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FURTHER OBSERVATIONS OF STARS IN THE INTERMEDIATE-AGE OPEN CLUSTER NGC 2477

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ABSTRACT

Recent *uvby*-Hβ photometry of main-sequence stars in NGC 2477 has led to the following conclusions: (i) Confirmation of previously determined reddenings and V-band photometry. (ii) The surface gravities of the turnoff stars are similar to those of analogous Hyades stars. (iii) The existence of a discrepancy between [Fe/H] inferred from m_1 and CN measures that can be at least partially resolved if the cluster contains a large number of rapidly rotating stars ($v \sin i \simeq 200$ km s^{-1}). (iv) NGC 2477 appears to have a number of Am stars. (v) Three stars identified as possible "blue stragglers" have higher masses than stars near the turnoff point. (vi) The upward-revised turnoff point at $V = 13.3$ mag ($M_V = 1.7$) leads to an age and turnoff mass of 0.9×10^9 years and 1.9 $\mathfrak{M}_\odot$, respectively.

Additional B, V photographic data for $\sim$1,200 stars are presented and used to construct a new color-magnitude diagram based on $\sim$1,900 stars to $M_V \simeq +6.4$ mag.

Results of a survey that revealed two carbon stars in the near vicinity of the cluster are presented and compared with results for other intermediate-age clusters, and photoelectric photometry demonstrating the variability of the two stars is given.

Finally, from a discussion of data in the literature we present evidence for a correlation between $\Delta\beta$ and $v \sin i$ in main-sequence A and F stars in the range $0.1 < (b - y)_0 < 0.25$ mag.

Subject headings: abundances, stellar — carbon stars — metallic-line stars — open clusters — photometry — rotation, stellar

I. INTRODUCTION

The intermediate-age southern cluster NGC 2477 ($\alpha = 7^h51^m.4$, $\delta = -38°29'$, 1975; $l = 254°$, $b = -6°$) is one of the most densely populated open clusters known. As such it is a potentially important object with which to compare the results of theoretical stellar-evolution calculations. In a recent observational study of NGC 2477, Hartwick, Hesser, and McClure (1972; hereinafter referenced H^{2}M) pointed out some difficulties in attempting to make such a comparison, particularly near the turnoff point.

For instance, the position of the turnoff in NGC 2477 adopted by H^{2}M was such that a large number of stars remained near the main sequence above the turnoff point (see fig. 7*b* of H^{2}M). In adopting this position, H^{2}M were influenced by the superposition of theoretical tracks with the gap on the upper main sequence and by a group of stars lying above the turnoff, a group that appeared to the characterized by lower surface gravities as judged from their positions in the two-color diagram. Additionally, the ultraviolet deficiencies and cyanogen band strengths in the giant stars had been found by H^{2}M to indicate a metallicity that is higher than that of the Hyades, and confirmation of that finding is desirable. Many of the difficulties are enhanced by the presence of the differential reddening first pointed out by H^{2}M.

In order to investigate further some of the problems that remained from our earlier study, additional observations have been obtained in the *uvby*-Hβ systems (Strömgren 1966; Crawford and Mander 1966). Since these photometric systems are capable of yielding accurate reddenings and relative surface-gravity and line-blanketing indices for A and F stars (Crawford 1970, 1972; Crawford and Barnes 1969), they are particularly well adapted to investigating the A and F stars near the turnoff in this intermediate-age cluster. Furthermore, in order to facilitate further observational studies of NGC 2477, as well as to improve the color-magnitude (C-M) diagram presented earlier in H^{2}M, we have included B, V photographic photometry for an additional $\sim$1,200 stars, bringing the total available to $\sim$1,900. In addition, we have been prompted by our previous studies near the intermediate-age cluster NGC 2660 (Hartwick and Hesser 1971, 1973) to search for carbon stars in the vicinity of NGC 2477, and the results of that search are discussed in Appendix A.

II. RESULTS OF FOUR-COLOR AND Hβ PHOTOMETRY

a) The uvby-Hβ Observations

The results of *uvby* and Hβ photometry for 18 stars near the main sequence in NGC 2477 are given in

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TABLE 1

RESULTS OF *uvby*-Hβ PHOTOMETRY FOR NGC 2477 STARS

Star	*V*	*B-V*	*U-B*	*y*	*b-y*	m_1	c_1	β	n*	E_{B-V}†	$M/M_\odot$
H	13.25	0.58	0.37	13.222	0.401	0.101	0.928	2.813	2/1/1	0.35/0.40	1.14
J	13.19	0.81	0.46	13.170	0.601	0.055	0.764	2.691	2/2/2	0.53/0.53	0.80
V	13.80	0.66	0.44	13.821	0.416	0.163	0.922	2.799	3/2/2	0.44/0.40	0.91
W	13.93	0.65	0.39	13.939	0.453	0.086	0.921	2.761	3/2/2	0.40/0.41	0.34
k	13.15	0.55	0.34	13.155	0.354	0.133	0.912	2.776	3/2/2	0.31/0.28	1.03
l	14.01	0.61	0.29	14.022	0.398	0.163	0.748	2.752:	3/2/1	0.31/0.29	1.10
m	12.62	0.57	0.32	12.633	0.384	0.173	0.738	2.773	1/3/3	0.31/0.30	5.81
n	13.38	0.80	0.37	13.383	0.537	0.152	0.530	2.622	3/2/2	0.46/0.29	
t	13.04	0.52	0.35	13.039	0.357	0.107	0.997	2.859	3/3/3	0.31/0.40	1.31
v	12.86	0.74	0.41	12.850	0.533	0.071	0.787	2.709	2/2/2	0.46/0.45	1.10
x	12.85	0.50	0.34	12.835	0.349	0.114	0.996	2.822	2/2/2	0.29/0.35	1.03
z	12.89	0.50	0.29	12.864	0.331	0.127	0.912	2.782	2/2/2	0.25/0.27	1.01
1078	13.27	0.54	0.36	13.266	0.374	0.088	0.951	2.820	4/2/2	0.32/0.38	0.82
3004‡	11.68	0.35		11.701	0.312	0.123	0.990	2.808	0/4/4	/0.28	2.33
4019	14.03	0.57	0.24	14.010	0.408	0.105	0.752	2.740	2/2/2	0.26/0.30	0.80
5027‡	12.29	0.38		12.267	0.351	0.123	0.973	2.803	0/4/4	/0.33	1.58
6029	12.84	0.55	0.32	12.835	0.373	0.116	0.872	2.752	2/3/3	0.30/0.28	1.02
7097‡	12.07	0.36		12.021	0.352	0.127	0.943	2.784	0/4/4	/0.30	1.93

Notes:

* Number of observations in *UBV*/*uvby*/Hβ, respectively.

† Reddenings determined from the two-color diagram (H²M) and *uvby*-Hβ photometry, respectively.

‡ *V*, *B* values are photographic, from H²M.

table 1, as are comparison *UBV* data from H²M. The data were obtained as part of a extensive program in the 1972 season with CTIO filter-set 3 and a single-channel, 1P21, refrigerated photometer on the 91-cm and 1.5-m telescopes of the Cerro Tololo Inter-American Observatory. Nearly all data were registered with the pulse-counting facilities of the CTIO data system (Lasker 1971). Following reduction of the raw readings by the authors, the data were very kindly transformed to the respective standard systems by Mrs. Jeannette Barnes at the Kitt Peak National Observatory. Mean transformation and extinction coefficients carefully determined on many nights were utilized in the reductions. Errors in transformation to the standard *uvby* and Hβ systems defined by Crawford and Barnes (1970) and Crawford and Mander (1966), respectively, were of the order 0.015, 0.009, 0.013, 0.012, and 0.009 mag for y, $b - y$, m_1, c_1, and β, respectively. In the same order, median standard errors of a single observation for those NGC 2477 stars with multiple observations were 0.021, 0.011, 0.015, 0.014, and 0.006 mag; the means presented in table 1 are expected to be more reliable in those cases where multiple observations are available.

By the use of *V*-magnitude values obtained from a variety of sources, principally the Naval Observatory catalog (Blanco *et al.* 1968) and the Lunar and Planetary Laboratory catalog (Johnson *et al.* 1966), the *y*-values were transformed to the *V*-magnitude of the *UBV* system; however, in order to emphasize that the *y* rather than *V*-filter was used, the designation *y* has been retained in table 1. As pointed out by H²M, a small systematic magnitude error appears to exist between the recent *UBV* photometry and the original photometry of Eggen and Stoy (1961) obtained in the earliest days of southern-hemisphere photoelectric work. The new, independently determined, *y*-values given in table 1 are in excellent agreement with the *V*-values obtained by H²M.

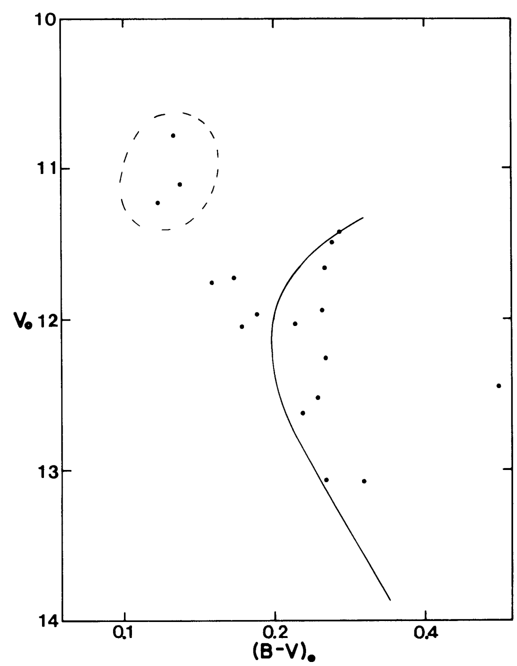

FIG. 1.—Unreddened color-magnitude diagram for the NGC 2477 stars measured in the *uvby*-Hβ systems. The photoelectric *B*, *V* values were taken from H²M, while the reddenings used were those determined from the *uvby*-Hβ photometry. The estimated location of the turnoff is indicated by the solid line.

