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INTERMEDIATE-BAND PHOTOMETRY OF THE OPEN CLUSTER NGC 3114

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Four-color and Hβ photometry has been obtained of 33 stars in the southern galactic cluster NGC 3114. This cluster contains many interesting stars including blue stragglers, red giants, and stars with spectral peculiarities. The distance modulus was found to be $V_0 - M_v = 10.26$ which corresponds to 1130 pc. The color excess is $E(b-y) = 0^{m}.060$. The cluster appears to be slightly older than the Pleiades. There are two extreme blue stragglers and six additional stars which might be considered milder cases of the same phenomenon. The distance moduli of the stars with peculiar spectra and the blue stragglers inferred from the photometry agree with those of the normal cluster stars and we conclude that this strengthens the view that the photometric indices of such stars are not affected significantly by their peculiarities.

Key words: open clusters—*uvbyβ* photometry—stellar evolution—blue stragglers—peculiar stars

I. Introduction

NGC 3114 ($\alpha = 10^{h}02^{m}$, $\delta = -60°00'(1975)$, $\ell = 238°$, $b = -4°$) is a rich open cluster situated in a region of Carina which has relatively low obscuration. This cluster has nearly 200 stars brighter than $V = 12$ within its boundaries and is about half a degree across. The richness of the cluster and its small absorption make it a useful object for studies of cluster properties and studies of various types of stars which might be members.

Lyngå (1959, 1962) and Jankowitz and McCosh (1963) have published *UBV* studies of stars in NGC 3114. They derived a distance of about 900 pc and a color excess in $(B-V)$ between $0^{m}.04$ and $0^{m}.09$. However, the distance is somewhat difficult to determine due to the presence of numerous field stars which are confused with the cluster stars. Lyngå estimated the age of this object at 200 to 500 million years while Jankowitz and McCosh found a slightly smaller age of 100 to 200 million years. On the other hand, Harris's (1976) discussion implies an age of about 30 million years and Mermilliod (1981) places it in an age class slightly older than the Pleiades (perhaps 60 million years).

Spectral types have been published for stars in NGC 3114 by Frye, MacConnell, and Humphreys (1970), Levato and Malaroda (1975) and Harris (1976). Of the 42 stars classified by one or more of these investigators, there are ten with peculiar spectra. Four are silicon stars, one is a Hg-Mn star, one is a Be star, one has enhanced N II lines, one has enhanced O II lines and two of the red giants have abnormal CN strengths.

The presence of so many interesting stars in this cluster made it a prime candidate for intermediate-band photometry. This photometry will serve to provide further information about the properties of peculiar stars in the *uvbyβ* system. Additionally, the relatively large number of red giants can be used to study the evolution of stars off of the main sequence. Basic to such studies are the distance, age, and color excess of the cluster. In this paper the results of a four-color and Hβ study of the B stars in NGC 3114 are reported.

II. The Observations

The star numbers used by Lyngå and Jankowitz and McCosh are listed in the first two columns of Table I and the spectral types are given in the following two columns. The *V* magnitudes are the averages of those from Lyngå, Jankowitz and McCosh, and the present photometry.

The four-color and Hβ photometry was obtained at Cerro Tololo Inter-American Observatory during March 1980 and May 1981 with the 0.91-meter telescope. A two-channel photometer was used with one channel serving to monitor the stability of the transparency. The photometric indices are given in the sixth through the ninth columns while the tenth column gives the number of nights on which each star was observed. It can be seen that most of the stars were observed three or more times.

The observations were made with standard four-color and Hβ filters. They were reduced to the standard system using secondary standards which were in turn referred to the four-color and Hβ standards of Crawford and Mander (1966) and Crawford and Barnes (1970). These secondary standard data will be published and discussed elsewhere. In the reduction of Hβ photometry it is necessary to consider the possibility of color terms (Muzzio 1978; Schmidt and Taylor 1979). However, in both observing seasons a filter set was used which has very well matched wide and narrow filters and no correction was necessary. The internal errors of the indices (standard deviation of a single measurement) are as follows: $(b-y)$, $0^{m}.009$; m_1, $0^{m}.011$; c_1, $0^{m}.013$; β, $0^{m}.010$.

