 and six of which are Am stars, have been measured, as well as seven F stars. For use in presentation of the data in Table 6, spectral classifications for all stars but VB 74 have been taken from Morgan and Hiltner (1965), *uvby*-Hβ photometry from Crawford and Perry (1966), and identification

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worthy of specific comments. For instance, the K-line strength in Figure 9 for half of the spectroscopically normal stars measured follows the mean relation given by the field stars (Papers I, II), while the other half of the stars (specifically VB 30, 33, 47, 54, 72, 84, 104, and possibly 108) appear to form a sequence approximately parallel to the normal one in the range $0.081 \lesssim b - y \lesssim 0.165$ mag and ~ 0.2 mag above the field-star relationship. This "sequence" appears clearly defined in that the photometric errors for these oft-observed bright stars are quite low. Despite the small observational errors, the reality of this "sequence" is challenged by other information. For instance, in Figure 10 we see that among those stars falling above the normal-field-star relation in Figure 9, all values of $d[m_1]$ are represented, and, vice versa, that at various values of $d[m_1]$ a wide range of dk values exists. Also, despite the fact that four of the stars in the strong-K-line group are more highly evolved (see dV in col. [21] of Table 6), while only two are similarly evolved for the undeviating group, the average dV values are only slightly (and probably insignificantly) different: $\langle dV \rangle = 0.058$ mag $\pm$ 0.013 mag m.e. for the deviant stars and $\langle dV \rangle = 0.045 \pm 0.016$ mag for the normal group.[3] Furthermore, the location of the upper group in the $(m_1, b - y)$-diagram (Crawford and Perry 1966) is not consistent with the suggestion that they form an identifiable sequence in metal abundance versus color.

It is interesting to note as well that, although the observed stars fall in all categories from normal to what we called metal-rich in Paper II for the field stars, the stars tend to fall in the metal-rich portion of the $(dk, d[m_1])$-plane, and that a small shift of the normal-star envelope into the metal-rich region of Figure 10 would encompass most of the Hyades stars. We conclude that the observations describe an inherent spread in calcium star-to-star abundance, and we ask if the envelope observed in k versus $b - y$ is significantly different from that of the field stars. If we include all but the most divergent stars in an envelope for the field stars in Figure 6 of Paper II, then the total width in the k-index at any given $b - y$ value in the range mentioned earlier is ~ 0.37 mag whereas that of the Hyades stars is ~ 0.15 mag; thus the Hyades stars are, indeed, seen to manifest less scatter in k than the field stars.[4] A similar conclusion is reached from a comparison of the envelopes in the $(m_1, b - y)$-diagram of the Hyades stars (Crawford and Perry 1966) and field stars (Strömgren 1963), where the respective envelope widths scale very nearly as the ~ 10 decrease in sensitivity between the k and m_1 photometric indices when used in conjunction with $b - y$ colors. We thus agree with the findings of Conti *et al.* (1965) and Nissen (1970*a*, *b*) that the Hyades stars exhibit constancy of composition, especially among the A5–F0 classes where our data are most abundant. However, it also appears from our discussion given earlier (Hesser and Henry 1971, and present paper) that NGC 6475 shows even less scatter than the Hyades.

IV. SUMMARY

Observations of 168 stars in five open clusters and one association performed on the system of K-line photometry introduced in Paper I and extended in Paper II bring the total number of stars observed to date to 537. After analysis of the observations of the field stars indicated an intrinsic width in the $(k, b - y)$-relation, at a given temperature—a width that has been attributed to abundance variations of a factor of 2 in calcium in

[3] If one could eliminate VB 60 from the normal star group for some adequate reason, then, inasmuch as it is the most highly evolved star of those measured, the value $\langle dV \rangle = 0.031 \pm 0.008$ mag is obtained for the normal-star group and a possible evolutionary effect seems more likely; lacking adequate evidence for adoption of this line of reasoning, we mention it only for completeness.

[4] If, however, we rather arbitrarily exclude the majority of those stars identified in Tables 3 and 4 of Paper II from consideration in determination of the field star width in k at a given temperature, we then find a field-star envelope width of ~ 0.23 mag. The Hyades stars still manifest less scatter than do the field stars in such a revised comparison, but then the field stars themselves exhibit less scatter in k versus $b - y$ than they do in m_1 versus $b - y$.