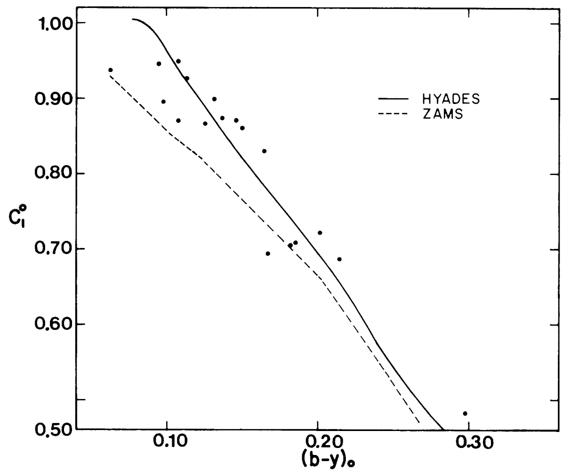

FIG. 2.—The $c_1{}^0$ versus $(b - y)_0$ diagram for each of the stars in table 1. The Hyades locus is from the work of Crawford and Perry (1966), while the zero-age main sequence (ZAMS) is from Crawford (1970).

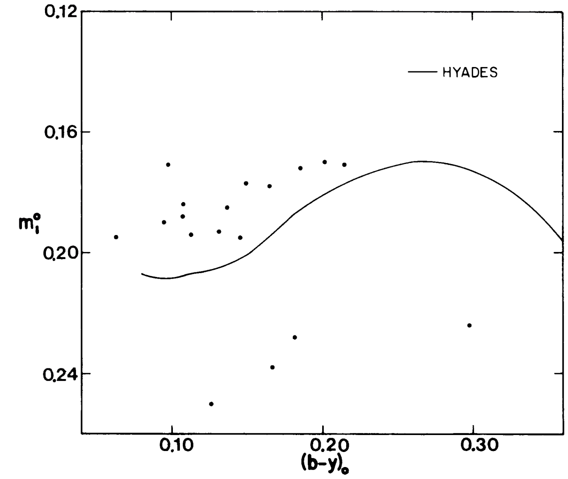

FIG. 3.—The $m_1{}^0$ versus $(b - y)_0$ diagram for the stars of table 1.

A conventional color-magnitude diagram based on the B, V data of H^2M and the reddenings determined below from the Strömgren-Crawford photometry is given in figure 1, and shows the relative positions of the measured stars with respect to the newly adopted (cf. § III) turnoff. Where necessary in this paper, we have adopted the values of A/E_{B-V} and A/E_{b-y} used by Crawford (1972) in his most recent calibration work on the photometric systems.

b) Reddening Determinations

Included in table 1 are values of the reddening determined from our data following the method of Crawford and Barnes (1969) and Crawford (1970, 1972); for comparison, the reddening determined by H^2M from the $[(U - B), (B - V)]$-diagram is also given. It is apparent that the two independent methods are in excellent agreement[1] and the case made by H^2M for the existence of differential reddening across the cluster is further strengthened.

c) The $[c_1{}^0, (b - y)_0]$-Plane

In figure 2 we have plotted $c_1{}^0$ versus $(b - y)_0$ for each of the stars in table 1. Also shown is the position of the zero-age main sequence (ZAMS; Crawford 1970) and the Hyades main sequence (Crawford and Perry 1966). From this diagram, which allows a determination of relative differences in surface gravity, we conclude that, on the average, the surface gravities of the NGC 2477 stars do not differ significantly from those of the Hyades stars.

d) The $[m_1{}^0, (b - y)_0]$-Plane

Figure 3 shows a plot of $m_1{}^0$ versus $(b - y)_0$ for the NGC 2477 stars, as well as the position of the Hyades locus. It is immediately apparent that for most of the stars the m_1 index in NGC 2477 is systematically lower than in the Hyades. Also evident from figure 3 are stars falling in the region of the diagram normally occupied by the classical Am stars. The low m_1 index for most of the NGC 2477 stars measured may be interpreted in two ways: (i) either the metal line blanketing is less in NGC 2477 than in the Hyades (cf. fig. 3 of Chaffee, Carbon, and Strom 1971) contrary to the cyanogen measures[2] and ultraviolet deficiencies for the giants reported by H^2M that suggests that $[Fe/H]_{NGC\,2477} > [Fe/H]_{Hyades}$; or (ii) the bulk of the NGC 2477 stars are fast rotators (Slettebak, Wright, and Graham 1968; Danziger and Faber 1972). While no satisfactory explanation has been found for why the m_1 index is affected by rotation, it has been suggested (Strömgren 1963) that the gravity dependence of m_1 could be due to the inclusion of $H\delta$ in the v-filter.

e) The $[\beta, (b - y)_0]$-Plane

The $H\beta$ index is also sensitive to surface gravity in the range of $(b - y)_0$ exhibited by the stars in table 1 (cf. Strom, Strom, and Bregman 1971). Figure 4 shows the position of the NGC 2477 stars with respect both to the ZAMS (Crawford 1970) and to the Hyades mean relation (Crawford and Perry 1966) in the $[\beta, (b - y)_0]$-plane. Naively we conclude from this diagram that the NGC 2477 main-sequence stars near the turnoff have lower surface gravities than similar

[1] Star n, whose position in fig. 1, as well as in the $[m_1{}^0, (b - y)_0]$ and other diagrams, is anomalous yields the most discrepant values of E_{B-V} determined by the two methods; its m_1 value seems consistent with it being a binary star.

[2] We note for completeness that, as part of an extensive new program, reobservation in the 1973 season of a small subset of the NGC 2477 giants observed by H^2M confirms the CN measures of H^2M; the filters and photometric equipment used were entirely independent of the ones used by H^2M.

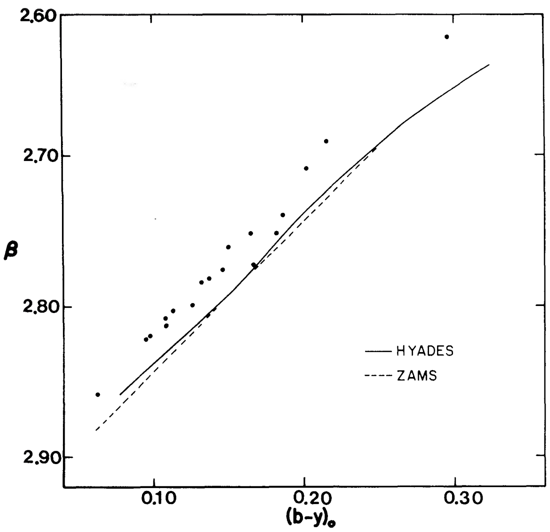

FIG. 4.—The β versus $(b-y)_0$ diagram for the NGC 2477 stars of table 1. The Hyades relation is that of Crawford and Perry (1966), while the ZAMS is from Crawford (1970).

Hyades stars, a conclusion that is in direct contradiction to that derived from the $[c_1{}^0, (b-y)_0]$-diagram. However, if the m_1 index is affected by rotation through the variation in the strength of Hδ, then it is conceivable that rotation may also affect the Hβ index; we shall return to this point later.

f) *Mass Determination*

The four-color and Hβ data can be combined with the calibrations of Strom *et al.* (1971) to obtain masses for the stars in table 1. Rather than attempt to interpolate values of surface gravity for the NGC 2477 stars directly from their figure 2, we have made the approximation

$$\partial \log g/\partial\beta \simeq 30\,,$$

so that the following expression for the mass follows:

$$\log\frac{\mathfrak{M}_*}{\mathfrak{M}_{\rm ms}} \simeq +30\Delta\beta - 0.4\Delta V\,,$$

where the differences are in the sense (star − main sequence). Using the above relation and the $[(b-y), \mathfrak{M}_{\rm ms}]$-relation of Bond and Perry (1971), we derived masses for the stars in table 1. From these results, which are given in table 1, we note that except for stars w, m, 3004, 5027, and 7097 all stars have the same mass, to within a rather large uncertainty. The average is 1 $\mathfrak{M}_\odot$. The average for the last three stars singled out above is 1.9 $\mathfrak{M}_\odot$. The position of these latter stars in the unreddened two-color diagram, figure 1, suggests that they are blue stragglers. The higher masses and normal gravities found for them strengthens the suggestion that blue stragglers are binary, rather than single, highly evolved stars, in agreement with the results of Bond and Perry (1971) and Strom *et al.* (1971) for the M67 blue stragglers. That the masses for the turnoff stars found above are lower than expected from theoretical models (see below and H²M) must be due in part to the anomalously low Hβ values for the NGC 2477 stars.

g) *Summary*

The results of this section are summarized below in table 2. A synthesis of these results with those of H²M will be made in § IV, following the discussion of the new *B*, *V* data and the revised C-M diagram in § III.

III. ADDITIONAL *B*, *V* PHOTOMETRY

In H²M it was stated that although photographic observations had been made for ~2,000 stars, those outside the circle indicated in their figure 1 were not included in their paper when it became apparent that differential reddening was causing large scatter in the C-M diagram. In view of the usefulness for future work on this rich cluster in having magnitudes and colors for as many stars as possible, we have included the additional observations in table 3. The stars are identified in figure 5 (plate 4). The number of plate pairs measured and the estimated errors of the observations are similar to those for table 3 of H²M.

The stars in table 3 have been combined with those in table 3 of H²M to form the color-magnitude diagram shown in figure 6. The former group of stars

TABLE 2

SUMMARY OF *uvby*-Hβ RESULTS FOR NGC 2477

Source	Interpretations
Reddening determination.....	*uvby*-Hβ reddening determinations are in excellent agreement with *UBV* values and confirm the differential reddening found earlier from *UBV* and DDO photometry. Similarly, the *y*- and *V*-magnitudes of the two investigations are in close accord.
$[c_1, (b-y)]$-diagram.........	NGC 2477 stars have surface gravities similar, on the average, to those of the Hyades A and F stars.
$[m_1, (b-y)]$-diagram........	Most of the main-sequence A and F stars in NGC 2477 have a lower line-blanketing index than the Hyades, in contradiction to the CN measures of the giants. About 17 percent of the observed sample appear to be Am stars.
$[\beta, (b-y)]$-diagram.........	All stars lie lower than the Hyades sequence, suggesting that they have lower gravities.
Mass determination..........	Stars immediately above and below the turnoff adopted by H²M have similar masses. Three stars are probably blue stragglers.