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TABLE I

Photometry of Early-Type Stars in NGC 3114

Designation		Spectral Type									
Lyngå	JM	Levato and Malaroda	Frye et al.	V	b-y	m_1	c_1	β	n	E(b-y)	$V_0 - M_V$
3	136	B8III	B8III	7.75	0.018	0.070	0.782	2.669	4	0.058	10.38
4	24	B8.5IVp	B9III	7.84	0.035	0.070	0.941	2.688	6	0.068	10.42
6	8	B9IV	—	8.32	0.020	0.078	0.837	2.696	5	0.057	10.22
8	108	B8.5IIIp	B9p-Si	8.49	-0.023	0.101	0.607	2.690	4	0.024	10.02
9	23	B2IVp	B3V	8.56	-0.028	0.078	0.304	2.658	4	0.056	10.43
10	86	B8III	B8IV	8.61	0.004	0.092	0.696	2.736	4	0.047	8.95
11	2	B9.5IV	B9IV	8.72	0.037	0.081	0.949	2.712	4	0.065	10.58
13	4	B9IV	—	9.19	0.017	0.076	0.738	2.723	3	0.058	9.94
14	210	B9III	B8IV	9.26	0.014	0.087	0.674	2.724	4	0.058	9.79
15	196	B4Vn	B7V	9.56	0.000	0.074	0.499	2.693	4	0.061	10.56
16	25	B8IVp	B9p-Si	9.64	-0.005	0.111	0.595	2.716	4	0.044	10.26
17	205	B8Vn	B8IV	9.75	0.001	0.096	0.823	2.729	3	0.039	10.73
18	211	B9III-IVp	B8IV	9.82	0.021	0.096	0.656	2.742	3	0.066	9.81
28	—	B7Vn	B8IV	8.90	0.021	0.089	0.829	2.690	4	0.059	10.95
33	—	A0Vn	—	9.40	0.015	0.089	0.751	2.693	3	0.056	11.09
43	202	—	—	10.00	0.023:	0.084:	0.821	2.737	2	0.061	10.66
47	180	B2Vnne	B4V	9.65	-0.016	0.075	0.254	2.561	4	0.074	16.97
61	—	B8III:p	—	9.72	-0.008	0.097	0.585	2.723	3	0.042	10.13
97	20	—	B9V	9.38	0.017	0.104	0.802	2.800	4	0.056	8.68
99	29	—	—	10.02	0.040	0.080	0.830	2.741	2	0.078	10.53
102	42	—	—	9.07	0.032	0.105	0.799	2.757	2	0.071	9.13
124	—	—	—	9.99	0.009	0.101	0.653	2.742	2	0.054	10.04
126	67	—	B8V:	9.30	0.031	0.080	0.868	2.737	2	0.066	10.14
127	74	—	—	9.95	0.018	0.072	0.825	2.747	2	0.056	10.41
129	94	—	B9V	9.43	0.034	0.077	0.794:	2.679	2	0.074	11.65
132	156	—	—	9.73	0.022	0.092	0.840	2.705	2	0.059	11.35
134	183	—	—	9.64	0.034	0.102	0.758:	2.804:	3	0.075	8.63
136	—	—	—	9.29	0.019	0.100	0.654	2.742	3	0.064	9.29
141	149	—	—	9.78	-0.009	0.071	0.341	2.627	3	0.071	13.10
149	164	—	B9III	8.48	0.011	0.075	0.769	2.700	2	0.051	10.03
173	148	—	B9V	9.34	0.033	0.073	0.865:	2.683	2	0.068	11.74
183	12	B9.5V:*	—	9.34	0.027	0.098	0.873	2.782	2	0.062	9.25
186	1	—	B9IV	9.65	0.024	0.086	0.574	2.686	2	0.076	10.98

*Classification from Harris (1976).

Therefore, all of the mean indices in Table I (except a few marked as uncertain by a colon) should be accurate to better than 0ᵐ010.