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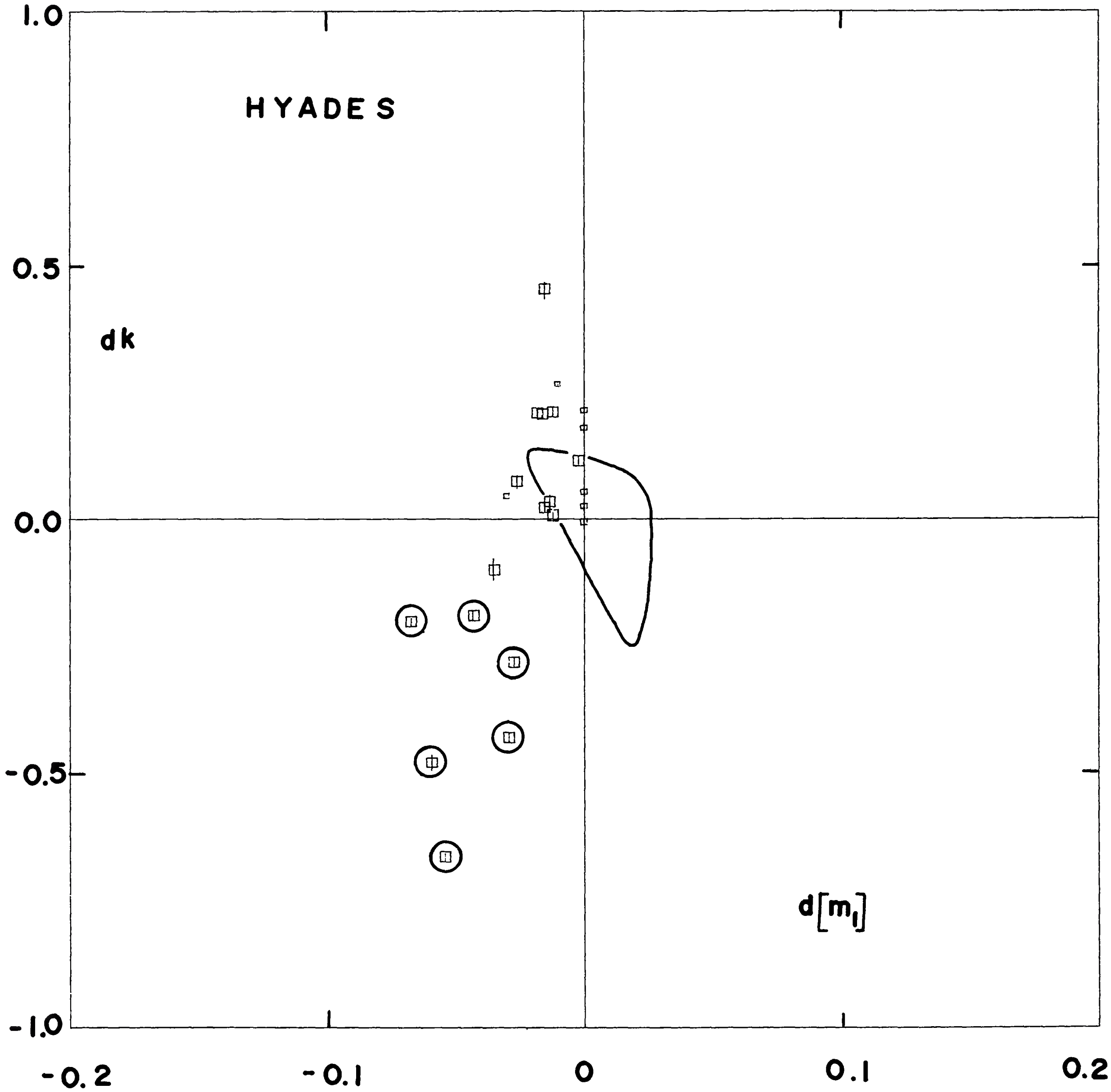

FIG. 10.—The (dk, $d[m_1]$)-diagram for the Hyades. Star HD 28355, found to be a weak Am star by Crawford and Perry, clearly stands apart from the origin with the previously known Am stars.