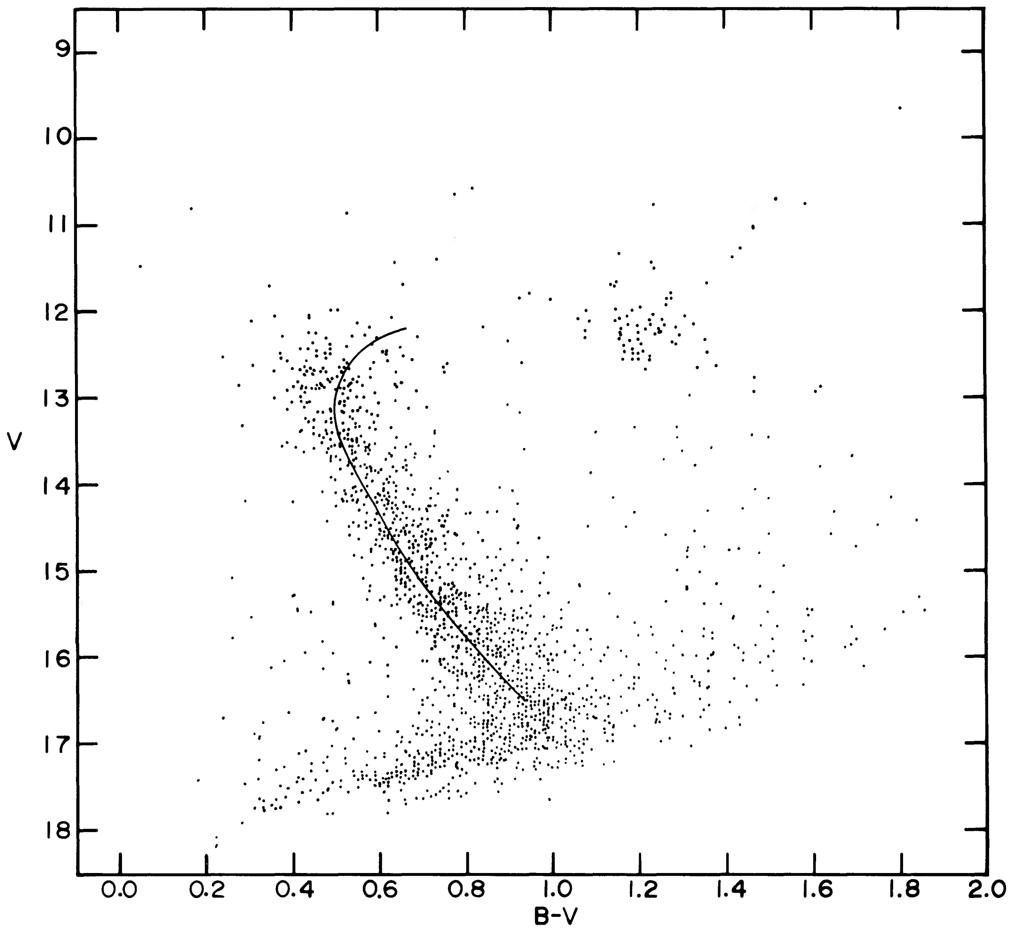

FIG. 6.—The color-magnitude diagram for ~1,900 stars in NGC 2477; the solid line is the estimated location of the turnoff. The diagram was constructed as described in § III of the text.

has been shifted by $\Delta V = 0.3$ mag and $\Delta(B - V) = 0.1$ mag to allow, approximately, for an apparently higher reddening in the outer regions of the cluster. The results of the previous sections of the present paper have influenced the position adopted in figure 6 for the turnoff, a position that is somewhat brighter than the one earlier adopted by H^2M.

IV. DISCUSSION

a) Are the Main-Sequence Stars in NGC 2477 Rapid Rotators?

i) *Analysis of Field Stars*

As summarized in table 2, we find that the NGC 2477 stars show: (1) an m_1 excess with respect to the Hyades; (2) a β excess with respect to the Hyades and ZAMS; and (3) no c_1 excess with respect to the Hyades on the average. As pointed out earlier, result (1) is in contradiction to the results of DDO photometry of the giant stars (H^2M). However, both Slettebak *et al.* (1968) and Danziger and Faber (1972) have shown from analyses of field-star data that an m_1 excess is correlated with $v \sin i$. Following Strömgren's (1963) tentative explanation of the m_1, $v \sin i$ effect, we were led to investigate the effects of rotation on the β and c_1 indices using recently published observational material.

The stars used in the following discussion were selected according to the criteria that: (1) $0.1 < (b - y)_0 \leq 0.253$ mag, and (2) luminosity class = V or IV–V. The first criterion was chosen after a preliminary survey indicated that the relation between β and $v \sin i$ was different for stars with $(b - y)_0 < 0.1$ mag (we note that most of the NGC 2477 stars relevant to the present discussion have $(b - y)_0 > 0.1$ mag, however). Criterion (2) was chosen to keep evolutionary effects to a minimum. The stars were selected from papers by Abt and Moyd (1973) and Danziger and Faber (1972). In order to increase the sample of stars with $v \sin i \geq 200$ km s^{-1}, all stars in Danziger and Faber (1972) for which no luminosity class was available but with $v \sin i \geq 200$ km s^{-1} and $(b - y)_0 \geq 0.15$ mag were included in our discussion; in Appendix B we identify the stars that are utilized in the following discussions. Four-color and Hβ photometry for these stars was obtained from the literature. Unreddened indices were derived according

TABLE 3

PHOTOGRAPHIC DATA

Star	V	B-V	Star	V	B-V	Star	V	B-V	Star	V	B-V	Star	V	B-V
1201	16.57	0.98	1310	17.99	0.41	2119	16.10	0.87	2315	16.94	1.14	3173	15.79	0.97
1202	16.26	0.81	1311	16.75	1.08	2120	13.75	0.49	2316	16.29	1.58	3174	16.88	0.69
1203	17.52	0.72	1312	15.70	1.91	2121	13.24	0.46	2317	13.05	0.62	3175	17.58	0.73
1204	14.39	0.72	1313	17.52	0.46	2122	14.50	1.54	2318	17.91	0.51	3176	12.57	1.30
1206	16.18	0.93	1316	15.56	0.67	2133	17.39	0.82	2319	14.52	0.81	3177	15.59	0.77
1207	16.08	0.83	1317	15.89	0.81	2201	15.94	0.89	2320	17.00	1.04	3178	12.80	0.48
1208	17.15	1.00	1319	16.71	0.98	2202	15.45	0.74	2321	16.33	1.01	3179	17.11	0.80
1209	17.24	1.12	1321	17.59	0.64	2204	12.03	1.05	2322	15.31	0.81	3180	16.70	0.93
1210	16.97	0.96	1322	17.12	1.10	2206	17.65	0.69	2323	16.35	0.85	3181	11.94	1.25
1213	15.46	2.96	1323	15.21	0.75	2207	13.80	0.51	2324	14.64	0.58	3182	14.29	0.57
1214	16.66	0.72	1324	16.10	0.74	2208	17.26	1.01	2325	15.53	0.85	3201	17.21	0.94
1216	17.00	0.94	1325	16.33	0.99	2209	17.72	0.61	2326	16.70	1.02	3202	13.75	0.65
1217	17.43	0.91	1326	17.47	0.75	2210	16.29	0.48	2327	16.02	1.47	3203	14.31	0.62
1218	16.66	0.97	1327	12.77	0.34	2211	13.12	0.53	2328	16.59	0.85	3204	16.42	1.03
1219	16.49	1.52	1328	17.25	1.00	2212	16.28	0.92	2329	14.98	1.41	3205	14.16	0.59
1220	12.66	3.85	1329	15.87	0.87	2214	15.56	0.70	2330	16.53	1.07	3206	12.35	1.25
1221	16.74	1.07	1331	15.54	0.88	2215	14.31	0.57	2331	17.66	0.72	3207	12.72	0.71
1222	16.74	1.07	1332	16.43	0.93	2216	17.40	0.80	2332	13.10	0.38	3208	17.10	0.85
1223	16.92	1.06	1333	13.29	0.50	2217	16.94	0.99	2333	16.32	0.99	3209	11.93	0.76
1224	17.53	0.82	1334	15.86	0.89	2218	17.21	0.75	2334	14.72	1.02	3210	15.59	0.90
1225	17.67	0.75	1335	14.46	0.74	2219	16.12	0.90	2335	13.94	0.59	3211	15.89	0.80
1226	13.10	1.72	1337	17.17	1.09	2220	16.86	1.09	2336	17.55	0.79	3212	17.36	0.87
1227	17.80	0.52	1338	17.16	1.09	2221	17.44	0.83	2337	17.64	0.77	3213	15.06	1.41
1228	13.06	0.64	1339	16.51	0.84	2222	15.76	0.81	2339	17.73	0.65	3214	17.20	0.77
1229	13.26	0.62	1340	16.16	0.97	2223	17.05	1.15	2340	13.90	1.79	3215	13.62	0.63
1230	15.43	1.41	1341	15.53	0.90	2224	14.95	1.45	2341	16.31	0.89	3216	14.01	0.65
1231	16.96	1.34	1343	17.50	0.79	2225	13.57	0.55	2342	13.05	0.59	3217	16.70	0.99
1232	17.07	1.08	1344	17.30	1.00	2226	15.61	0.74	2343	14.74	0.63	3218	15.80	0.99
1233	16.82	1.45	1345	16.60	0.78	2227	14.43	0.50	2344	12.87	0.41	3219	16.16	0.96
1234	12.71	0.72	1346	13.93	0.65	2228	14.32	0.60	2345	17.56	0.76	3220	13.75	0.67
1237	15.76	1.02	1347	16.39	1.46	2229	13.16	1.71	2346	16.42	0.91	3221	17.20	0.86
1238	14.67	0.85	1348	17.21	0.90	2230	17.41	0.42	2348	16.28	0.80	3222	17.95	0.47
1239	15.17	0.84	1349	16.71	1.12	2231	16.79	0.95	2349	17.34	0.88	3223	17.58	0.73
1240	13.66	0.66	1350	15.73	0.95	2232	17.12	0.84	2350	15.68	0.51	3224	17.74	0.49
1241	16.55	1.02	1351	15.70	1.60	2233	17.36	0.94	2352	17.00	0.95	3226	14.91	0.81
1242	13.82	0.68	1352	17.37	0.58	2234	12.90	0.57	2353	17.34	0.84	3227	16.20	0.91
1243	17.04	0.88	1354	16.59	1.10	2235	16.20	1.40	2354	17.33	0.82	3228	16.88	1.34
1244	14.36	1.88	1356	17.48	0.93	2236	16.04	0.93	2355	16.68	0.97	3229	16.46	0.72
1245	16.91	1.18	1357	15.70	0.93	2237	15.73	0.86	2356	17.37	0.71	3230	15.15	0.81
1246	16.98	0.94	1358	17.33	0.79	2238	15.91	0.81	2357	16.50	0.93	3231	14.58	0.90
1247	14.65	0.73	1360	15.91	0.93	2239	17.62	0.66	2359	12.80	1.29	3232	17.02	1.00
1248	12.81	0.49	1361	15.74	0.79	2241	15.61	0.80	2360	15.78	1.52	3233	16.57	1.08
1249	14.66	0.67	1362	17.25	0.87	2242	15.41	0.76	2361	17.02	1.24	3234	13.79	0.83
1250	16.85	1.09	1363	17.08	1.22	2243	13.59	0.73	2362	17.16	1.06	3235	16.08	1.52
1252	11.28	1.57	1364	17.57	0.69	2244	15.53	0.71	2363	16.44	1.08	3236	16.52	0.99
1253	17.78	0.51	1365	14.98	0.77	2245	15.84	1.29	2364	13.37	0.57	3237	16.68	1.22
1254	15.02	0.73	1366	13.71	0.63	2246	16.73	1.32	2365	14.43	0.39	3238	15.54	0.85
1255	16.47	0.98	1367	17.03	0.98	2247	17.39	0.70	2366	16.90	1.40	3239	16.11	1.07
1256	17.71	0.70	1368	15.62	0.90	2248	16.75	0.92	2367	16.96	1.17	3240	16.55	1.07
1257	17.18	1.17	1369	17.06	1.22	2249	16.73	0.80	2368	13.97	0.59	3241	15.08	0.89
1258	14.30	0.66	1370	16.21	0.98	2250	17.33	0.91	2369	17.66	0.61	3242	17.45	0.62
1260	15.51	1.07	1371	16.71	1.57	2251	17.27	0.97	2370	16.82	1.04	3243	17.08	0.85
1264	17.39	0.96	1372	15.67	1.70	2252	17.21	0.92	2371	14.41	0.65	3244	16.94	1.08
1265	16.58	1.01	1373	16.40	0.87	2253	13.14	0.56	2372	15.98	1.45	3245	16.97	0.91
1268	17.27	0.92	1374	16.49	1.02	2254	17.64	0.56	2373	17.65	0.28	3246	16.56	1.44
1270	17.05	1.05	1375	15.55	0.84	2255	15.61	1.49	2374	17.11	0.94	3247	16.29	0.94
1271	17.02	1.09	1376	16.37	1.61	2256	16.76	1.07	2375	15.37	1.48	3248	17.20	0.89
1272	12.24	1.18	1377	15.41	1.58	2257	17.03	0.97	2376	16.14	0.88	3249	11.05	0.27
1273	15.31	0.93	1378	13.30	0.70	2258	16.03	0.85	2377	16.97	0.91	3250	12.67	0.59
1274	13.25	0.63	1379	16.37	1.05	2259	17.25	0.59	2378	14.55	0.73	3251	16.61	0.90
1275	15.71	0.86	1380	15.59	0.90	2260	15.60	0.59	2379	17.26	0.89	3252	16.67	1.10
1276	17.88	0.42	1381	14.92	0.78	2261	13.64	0.52	2380	15.69	1.96	3253	14.43	0.63
1277	17.23	0.94	1382	15.78	0.83	2262	15.97	0.88	2381	16.69	1.02	3254	15.93	1.16
1278	16.05	0.83	1383	16.83	1.16	2263	16.68	1.04	2382	16.46	1.29	3255	16.22	1.27
1279	14.98	0.68	1384	17.40	0.86	2301	15.74	0.78	2383	15.72	0.54	3256	17.29	0.84
1280	15.00	0.68	1385	12.89	1.44	2302	17.10	1.06	2384	13.80	1.47	3257	16.19	0.95
1281	15.59	1.36	1386	16.68	1.26	2303	16.70	0.93	3152	17.12	0.41	3260	16.71	1.09
1282	16.10	0.95	1387	14.87	0.94	2304	17.99	0.43	3158	13.17	1.57	3261	17.29	0.98
1283	17.70	0.39	1388	12.48	1.35	2305	17.34	0.98	3159	13.14	0.52	3262	17.59	0.69
1284	17.16	1.13	1389	14.28	1.57	2306	17.87	0.46	3161	17.48	0.88	3263	17.16	1.10
1301	17.75	0.58	1390	16.79	1.10	2307	16.18	1.47	3162	17.27	0.92	3264	14.78	0.77
1303	15.51	0.87	1391	16.27	1.02	2308	16.12	0.95	3163	14.68	0.70	3265	15.35	0.82
1304	17.23	1.03	2101	16.08	0.94	2309	13.84	0.67	3164	17.62	0.72	3301	16.87	0.94
1305	13.63	0.83	2102	12.52	0.64	2310	15.69	0.94	3166	17.30	0.99	3303	16.58	0.93
1306	14.26	0.82	2105	15.52	0.74	2311	14.95	1.80	3167	17.32	0.97	3304	16.66	1.33
1307	16.15	0.88	2116	17.39	0.77	2312	17.61	0.76	3170	12.27	1.34	3305	16.57	1.46
1308	17.40	0.62	2117	9.90	1.91	2313	14.79	0.75	3171	16.31	1.09	3306	17.28	0.87
1309	13.81	0.68	2118	14.16	0.84	2314	15.87	1.79	3172	15.19	0.91	3307	13.66	0.55