All the stars with spectral types in Table I except number 33 are B stars. Rough spectral types can also be inferred from the four-color indices; for example, the $[m_1]$,$[c_1]$ diagram is useful in this regard. This test indicated that all stars in Table I are B stars including those with no assigned spectral types. Therefore, we have applied Crawford's (1978) B-star calibration to each star to obtain the color excess and true distance modulus. These are listed in the last two columns of the table. In these calculations we have assumed that $A_v = 4.28\ E(b-y)$ (Crawford and Mandwewala 1976).

III. The Distance and Reddening

Because NGC 3114 is located in a crowded field of the Milky Way, there are likely to be a significant number of field stars in our sample. To study the membership of a cluster, proper motions of the individual stars are needed. Since these are lacking for NGC 3114, we will resort to the photometric indices to remove obviously discordant stars. Figures 1, 2, 3, and 4 are useful in this regard. In the first three diagrams we have marked those points which seem to deivate from the group of cluster data points. If we form the mean distance modulus omitting these deviant points, we obtain $V_0 - M_V = 10.41 \pm 0.70$ (standard deviation for a single star). In Figure 4 it appears that there is a grouping of points be-

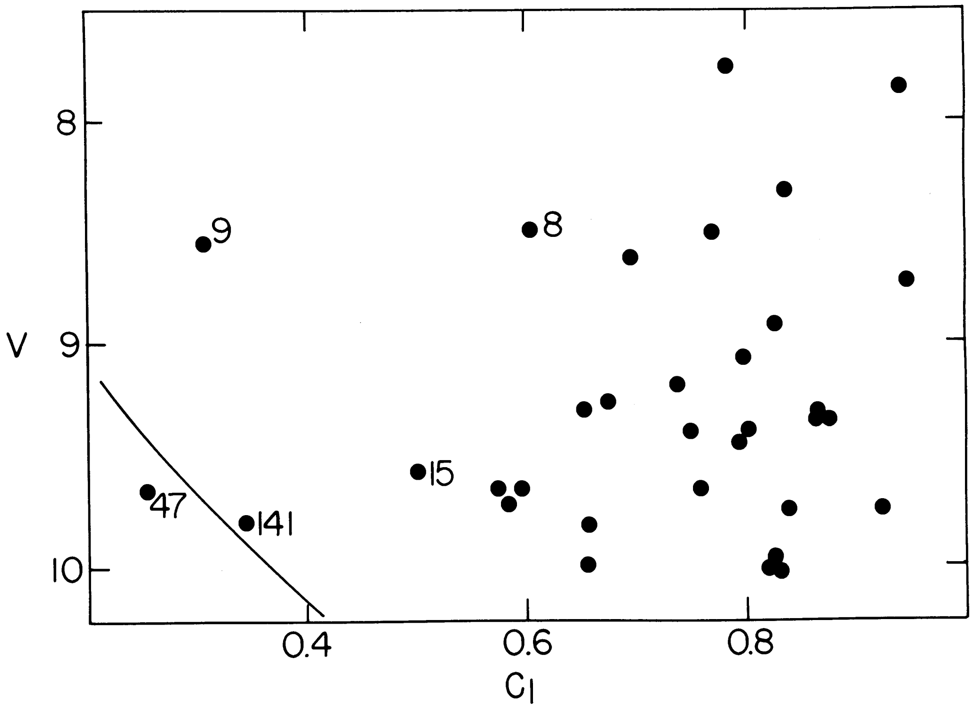

FIG. 1—The $V - c_1$ diagram for the stars from Table I. In this diagram and in the other figures the solid curve is the zero-age main-sequence relation from Crawford (1978) adjusted to a color excess of $E(b-y) = 0.060$ and a distance modulus of $V_0 - M_V = 10.26$. Deviant stars are identified by number.