Am star. The earliest star observed, VB 56 or 68 Tau (A3 V) falls on the borderline of the metallic-star region in the (dk, $d[m_1]$)-plane. As the Hyades possess a well-known metal richness (i.e., a tendency to have negative $d[m_1]$-values [Strömgren 1958; Parker *et al.* 1961; Crawford and Strömgren 1966; Nissen 1970*a*, *b*]), we see that the K-line and intermediate-band photometry does not clearly support the suggestion of Conti, Wallerstein, and Wing (1965) that VB 56 is a weak Am star. In turn, however, if the detailed analysis that suggests VB 56 to be somewhat unusual is accepted, then the photometry cited would indicate that VB 95 and 103 may share the properties of VB 56.

While restricting ourselves to the spectroscopically normal stars (excluding VB 74 as well), we find that some of the general characteristics of the two Hyades figures are

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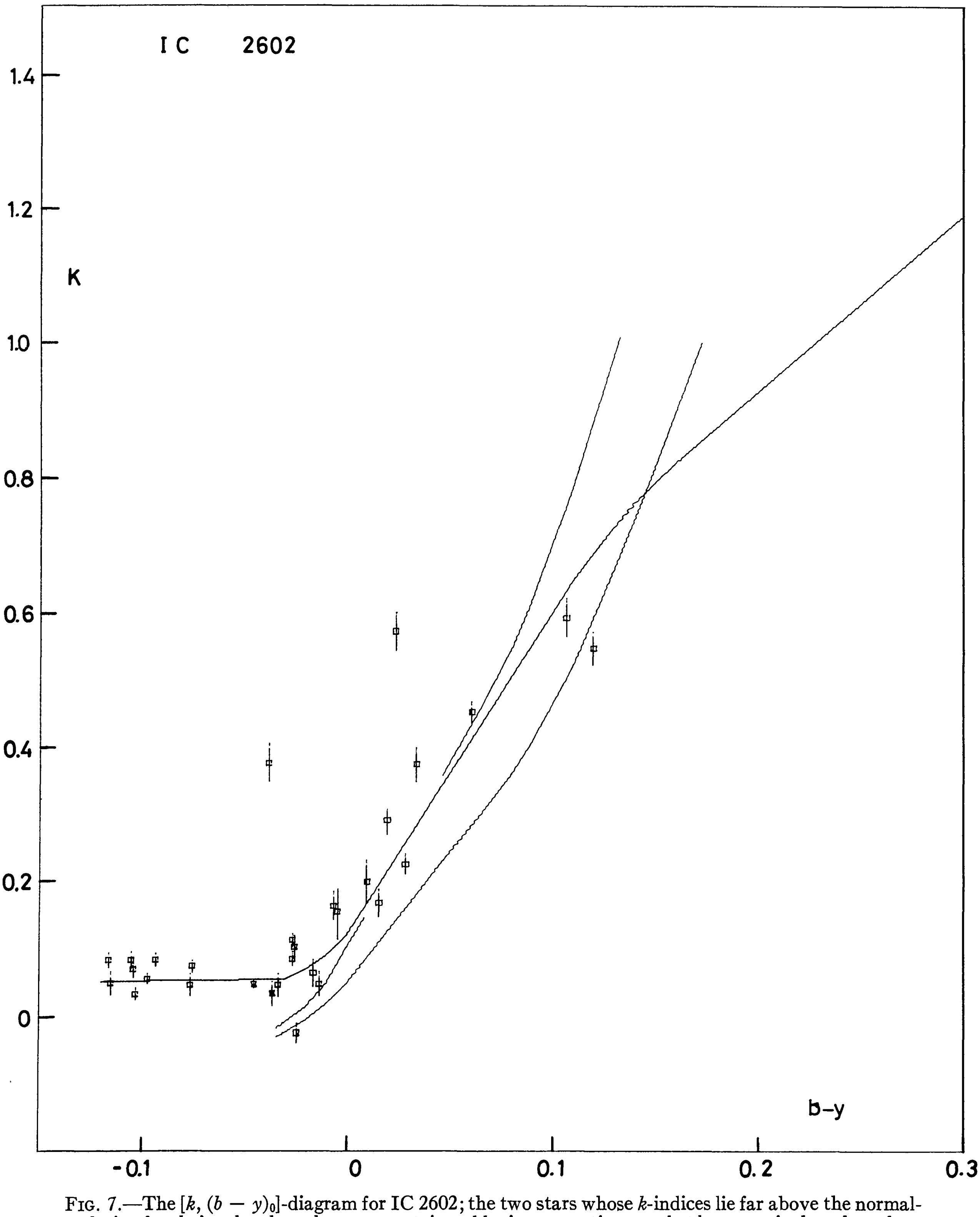