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TABLE 3—*Continued*

Star	V	B-V	Star	V	B-V	Star	V	B-V	Star	V	B-V	Star	V	B-V
3309	16.63	1.20	4133	17.39	0.69	4271	16.07	1.79	4380	15.49	1.61	5276	15.71	0.79
3310	16.55	0.91	4134	16.31	1.30	4272	16.20	1.02	4381	17.35	0.84	5277	15.73	1.01
3311	12.69	1.29	4135	16.31	1.04	4273	17.30	0.86	4382	15.91	1.18	5278	16.75	0.97
3312	16.96	1.34	4136	14.38	1.60	4274	16.79	1.14	4383	14.31	0.88	5279	17.37	0.81
3313	13.70	1.60	4137	11.69	1.33	4275	16.99	0.95	4384	15.08	0.95	5280	17.01	1.03
3314	17.83	0.48	4138	17.19	0.87	4276	17.54	0.74	4385	17.22	0.84	5281	16.79	1.05
3315	16.54	1.29	4139	13.31	0.54	4277	16.53	1.44	4386	15.88	1.12	5282	14.50	0.72
3316	15.93	0.79	4140	15.56	0.84	4278	14.63	0.75	4387	16.18	0.59	5301	12.91	0.63
3317	14.27	0.71	4142	15.95	1.47	4280	15.88	1.62	4388	15.30	0.93	5302	16.27	1.09
3318	14.55	1.29	4143	15.87	1.11	4281	17.07	1.00	4389	14.48	0.82	5303	12.88	1.48
3319	17.56	0.64	4144	16.49	0.92	4282	15.36	1.07	5174	14.88	0.81	5304	16.89	1.37
3322	16.00	0.98	4146	11.94	1.25	4284	14.94	0.78	5175	12.28	0.54	5305	16.60	1.16
3323	16.75	1.11	4201	15.71	0.97	4285	15.06	0.81	5193	17.02	0.94	5306	17.57	0.74
3324	16.66	1.04	4202	15.95	0.91	4301	12.91	1.32	5194	13.88	0.64	5307	17.45	0.82
3325	16.78	0.99	4203	15.68	1.12	4302	17.64	0.71	5195	14.02	0.76	5309	17.13	0.96
3326	16.10	1.78	4204	16.16	0.97	4304	16.91	1.06	5201	16.84	1.10	5310	14.72	0.79
3327	16.03	1.69	4206	17.65	0.72	4305	15.02	0.78	5202	16.63	1.38	5311	16.89	0.79
3328	17.20	1.16	4207	15.61	0.86	4306	16.77	1.19	5203	17.46	0.78	5312	16.26	1.15
3329	16.05	1.00	4208	15.23	0.96	4307	15.86	1.33	5206	17.12	1.05	5313	13.61	0.63
3330	15.75	1.01	4209	17.66	0.51	4308	16.96	1.06	5207	12.72	1.46	5314	17.64	0.42
3331	16.99	1.34	4210	14.46	1.02	4309	15.54	0.98	5208	17.20	0.91	5316	17.38	0.80
3332	17.40	0.99	4211	16.87	0.95	4310	17.14	1.04	5209	16.15	1.61	5317	12.61	1.38
3335	17.28	0.62	4212	13.94	1.36	4311	14.03	1.72	5210	15.89	1.11	5318	16.05	0.57
3337	15.51	0.89	4213	13.81	0.55	4312	17.51	0.88	5211	14.09	0.86	5319	16.90	1.03
3338	15.49	0.88	4214	12.72	0.58	4313	12.75	0.76	5212	15.66	0.84	5320	17.58	0.66
3339	16.22	1.60	4215	14.09	0.74	4314	14.96	0.77	5213	16.79	1.06	5321	16.45	0.94
3341	17.49	0.88	4216	16.83	0.89	4315	15.21	1.03	5214	17.02	1.29	5322	14.49	0.83
3342	14.91	0.74	4217	17.86	0.56	4316	16.70	0.97	5215	14.29	0.98	5323	15.77	1.03
3343	17.29	1.09	4218	16.12	1.53	4317	16.26	0.93	5216	17.43	0.92	5324	14.51	0.78
3344	17.54	0.79	4219	16.32	0.72	4318	13.59	1.39	5217	15.15	0.88	5325	14.97	0.81
3345	13.23	1.42	4220	14.81	0.70	4323	15.62	0.84	5219	17.40	0.97	5326	16.81	1.14
3346	17.94	0.45	4221	12.22	1.25	4324	16.94	0.57	5220	17.41	0.80	5327	14.18	0.72
3347	17.79	0.63	4222	16.35	0.57	4325	17.48	0.81	5221	14.41	0.62	5328	15.60	0.85
3348	16.79	1.20	4223	16.55	1.18	4326	16.97	1.03	5222	17.59	0.54	5329	15.82	0.95
3349	17.15	0.98	4224	16.29	0.84	4327	12.62	1.39	5223	17.62	0.77	5330	17.26	1.03
3350	15.64	1.05	4225	17.10	1.00	4328	14.44	0.76	5225	15.42	0.78	5331	16.32	1.82
3351	16.77	1.03	4226	14.25	0.74	4329	13.92	0.82	5227	17.48	0.79	5332	15.96	1.09
3352	16.11	1.05	4227	17.27	0.87	4330	17.03	1.09	5228	15.23	0.81	5333	16.22	0.92
3353	16.56	1.29	4228	14.83	0.71	4331	16.78	1.46	5229	17.34	0.85	5334	12.84	0.69
3354	17.68	0.72	4229	16.94	0.90	4332	16.08	1.08	5231	15.15	0.86	5335	14.78	0.86
3355	16.92	1.15	4230	17.66	0.76	4334	16.21	1.22	5232	17.11	0.79	5336	14.74	0.76
3356	17.69	0.70	4231	14.99	1.51	4335	16.01	1.03	5233	16.03	1.61	5337	16.69	0.94
3357	15.82	2.11	4232	14.68	1.85	4336	16.80	1.10	5234	16.50	0.88	5338	12.48	1.35
3358	17.07	1.13	4233	15.21	0.76	4337	14.83	0.72	5235	15.15	0.71	5339	15.60	0.84
3359	16.03	1.80	4234	12.92	0.57	4338	16.70	0.98	5236	13.32	1.00	5340	14.41	0.88
3360	17.62	0.75	4235	12.31	0.73	4339	12.92	0.55	5238	12.60	1.00	5341	15.67	1.69
3361	17.63	0.72	4236	17.17	1.05	4341	15.89	0.92	5239	13.75	0.57	5342	15.21	0.87
3362	15.59	1.14	4237	16.69	0.86	4342	15.15	0.77	5240	17.30	0.97	5343	16.94	0.65
3363	16.98	1.15	4238	14.90	0.74	4344	17.63	0.73	5241	15.45	0.97	5344	17.57	0.79
3364	16.89	1.07	4239	15.35	0.82	4345	14.58	0.91	5242	15.23	1.39	5345	12.54	1.26
3365	17.03	0.86	4240	16.96	1.06	4346	16.61	1.12	5243	15.26	0.75	5346	17.21	0.75
3366	17.05	1.15	4241	17.59	0.67	4347	15.34	0.96	5244	14.38	0.69	5347	16.54	0.63
3367	13.53	0.69	4242	16.87	0.94	4348	13.82	0.74	5245	14.58	0.74	5348	17.31	0.53
3368	15.66	0.95	4243	16.79	0.99	4349	16.54	1.68	5246	16.87	1.26	5349	15.78	0.95
3369	15.01	1.58	4244	15.68	0.84	4350	14.70	0.85	5249	15.76	0.83	5350	17.46	0.88
3370	16.09	1.57	4245	17.41	0.94	4351	16.71	1.44	5250	15.05	0.64	5351	17.23	0.99
3371	15.37	0.87	4246	16.98	1.10	4352	14.39	0.74	5251	16.77	1.06	5352	17.26	1.11
3372	16.21	0.97	4247	16.77	1.14	4353	16.74	1.08	5252	13.63	0.61	5353	17.35	0.89
3373	16.09	0.92	4248	12.64	1.27	4354	16.42	1.02	5253	14.72	1.27	5354	17.17	0.99
3374	14.74	0.76	4249	16.35	1.02	4355	17.53	0.74	5255	15.56	0.85	5355	17.41	0.85
3375	14.85	0.72	4250	17.57	0.73	4357	15.68	0.93	5256	14.64	0.69	5356	17.55	0.78
3376	16.89	1.03	4251	17.66	0.59	4359	17.32	0.91	5257	16.90	0.96	5357	17.34	0.81
3377	13.27	0.74	4252	17.79	0.57	4360	16.08	1.38	5258	17.47	0.74	5358	15.60	0.80
3378	17.16	0.95	4253	17.15	1.10	4361	16.38	1.10	5259	16.47	1.04	5359	16.80	1.09
3379	15.85	0.97	4254	17.23	1.13	4363	17.41	0.93	5260	13.83	1.40	5360	15.10	0.76
3380	13.17	0.79	4256	16.50	1.01	4364	14.70	0.78	5261	16.84	0.84	5361	17.30	0.93
3381	15.79	1.03	4258	17.23	0.90	4365	13.02	1.57	5262	14.85	0.71	5362	13.80	0.65
3382	17.44	0.91	4260	12.42	0.68	4366	17.69	0.72	5263	15.55	0.85	5363	16.49	0.82
3383	16.89	1.16	4261	17.66	0.71	4367	17.51	0.79	5264	16.78	1.08	5364	15.11	2.97
3384	17.99	0.43	4262	17.96	0.46	4368	13.11	0.63	5265	16.25	0.85	5365	16.11	0.98
3385	16.63	1.38	4263	15.01	0.75	4369	17.53	0.58	5266	16.39	1.10	5366	17.43	0.85
3386	17.47	0.95	4264	15.66	1.03	4370	15.48	1.03	5267	17.25	0.74	5367	15.07	0.97
3387	14.44	2.07	4265	17.75	0.54	4371	14.82	0.80	5270	14.41	0.64	6220	15.25	0.81
3388	17.38	0.71	4266	15.82	0.80	4372	13.72	0.65	5271	14.11	0.65	6222	15.74	0.99
3389	16.01	0.71	4268	17.02	0.78	4374	15.89	1.87	5272	16.77	1.13	6223	16.54	0.97
4130	15.66	0.78	4269	13.90	0.73	4375	17.22	1.17	5273	15.40	0.87	6224	17.49	0.67
4132	13.62	0.60	4270	17.30	0.98	4378	12.91	0.68	5274	17.37	0.79	6225	12.93	0.46