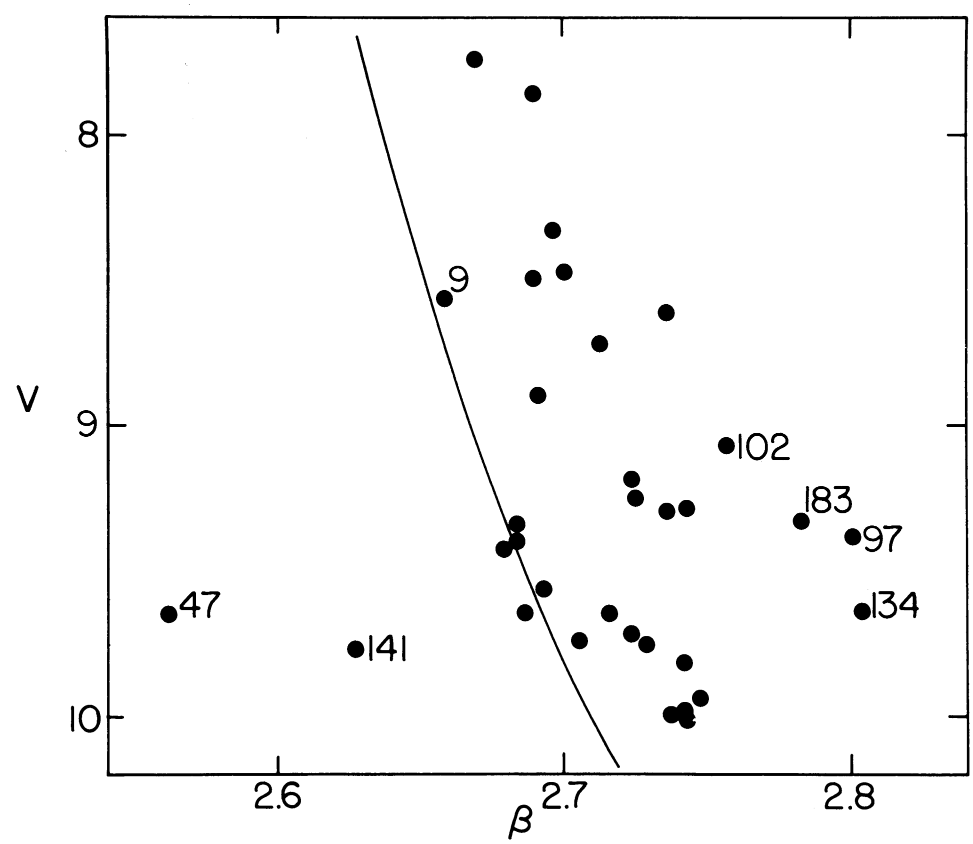

FIG. 2—The $V - \beta$ diagram of the stars from Table I.