FIG. 7.—The $[k, (b-y)_0]$-diagram for IC 2602; the two stars whose k-indices lie far above the normal-star relation for their colors have large, uncertain reddening corrections, and at least one is thought to be a nonmember.

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the solar-neighborhood A stars—we naturally wished to investigate the $[k, (b-y)_0]$-relationship in clusters where the spread would presumably be less if the cluster formed from a homogeneous portion of the interstellar medium. At least two such regions, where greater homogeneity exists in calcium, and presumably general metal abundances, have emerged from our studies: NGC 6475 and the Hyades. The A stars of NGC 6475 seem to be even more homogeneous in k than those of the Hyades, and we urge inclusion of this cluster in future intercluster comparison programs for authentication and exploitation of this finding. Improved spectroscopy and photometry are badly needed for NGC 6475, for, as noted by Abt and Jewsbury (1969), NGC 6475 may be a far larger and richer cluster than has heretofore been assumed. Other regions over which the interstellar medium that condensed to form the Population I open clusters was uniform in calcium abundance may have been obscured in our photometry by the use of inadequate reddening corrections for individual stars, for example in the Pleiades or IC 2602.

The data gathered and interpreted in this and the previous investigation (Paper II) provide support for three relatively new observational constraints to the phenomenon of Am stars. As described in the discussion of Figure 12 in Paper II, within the limitations of the preliminary calibration of the *uvby*-Hβ system for A and Am stars, our data tend to support the conclusion of Abt (1966) and Smith (1971) that the metallicity anomaly is moderated by mild evolution off the zero-age main sequence. Furthermore, we have seen that a relatively smooth transition appears to exist in the $(dk, d[m_1])$-plane between normal and metallic-line stars, and that metallicism does not appear as a discrete phenomenon in that plane. Finally, our cluster data have provided new information on the occurrence of Am stars in young Population I clusters. After demonstration in Papers I and II of the efficacy of the combination of K-line and intermediate-band photometry for the detection of classical (i.e., weak K-line and strong metals) Am stars, our results for known Am stars in the Hyades provide strong additional support for the technique. Moreover, we have also seen how stars that are weakly metallic—such as VB 74 in the Hyades and Hz 531 in the Pleiades, discovered by very careful use of normal spectroscopic and photometric techniques—readily stand out in the $(dk, d[m_1])$-plane. This in turn lends a measure of confidence to our detection of new, weak Am stars in NGC 6475 and IC 2391, both of which are young clusters. The repercussions of such observations, when confirmed, have been explored by Conti and van den Heuvel (1970) and need not be repeated here. Extensive application of four-color and K-line photometric techniques to clusters of different ages should readily and unambiguously enable the delineation of metallicity characteristics as a function of age to be carried out.

We are indebted to Lyman Spitzer, Jr., and the Princeton University Observatory for the loan of the K-line photometer, to D. L. Crawford and J. V. Barnes for communicating their photometry, especially that of the Pleiades, to us prior to publication and for allowing us to use it freely herein, and to D. J. Ludden for his efforts to improve the mechanical properties of the photometer. One of us (J. E. H.) particularly wishes to thank D. L. Crawford and P. S. Osmer for many stimulating discussions during the course of writing this manuscript. One of the authors (R. C. H.) was partially supported by National Science Foundation grants GP 7086, 8313, and 11855, and wishes to express his gratitude to Jorge Sahade and the Government of Argentina for providing funds for one of the trips to South America. Finally, we gratefully acknowledge the support of the Cerro Tololo Inter-American Observatory by the National Science Foundation.

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