TABLE 3—*Continued*

Star	V	B-V	Star	V	B-V	Star	V	B-V	Star	V	B-V	Star	V	B-V
6229	17.18	0.75	6326	17.15	0.42	7245	16.40	0.94	7367	11.56	1.26	8305	17.20	1.00
6230	16.27	1.36	6327	17.51	0.89	7246	13.41	0.57	7368	16.79	1.02	8307	14.80	1.74
6231	17.56	0.66	6328	16.84	1.07	7247	14.35	0.62	7369	16.74	1.06	8308	14.30	0.74
6238	17.02	0.98	6329	16.23	0.87	7248	14.85	0.82	7370	16.60	1.38	8309	14.63	1.94
6239	17.08	0.97	6330	15.38	0.85	7249	14.87	0.73	7371	14.75	0.70	8311	17.17	0.87
6241	15.16	0.92	6331	14.74	0.67	7251	16.89	1.01	7372	14.04	0.68	8312	16.89	1.02
6243	17.66	0.75	6332	17.15	1.03	7252	14.83	0.63	7373	15.99	0.93	8313	16.97	0.82
6245	13.73	0.62	6333	13.68	1.39	7253	14.78	0.71	7374	14.23	0.71	8314	15.06	0.80
6246	17.62	0.51	6334	16.94	1.20	7254	15.53	1.95	7375	16.90	1.01	8315	13.24	0.65
6247	17.26	1.08	6335	14.47	0.70	7255	16.00	0.36	7377	16.82	0.96	8316	15.43	0.84
6248	17.64	0.52	6336	16.77	0.80	7267	16.06	0.94	7378	16.85	1.04	8317	14.79	0.76
6249	17.25	1.15	6337	14.53	1.46	7268	15.34	0.77	7379	14.85	0.65	8318	15.50	0.90
6250	17.02	1.02	6339	16.31	1.05	7269	15.98	1.70	7380	17.19	0.89	8319	16.35	0.93
6251	12.41	1.26	6340	12.17	1.54	7270	15.90	1.45	7381	15.16	0.99	8320	15.86	0.69
6252	12.94	0.58	6341	17.40	0.78	7271	13.79	0.59	7382	17.33	0.67	8321	15.78	0.92
6253	16.06	0.92	6342	13.94	0.72	7273	12.35	1.19	7383	16.94	1.08	8322	16.74	1.07
6254	10.83	0.92	6343	15.63	0.95	7274	16.70	0.98	7384	16.55	1.62	8324	14.08	0.70
6255	14.50	0.73	6344	16.87	0.90	7275	14.99	0.73	7385	11.70	0.15	8325	15.31	0.97
6256	13.19	0.53	6345	15.23	0.74	7301	17.39	0.74	7386	16.75	1.02	8327	14.90	0.82
6257	15.52	0.50	6347	14.33	0.72	7302	11.68	0.74	7387	14.77	0.70	8328	16.18	1.34
6258	17.34	0.94	6348	14.28	0.71	7303	16.43	1.26	7388	13.78	0.61	8329	14.09	0.68
6259	17.09	0.97	6349	13.36	0.66	7304	14.27	0.64	7390	15.83	0.85	8330	16.65	1.03
6260	16.47	0.93	6350	17.00	1.03	7305	16.76	1.23	7391	15.73	0.98	8331	16.99	0.92
6261	17.29	1.02	6351	15.67	0.88	7306	17.42	0.80	7392	15.88	0.96	8332	14.68	0.78
6262	14.34	0.70	6352	14.76	0.71	7307	15.02	0.83	7393	15.67	0.98	8333	14.17	0.60
6263	17.16	1.14	6353	17.38	0.86	7308	16.73	0.95	7394	13.15	0.49	8334	16.57	1.28
6264	13.84	0.64	6354	15.99	0.90	7309	15.98	1.30	7395	16.92	1.04	8335	15.95	0.89
6265	17.47	0.85	6355	16.72	1.34	7310	12.33	1.33	7396	15.82	0.91	8336	14.77	2.10
6266	17.27	0.97	6356	15.78	0.75	7312	16.87	0.49	8201	16.40	0.87	8337	16.94	0.97
6267	16.38	0.86	6357	15.37	0.75	7313	16.52	1.04	8202	16.94	0.34	8338	15.35	0.75
6268	15.92	1.01	6358	14.15	0.67	7314	14.65	0.73	8203	15.21	0.78	8339	16.57	0.88
6269	17.09	1.17	6359	16.39	0.89	7315	14.54	0.70	8204	14.48	0.60	8340	16.84	0.98
6270	16.10	2.24	6360	13.54	0.65	7316	16.31	1.17	8205	14.64	1.01	8341	16.09	0.94
6271	17.71	0.47	6361	15.64	0.90	7317	15.93	0.93	8206	17.29	0.83	8342	16.36	1.04
6272	15.74	0.85	6363	15.77	1.01	7318	16.77	0.87	8207	17.28	0.94	8343	16.46	0.90
6274	17.26	1.06	6364	15.22	0.81	7319	15.74	0.83	8208	14.78	0.80	8344	15.92	1.01
6275	12.48	0.54	6365	17.27	1.01	7320	12.74	0.59	8209	14.65	0.84	8346	17.08	1.06
6276	17.00	0.96	6367	17.28	0.93	7322	15.62	0.79	8210	16.58	1.07	8347	15.72	0.88
6277	17.17	0.64	6368	16.12	0.82	7323	14.73	2.72	8216	12.10	1.37	8348	15.10	0.77
6278	13.49	0.53	6369	17.48	0.78	7325	15.51	0.79	8217	14.67	0.73	8349	16.19	0.98
6279	17.19	0.96	6370	16.91	1.05	7326	16.97	0.59	8218	16.24	0.88	8351	14.83	0.85
6281	15.19	0.78	6371	13.57	0.58	7327	13.79	0.61	8219	16.75	1.00	8352	14.80	1.60
6282	15.31	0.84	6372	15.71	1.04	7329	15.98	0.93	8222	17.07	0.70	8353	14.46	0.72
6283	16.34	1.07	6373	15.08	0.80	7330	16.81	0.04	8224	12.93	0.55	8356	12.77	0.58
6284	15.58	0.82	6374	13.79	0.48	7331	17.34	0.94	8225	17.02	1.12	8357	15.88	1.10
6285	14.44	0.65	6375	15.57	0.87	7332	15.93	0.97	8226	13.81	0.67	8358	13.80	0.61
6286	15.90	0.80	6376	16.62	0.91	7333	15.50	0.91	8227	16.17	0.90	8359	14.20	0.72
6287	17.44	0.57	6377	17.02	0.95	7334	12.78	1.33	8228	16.85	1.04	8360	13.95	0.61
6289	14.33	0.60	6378	16.68	0.95	7335	16.45	1.42	8229	17.08	0.81	8361	14.43	0.73
6290	16.71	1.04	6379	14.34	0.78	7336	13.16	0.69	8237	15.64	0.81	8362	17.14	0.82
6291	15.96	0.95	6380	15.24	1.44	7339	15.91	1.10	8238	16.03	0.89	8363	17.31	0.76
6292	16.23	0.87	6381	13.26	0.61	7340	14.81	0.88	8239	15.99	0.87	8364	14.87	0.83
6293	13.51	0.66	6382	16.71	1.17	7341	15.72	0.91	8240	16.94	1.07	8365	17.27	1.04
6294	15.64	0.80	6383	16.89	1.13	7342	17.08	0.74	8241	16.59	1.06	8366	15.12	0.82
6296	17.71	0.69	6384	17.64	0.65	7343	15.49	1.09	8242	17.28	0.98	8367	17.57	0.69
6297	16.85	1.36	6385	16.48	1.08	7344	13.09	0.74	8243	15.73	0.88	8368	15.08	0.72
6302	15.51	0.78	6386	16.07	1.15	7345	16.13	0.99	8246	16.20	0.96	8369	16.37	1.36
6303	13.20	0.52	6388	17.30	0.96	7346	16.73	1.12	8247	16.43	0.98	8370	16.94	1.22
6305	17.20	0.92	6389	14.77	0.82	7347	12.41	0.68	8248	16.34	0.94	8371	15.98	0.83
6307	16.21	1.43	7201	17.28	1.07	7348	14.98	0.74	8249	16.56	1.03	8372	13.75	0.65
6308	17.25	1.13	7202	16.87	1.02	7349	12.42	1.39	8250	17.05	0.60	8373	14.82	0.76
6309	15.08	0.87	7203	12.51	1.34	7350	16.21	0.99	8251	16.59	0.91	8374	16.94	0.87
6310	16.76	1.10	7204	14.51	0.86	7351	13.41	0.62	8252	15.25	0.83	8375	16.96	0.81
6311	15.23	0.79	7205	13.08	0.57	7352	15.91	1.02	8253	13.09	0.56	8376	17.22	0.77
6312	16.13	0.91	7206	12.71	1.31	7353	16.70	1.03	8254	17.55	0.75	8377	17.25	0.83
6313	16.03	0.90	7207	13.58	0.65	7354	12.74	1.30	8255	16.59	1.00	8378	15.49	0.93
6314	14.62	0.80	7208	15.52	0.78	7355	13.80	0.64	8256	11.94	1.24	8380	16.00	0.95
6315	14.27	0.64	7220	15.07	1.09	7356	16.26	0.95	8257	16.99	0.43	8381	17.04	0.95
6316	16.69	0.94	7221	14.52	0.72	7357	16.40	0.89	8268	16.28	0.94	8382	12.85	0.86
6317	16.66	1.04	7222	16.04	0.96	7358	16.75	1.51	8269	17.42	0.82	8383	13.33	0.62
6318	14.78	0.76	7224	15.32	0.80	7359	14.70	0.68	8270	17.21	0.99	8384	15.77	1.25
6319	14.60	0.71	7225	16.37	1.09	7360	15.88	0.81	8272	17.56	0.66	8385	14.54	1.75
6320	16.67	0.97	7239	17.04	0.82	7361	16.46	1.19	8274	17.47	0.83	8386	14.45	0.72
6321	13.69	0.74	7240	14.38	0.82	7362	14.86	0.78	8301	16.08	1.00	8387	13.00	0.68
6322	12.79	0.78	7241	14.91	0.77	7364	16.15	1.01	8302	15.49	0.82	8388	14.05	0.68
6323	16.22	1.68	7243	15.86	0.84	7365	12.91	0.50	8303	17.58	0.78	3160	17.18	1.00
6324	13.57	1.29	7244	16.69	1.13	7366	13.24	0.67	8304	15.45	0.77	3165	17.60	0.75
5177	15.61	0.87	5196	15.12	0.86	6390	17.28	0.94	6391	16.78	1.47	6392	14.33	0.74