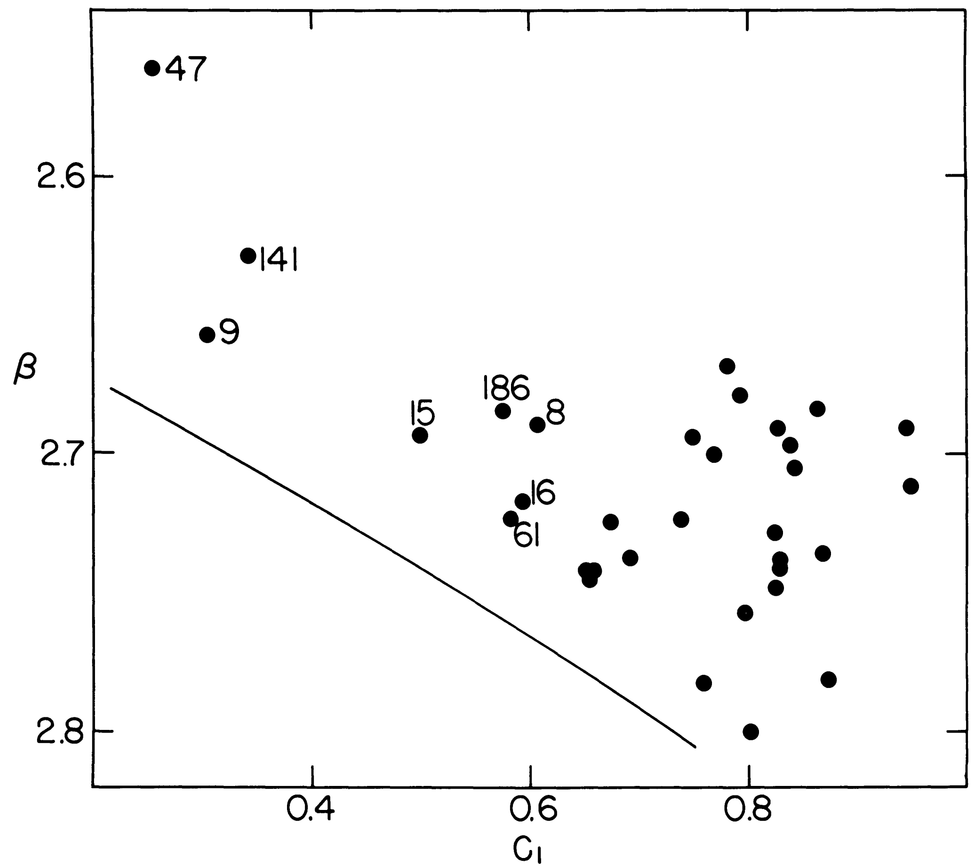

FIG. 3—The $\beta - c_1$ diagram of the stars from Table I.

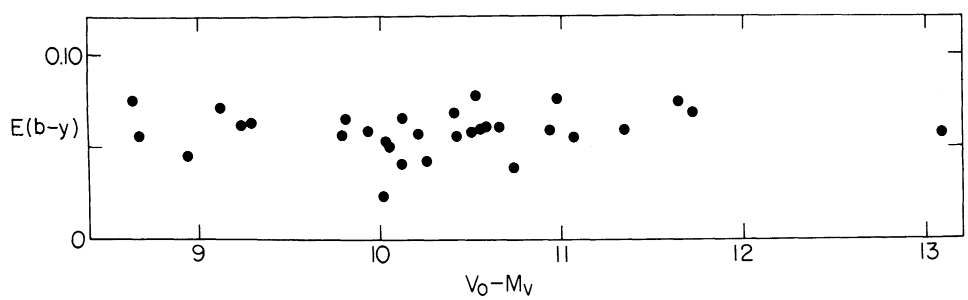

FIG. 4—The color excesses plotted against the true distance moduli for all the stars from Table I except star 47.

tween $V_0 - M_V = 9.7$ and 10.8. If we assume that the stars in this range are all members and reject the remainder, we obtain a mean distance modulus of 10.27 ± 0.28. Applying both criteria reduces the sample to 14 stars but is likely to be the best estimate because it should contain few field stars. We therefore adopt that value which is 10.26 ± 0.10 (standard error of the mean). This corresponds to a distance of 1130 ± 50 pc. The error quoted is the internal error and does not include uncertainties due to the calibration and possibly due to selection effects in the rejection of stars as nonmembers.

There is little reddening in this field and the mean reddening is not affected by our choice of member stars. The mean for the stars which appear to be members in Figures 1, 2, and 3 is $E(b-y) = 0.060 \pm 0.009$ and we adopt this as the cluster color excess.

One star in Table I, number 47, deserves special mention. The derived distance modulus of this object, 16.97, implies the implausibly large distance of nearly 25 kpc. However, one of the spectral types indicates emission in this star and it is likely that there is some filling in of the Hβ line. This will lower the measured Hβ index and cause the luminosity to be overestimated. Therefore, it is quite possible that this star is actually a member of the cluster.

IV. Discussion

Lyngå (1962) and Jankowitz and McCosh (1963) have derived distance moduli for NGC 3114 of 9.7 and 9.8, respectively. These are based on a Hyades distance modulus of 4.04 and should perhaps be increased to about 10.0 in view of recent discussions of the Hyades distance (Hanson 1980). It should also be noted that Lyngå commented that his distance for NGC 3114 should be regarded as a minimum estimate since a larger value would be allowed by the data. Therefore, the current value, 10.26, is in reasonable agreement with these previous determinations. However, Mermilliod (1981) obtained the much smaller value of 9.35 from his rediscussion of the *UBV* data.

Lyngå estimated the color excess for this cluster to be $E(B-V) = 0.04$, Jankowitz and McCosh obtained 0.09 and Mermilliod derived 0.10. The present value of $E(b-y) = 0.060$ corresponds to about $E(B\text{-}V) = 0.08$ and is thus in good agreement with the previous determinations.