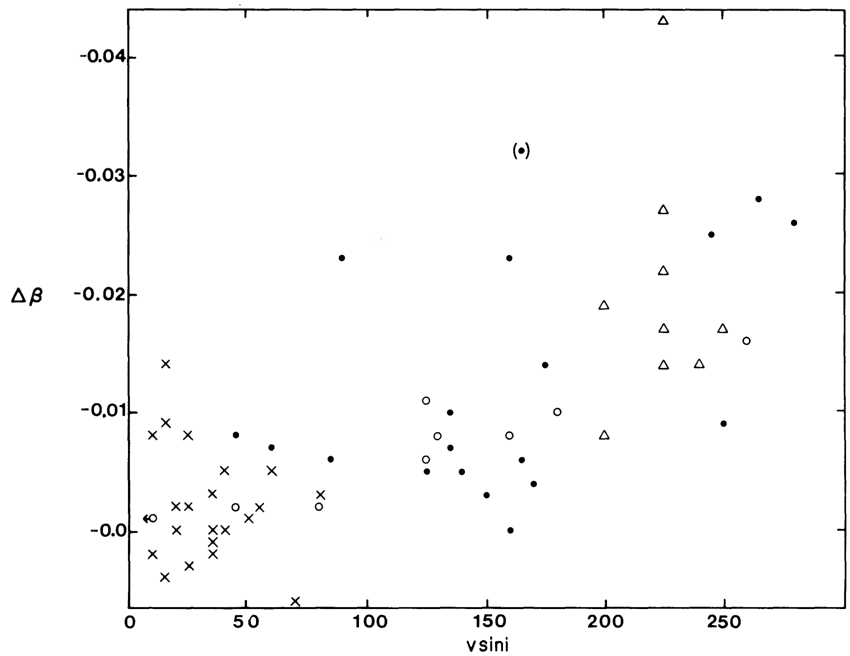

FIG. 7.—The $\Delta\beta$ versus $v \sin i$ diagram for field A and F stars with $(b - y)_0 > 0.1$ mag. Closed circles represent stars of luminosity class V from Abt and Moyd (1973), *open circles*, similar stars from Danziger and Faber (1972). *Triangles*, the stars without luminosity classification and with $(b - y)_0 > 0.15$ mag from Danziger and Faber and *crosses*, Am stars from Abt and Moyd.

to the precepts of Crawford and Barnes (1970). Those stars with $E(b - y) < -0.009$ mag were not included in the following discussions.[3]

ii) *Effects of Rotation on the* Hβ *Index*

Figure 7 is a plot of $\Delta\beta = (\beta - \beta_{\text{ZAMS}})$ versus $v \sin i$ for the groups of stars selected above. The diagram suggests that a threshold phenomenon may exist in that no significant $\Delta\beta$ occurs until $v \sin i \gtrsim 180$ km s^{-1} when the effect becomes quite large. Figure 8 is the $[\beta, (b - y)_0]$-plane on which the same data are displayed with the ZAMS and the NGC 2477 observations. The diagram suggests that $v \sin i_{2477} \gtrsim 200$ km s^{-1}.

iii) *Effects of Rotation on the* c_1 *Index*

In the range of $(b - y)$ we are considering here, β is both temperature and gravity sensitive (Strom *et al.* 1971). Hence we expect rotation to affect the position of a star in the $[c_1, (b - y)_0]$-plane as well, as discussed by Kraft and Wrubel (1965) and Chaffee *et al.* (1971), and in figure 9 we indeed note the very clear separation of fast and slow rotators. We previously concluded that on the average, the NGC 2477 stars in this diagram were similar to the Hyades. However, by eliminating the Am stars and considering only those stars with $(b - y)_0 > 0.1$ mag, the NGC 2477 stars appear to lie higher than the Hyades (i.e.,

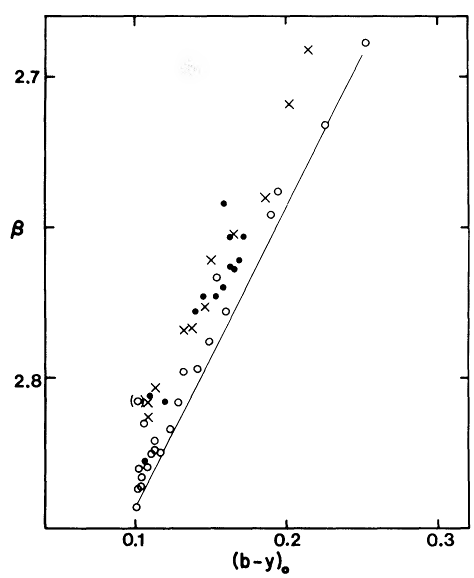

FIG. 8.—The β versus $(b - y)_0$ diagram. Open circles represent those field stars from fig. 7 with $v \sin i \lesssim 180$ km s^{-1}, while closed circles represent those stars with $v \sin i \gtrsim 200$ km s^{-1}; crosses are all the NGC 2477 stars except the Am stars, and the solid line is the ZAMS.

[3] For some of the stars with large $v \sin i$ it was found that the unreddened $(b - y)$ color was redder than the observed color by up to 0.027 mag. It may be that a small systematic or larger random errors exist in the reddening calibrations for stars with large $v \sin i$ values (see discussions in Slettebak 1970); a perhaps analogous situation may exist for the reddening calibrations as applied to extreme Am stars (Henry and Hesser 1971). Nevertheless, we note that the reddening derived from the four-color data for the NGC 2477 stars agrees well with that derived from *UBV* photometry.

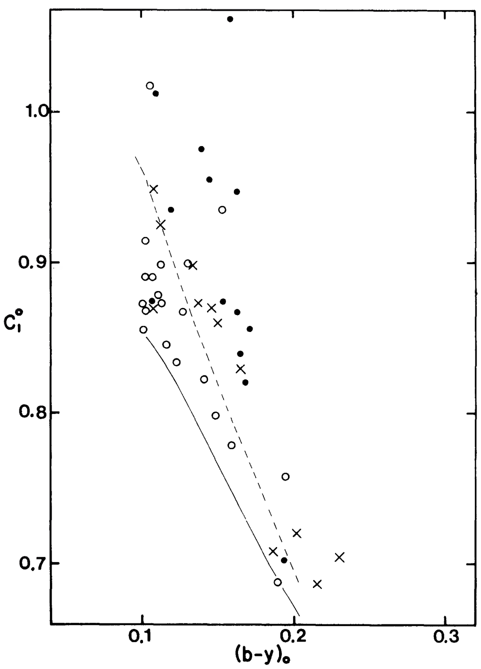

FIG. 9.—The $c_1{}^0$ versus $(b - y)_0$ diagram; the symbols are the same as for fig. 8, except that the dashed line represents the Hyades locus.

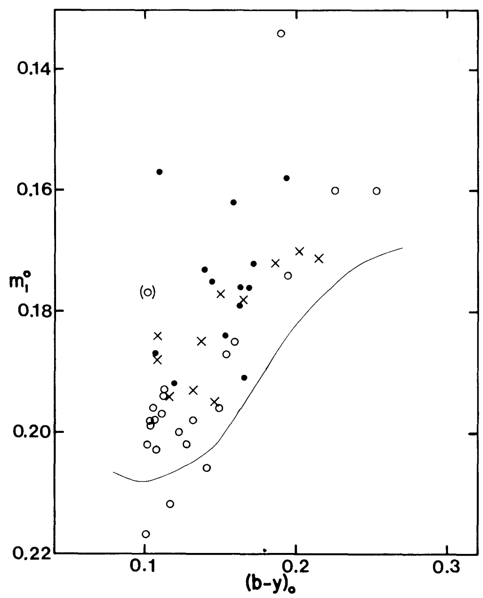

FIG. 10.—The $m_1{}^0$ versus $(b - y)_0$ diagram. The symbols are the same as in fig. 8.

they apparently have lower gravities). But comparison of the C-M diagrams of the two clusters reveals that NGC 2477 is slightly older than the Hyades and, hence, because they are not as evolved, we would expect the NGC 2477 stars to lie below the Hyades locus in figure 9. This dilemma can be resolved, however, if the NGC 2477 stars are rapidly rotating.

iv) *Effects of Rotation on the m_1 Index*

Figure 10 illustrates the effect found previously by Slettebak *et al.* (1968) and Danziger and Faber (1972), namely that rapid rotators have an apparent m_1 excess. The position of the NGC 2477 stars in this diagram is consistent with these stars rotating at velocities $v \sin i \gtrsim 200$ km s^{-1}.

Up to this point we have presented a case for the stars in NGC 2477 being rapid rotators, while also showing new relations on the effects of rotation on Hβ and c_1 for main-sequence A and F stars. We now would like to point out some problems with this interpretation. The first concerns the coolest stars in figure 8. Theoretically, the gravity dependence on the Hβ index becomes very small when $(b - y)_0 > 0.2$ mag, yet two stars with $(b - y)_0 > 0.2$ mag have large $\Delta\beta$. The other problem concerns the stars with $(b - y)_0 < 0.1$ mag. While the $[c_1{}^0, (b - y)_0]$-diagram for stars with $(b - y)_0 < 0.1$ mag shows these stars lying in a position similar to or toward regions of higher gravity than the Hyades, these same stars in the $[\beta, (b - y)_0]$-diagram show the same displacement as the cooler stars. Perhaps these stars, which we would expect to be further evolved, are rotating less rapidly due to evolution.

b) *The Metallicity and Low-Gravity Star Puzzles*

Clearly the CN measures of H^{2}M, interpreted as a metallicity index, are at odds with a line-blanketing interpretation of the $[m_1{}^0, (b - y)_0]$-diagram. Adopting the usual assumption that main-sequence and giant stars in a stellar cluster have similar chemical composition, it would be possible to diminish the discrepancy between the m_1 and CN observations if we assume that the bulk of the NGC 2477 A and F stars are fast rotators. This conclusion is in accord with the interpretation of the $[\beta, (b - y)_0]$-diagram, where the observed low Hβ indices for the majority of the stars can, apparently, be attributed to high rotation, as shown by analysis of field, main-sequence A and F star data (figs. 7, 8).

If the NGC 2477 stars have rotational velocities different from those of similar Hyades stars, as our observations suggest, then it is not yet possible to use figure 3 to estimate reliably the metal abundance of the main-sequence stars. Rather, we must rely on the giants. Here both the CN index and the two-color diagram indicated $[\mathrm{Fe/H}]_{2477} > [\mathrm{Fe/H}]_{\mathrm{Hyades}}$. However, following a suggestion of Paczyński (1973) that nitrogen produced in the CN cycle may be mixed to the surface of stars with masses $\sim 3\,\mathfrak{M}_\odot$ by meridional circulation due to rotation, Demarque and McClure (1973) have pointed out that observed CN excesses in several intermediate-age clusters, including NGC 2477, may be caused, in part, by meridional circulation. Our deduction of rapid rotation in the NGC 2477 main-sequence stars lends support to this idea; however, in view of the ultraviolet deficiency also observed in the NGC 2477 giants, we feel it may be premature to consider the question of the high metallicity of NGC 2477 closed. And even though we have been able, by the above arguments, to provide a plausible explanation for the behavior of the observations presently available for NGC 2477, the case we have built for the NGC 2477 stars being rapid rotators is based on indirect evidence and only direct determinations of $v \sin i$ from high-dispersion spectra will settle the question unambiguously.

We have seen from the $[m_1{}^0, (b-y)_0]$-diagram that NGC 2477 has a number of Am stars, in addition to many apparently rapidly rotating stars. As Abt and Moyd (1973) have reviewed, the apparent contradiction of having simultaneously present in the same cluster both intrinsically slowly rotating Am stars and rapidly rotating normal stars can be understood if the angular momentum of the protocluster material manifests itself both in the formation of close binary systems (Am stars?) and of rapidly rotating single stars. As the locus of the stars observed here superposes on the average, that of the Hyades stars in the $[c_1{}^0, (b-y)_0]$-diagram, it appears that the A and F stars in both clusters have similar gravities. Hence presence of: (*a*) a relatively large number of Am stars with their inherent ultraviolet deficiencies (Baschek and Oke 1965); (*b*) some differentially more highly reddened stars; and (*c*) some extremely rapidly rotating stars may be conspiring to produce the "low-gravity stars" near the top of the main sequence in H²M's two-color diagram.

c) *Summary*

The principal results of this reinvestigation of NGC 2477 are:

1. Confirmation of the reddening values, the existence of differential reddening, and the magnitude scale found by H²M. Additional *B*, *V* photometry suggests that the outer regions of the cluster are more heavily reddened than the central region studied by H²M.
2. A revised estimate of the turnoff places at $V_0 = 12.3$ mag, and, taken together with the distance modulus of 10.6 found by H²M, yields an age and turnoff mass of 0.9×10^9 years and $1.9\, \mathfrak{M}_\odot$, respectively, according to figure 10 of H²M.[4]
3. The C-M diagram has been augmented, bring the total number of measured stars to ~ 1900.
4. A series of indirect arguments has been invoked to suggest that the NGC 2477 upper main-sequence stars have $v \sin i \geqslant 200$ km s^{-1}. From these arguments, based on analysis of observations of field A and F stars, small but significant effects on the β, c_1, and m_1 indices as a function of $v \sin i$ have appeared.
5. Several probable Am stars have been photometrically identified.
6. The m_1 photometry suggests that the NGC 2477 stars have less, while CN photometry suggests that they have more, metal blanketing than comparable Hyades stars. This discrepancy between the photometrically determined values of [Fe/H] for the main-sequence and giant stars may be diminished, and perhaps eliminated, if the NGC 2477 stars are rapid rotators and if meridional circulation is taking place in the giants. The ultraviolet deficiencies observed by H²M support the view that the giants have metallicities higher than those of the Hyades giants, but until the rotation effects on the m_1 and CN indices are calibrated further, the exact value of [Fe/H] remains uncertain.
7. Three stars identified as blue stragglers in the C-M diagram have higher masses than stars near the turnoff point.
8. It is suggested that the presence of Am stars, high differential reddening, and rapid rotation may be conspiring to produce the stars pointed out by H²M to lie in the low-gravity region of the two-color diagram.
9. In Appendix A photometry of two carbon stars in the near vicinity of NGC 2477 is presented.

We wish to acknowledge the generous aid of Mrs. Jeanette Barnes in running the *ubvy*-Hβ photometry on the KPNO computers for us, and Srta. Laura Vega G. for her invaluable aid during all steps of the data reduction. We are also grateful to Drs. V. M. Blanco and B. M. Lasker for their contributions to our studies of the carbon stars near NGC 2477, and to Drs. D. L. Crawford, R. D. McClure, and S. Strom for criticisms of earlier drafts of this article.

APPENDIX A

CARBON STARS NEAR NGC 2477

The proximity of carbon stars to the intermediate-age open clusters NGC 2660 (Hartwick and Hesser 1971, 1973) and NGC 7789 (Mavridis 1960; Gaustad and Conti 1971) prompted us to search the area around NGC 2477 for such stars. Several carbon-star candidates were isolated using the 1° × 1° plates of the cluster taken with the Ritchey-Chretien focus of the 1.5-m telescope. Then 5° × 5° widened and unwidened 1N objective-prism plates obtained by Sr. G. Araya with the Curtis-Schmidt telescope were kindly surveyed by Dr. V. M. Blanco. Two photometrically discovered carbon stars in the near vicinity of the cluster were verified from their appearance on the Schmidt plates, and, in the case of C2, by photoelectric spectrum scans obtained by Dr. B. M. Lasker. The entire 25 square degree field of the Schmidt plates was

[4] This age is derived under the assumption that rotational effects on the position of the turnoff are negligible. According to Maeder (1972) the age could be overestimated by up to 30 percent if the stars are rotating at 200 km s^{-1}.