Following Danford and Thomas (1981) we will use the β,c_0 diagram to compare the age of NGC 3114 with other clusters. For young clusters this diagram is sensitive to age and the point of evolution off of the zero-age main sequence is quite obvious. Figure 5 shows such a plot for NGC 3114 and α Persei cluster, the Pleiades and NGC 6475. The data for the three comparison clusters came from Crawford and Barnes (1974), Crawford and Perry (1976), and Snowden (1976). For each cluster we have only plotted the B stars and in NGC 3114 have only included stars between $V_0 - M_V = 9.7$ and 10.8 to reduce the number of nonmembers. As a cluster becomes older, the turnoff from the ZAMS moves to larger values of c_0 (i.e., toward the temperature of the maximum of the Balmer jump). It can be seen that NGC 3114 is slightly older than the Pleiades but considerably younger than NGC 6475. From Harris' (1976) age parameters for these clusters and her calibration of the parameter in terms of the age, we estimate that the Pleiades is about 60 million years old while NGC 6475 is about 90 million years old.

From Figure 5 we can then estimate the age of NGC 3114 to be about 65–75 million years. It is quite clear that it cannot be as young as 30 million years as given by Harris or it would resemble the α Per cluster

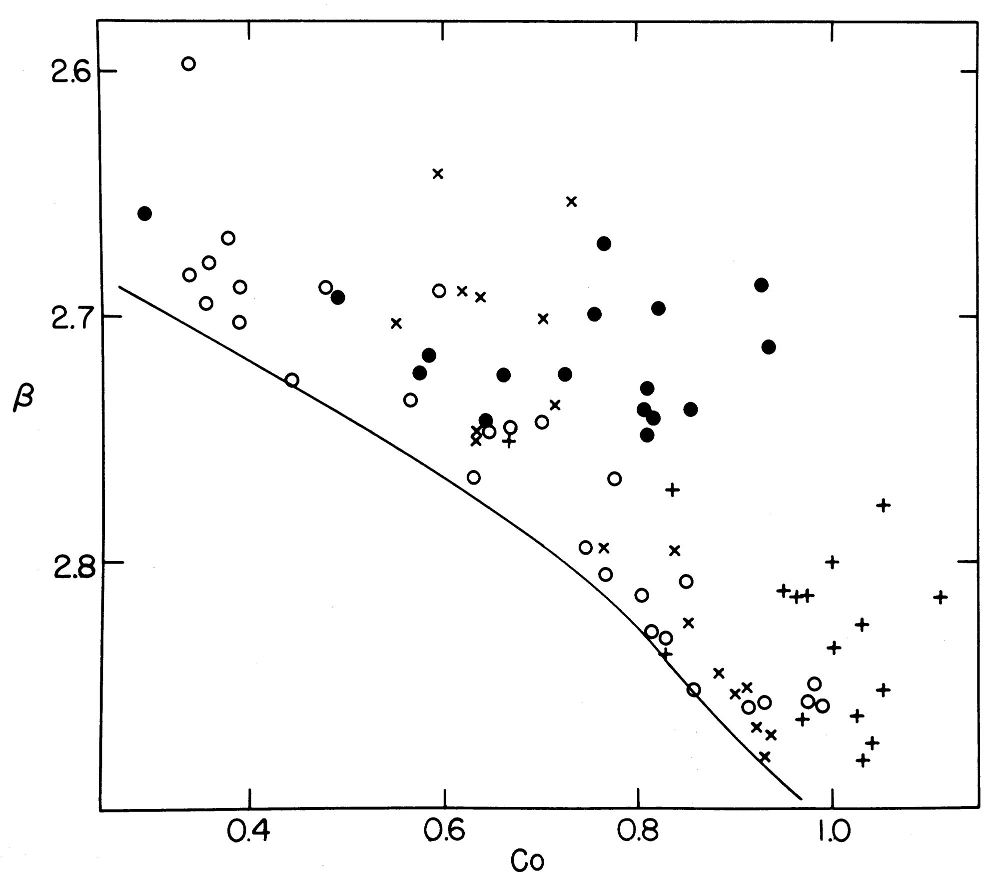

FIG. 5—The $\beta - c_0$ diagram for several clusters. The stars from the various clusters are indicated by the following symbols: NGC 3114, ●; the α Per cluster, ○; the Pleiades, x; NGC 6475, +. Only the B stars in each cluster are plotted.