TABLE A1

PHOTOELECTRIC DATA FOR CARBON STARS NEAR NGC 2477

Star	Date	$V_{\mathrm{p.e.}}$	$(B-V)_{\mathrm{p.e.}}$	$\sim M_V$
1220.......	1973 Mar. 28/29	13.08	3.44	
	1973 June 01/02	13.24	3.33	
	1973 Oct. 28/29	13.18	3.45	
	1973 Oct. 31/32	13.19	3.40	+1.5
	1973 Nov. 01/02	13.17	3.38	
	1973 Nov. 24/25	13.00	3.45	
	1973 Nov. 25/26	13.01	3.47	
C2........	1972 Nov. 03/04	10.17	2.89	
	1973 Mar. 28/29	10.56	3.08	
	1973 June 01/02	10.58	3.05	
	1973 Oct. 28/29	10.50	3.05	
	1973 Oct. 31/32	10.55	3.06	−1.4
	1973 Nov. 01/02	10.55	3.04	
	1973 Nov. 24/25	10.56	3.14	
	1973 Nov. 25/26	10.57	3.14	

searched and 11 certain and two probable carbon stars were found, including the two nearest NGC 2477. With an angular radius of ~16′.5 for NGC 2477 (Alter, Balazs, and Ruprecht 1970) we would expect ~0.1 carbon stars in an area where one has been found, while within 25′ we would expect ~0.3, where two have been found. While this simple argument suggests a possible physical association with the cluster only radial velocities will ultimately determine cluster membership. Fortunately the star here designated as C2 was independently investigated by Catchpole and Feast (1973), who have provided a finding chart and given radial-velocity data that suggest a high probability of membership. No radial-velocity data are yet available for star 1220, however. CTIO data for these stars are given in tables A1 and A2. The low absolute magnitude found for star 1220 in NGC 2477 is at variance with the usual value of $M_V \sim -2$ mag thought to apply to N-type carbon stars, and thus spectroscopic investigation of its membership is particularly desirable. From the data available, both stars are seen to be variable.

Figure 11 shows the superposition of the C-M diagrams of the three clusters mentioned above and shows the relative positions of the carbon stars assuming membership. The approximate ranges of variability of three of the five carbon stars are represented in figure 11; in the case of the NGC 2477 stars, the photoelectric data of table A1 are probably insufficient to securely delineate the ranges, while for the NGC 7789 star, no photoelectrically measured colors are available. Data for the diagrams were taken as follows: (*a*) NGC 2477, H²M and this paper; (*b*) NGC 2660, Hartwick and Hesser (1973); (*c*) NGC 7789, Burbidge and Sandage (1958); and (*d*) M67 Eggen and Sandage (1964).

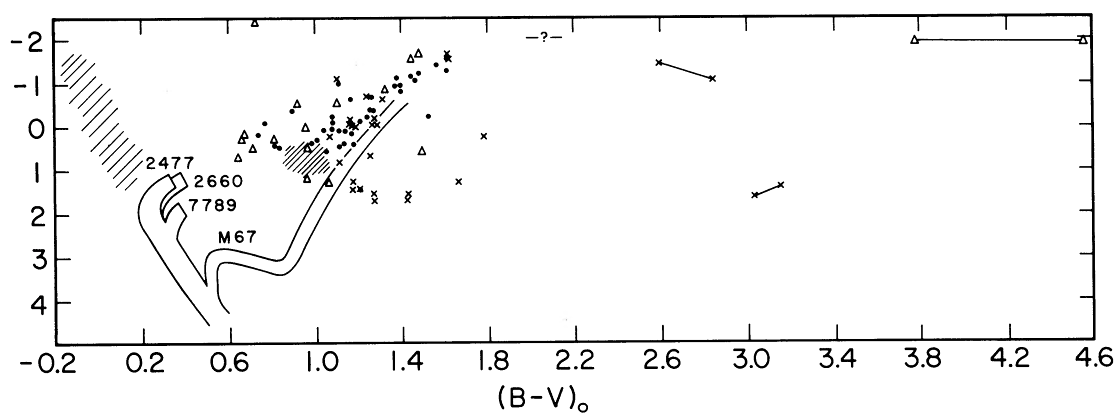

FIG. 11.—A combined $[M_V, (B-V)_0]$-diagram for the three intermediate-age clusters NGC 2477, 2660, and 7789, and the old cluster M67. The approximate ranges of variability for the four known carbon stars in the vicinity of the intermediate-age clusters are shown, except in the case of the NGC 7789, where –?– indicates that no photoelectric colors are available. The symbols used to plot individual (usually giant) stars are: *crosses*, NGC 2477; *triangles*, NGC 2660; and *filled circles*, NGC 7789. The "blue stragglers" are shown as an apparent extension of the main sequence by light hatching and the giant "clump" is shown by heavy hatching.

TABLE A2

INTERMEDIATE-AGE CLUSTERS WITH NEARBY N-TYPE CARBON STARS

Cluster Number (NGC)	Cluster Diameter (arc min)	Distance From Cluster Center (arc min)	V_0, max (mag)	M_V (mag)	Notes
2477...............	25–33	6	12.0	+1.4	1
		25	9.21	−1.4	1, 5
2660...............	1.5–4	1	10.3	−2.0	2
7789...............	10–51	22	10.2	−2.1	3, 4

NOTES.—(1) This paper, assuming $E_{B-V} \simeq 0.30$ mag. (2) Hartwick and Hesser (1971, 1973). (3) Mavridis (1960). (4) Gaustad and Conti (1971). (5) Catchpole and Feast (1973).

APPENDIX B

FIELD STARS

Table B1 consists of the *Bright Star Catalog* numbers of the field stars used in the discussion of $v \sin i$ effects (§ IV*a*); the references AM and DF represent Abt and Moyd (1973) and Danziger and Faber (1972), respectively.

TABLE B1

FIELD STARS USED FOR DISCUSSION OF ROTATIONAL-VELOCITY EFFECTS

HR	REF	HR	REF	HR	REF
178.......	AM	3469........	AM	5721........	DF
578.......	DF	3569........	DF	5887........	AM
916.......	DF	3619........	AM	6123........	AM
1329.......	AM	3662........	AM	6277........	DF
1368.......	AM	3758........	DF	6391........	AM
1376.......	AM	3945........	DF	6554........	AM
1392.......	DF	3974........	AM	6555........	AM
1394.......	AM	4141........	DF	6655........	AM
1403.......	AM	4197........	AM	6877........	AM
1428.......	AM	4405........	AM	7469........	DF
1444.......	AM	4535........	AM	7557........	AM
1511.......	AM	4650........	AM	7990........	AM
1528.......	AM	4733........	DF	8162........	DF
1632.......	DF	4847........	AM	8410........	AM
1672.......	AM	4904........	DF	8782........	DF
2143.......	AM	5010........	DF	8799........	AM
2532.......	AM	5333........	DF	8944........	AM
2551.......	DF	5350........	AM	8984........	AM
2914.......	AM	5702........	AM	9092........	AM

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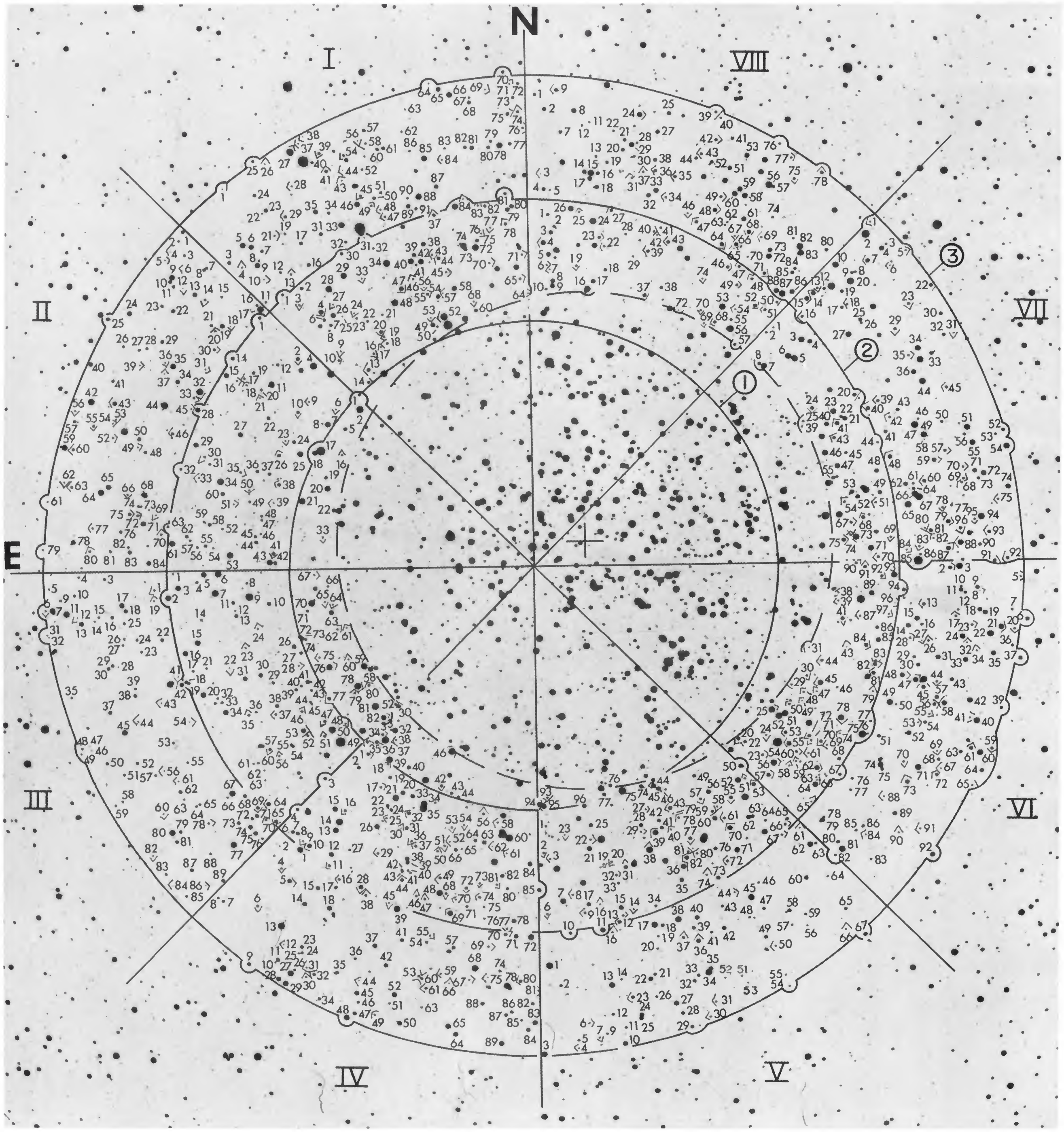

FIG. 5.—A 30-min B (103aO + GG13) plate of NGC 2477 identifying the ~1,200 additional stars for which photographic magnitudes and colors are given in table 3.

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