much more closely. However, our data (together with the spectral types) also rule out an age as great as those estimated by Lyngå (200 to 500 million years) and Jankowitz and McCosh (100 to 200 million years). For this cluster to be that old it would have to be more similar to NGC 6475 than to the Pleiades. Mermilliod placed NGC 3114 in an age group slightly older than the Pleiades in agreement with the present result. Because the isochrones in the $V,(B-V)$ diagram are near the zero-age main sequence and both the isochrones and the ZAMS are very steep for clusters which are less than several hundred million years old, ages estimated from *UBV* photometry are sensitive to both the adopted cluster distance and the reddening correction. The use of c_0 and β avoids these problems and provides a much more reliable and sensitive measure of the relative ages of clusters.

In Figure 5 there are several points representing stars from NGC 3114 which appear to be blue stragglers. The most extreme, stars 9 and 15, are well above the cluster turnoff. Additionally, depending on the actual shape of the isochrones, we might consider the stars with c_0 between 0.51 and 0.70 to be less extreme cases of blue stragglers. This includes stars 8, 14, 16, 18, 61, and 124. It is interesting to note that of these stars five have been reported as having spectral peculiarities. Stars 8, 16, and 61 are silicon stars, star 18 is a Hg-Mn star, and star 9 has exceptionally intense O II lines for its spectral type. Of the three remaining stars, one, star 124, has no reported spectral observations. Furthermore, of the stars with reported spectral peculiarities which we have included in our observations, only one, star 4, does not fall to the blue side of the distribution in Figure 5.

Of the 16 stars in Figure 5 for which spectral types have been determined, six are peculiar. Abt (1979) has studied the incidence of spectral peculiarity among stars in clusters. From his results we would expect that perhaps 10% of the stars near the turnoff in NGC 3114 would show peculiarities. The comparison is not entirely valid because Abt limited his statistics to stars between $M_V = -1.5$ and $M_V = 1.4$ while most of the stars in the present sample are brighter than that. Nonetheless, it is surprising to find that nearly 40% of the stars in NGC 3114 are peculiar. Maitzen, Seggewiss, and Tug (1981) have attempted to determine whether the incidence of spectral peculiarity is greater among blue stragglers than among other stars. They concluded that the incidence is normal. However, in NGC 3114 we find that of the seven apparent blue stragglers with spectral types, five have abnormalities. The high incidence of both blue stragglers and spectral peculiarities in this cluster is apparently unusual and suggests that this object would be of great interest in studies aimed at explaining such stars.

In deriving the distance of NGC 3114, the blue stragglers and peculiar stars were mostly rejected due to their location in the various diagrams. However, it is of interest to question whether the peculiarities will affect their photometric distance moduli. If we take the mean distance modulus of all the NGC 3114 stars represented in Figure 5 which neither have peculiar spectra nor are apparent blue stragglers, we find $V_0 - M_v = 10.36 \pm 0.08$ (standard error of the mean). By comparison, the stars which have spectral peculiarities give a mean of 10.18 ± 0.10 which is less than 1.5 standard errors smaller. Taking the stars which have c_1 less than 0.7 (presumed blue stragglers) we find a mean modulus of 10.13 ± 0.10. Although this differs by somewhat more than for the peculiar stars, it should be noted that two stars, numbers 14 and 18, lower the mean significantly. If we take only the more extreme blue stragglers, those with c_1 less than 0.62, the mean distance modulus becomes 10.28 ± 0.10 in good agreement with the normal stars. Thus, we can conclude that the photometric indices of blue stragglers and stars with spectral peculiarities do not differ from those of normal stars in any way which affects their derived distance moduli by more than a few tenths of a magnitude. Strom and Strom (1970), Strom, Strom and Bergman (1971), and Eggen (1981) have also studied blue stragglers in clusters and have found no evidence that they differ in their intermediate-band indices from the normal stars.

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