THE ASTROPHYSICAL JOURNAL, 162:523–533, November 1970

A STUDY OF THE BLUE STRAGGLERS IN THE OPEN CLUSTER NGC 7789

K. M. STROM*
State University of New York at Stony Brook

AND

S. E. STROM*†
State University of New York at Stony Brook, and Smithsonian Astrophysical Observatory, Cambridge, Massachusetts
Received 1970 April 24; revised 1970 May 18

ABSTRACT

Image-tube spectrograms and Strömgren 4-color and Hβ photometry were obtained for twelve possible blue-straggler members of the open cluster NGC 7789. Membership was established for eight of these twelve blue-straggler candidates. From the data obtained, it was possible to test three competing hypotheses for the origin of these stars. Estimates of masses based on a match of our photometry with model atmospheres show that blue stragglers have masses appropriate to their location in the color-magnitude diagram. Furthermore, of four blue-straggler members studied carefully for radial-velocity variations, all four exhibited definite changes in velocity. These observations suggest strongly that blue stragglers are members of binary systems in which mass exchange has taken place.

I. INTRODUCTION

Several globular clusters and a few fairly old open clusters (for example, M3, M67, NGC 752, NGC 7789) contain stars which fall close to the main sequence but which extend a few magnitudes above the turnoff point of the cluster. These stars have been called "blue stragglers."

Various theoretical explanations have been offered to explain the anomalous location of the blue stragglers in the H-R diagrams. Among the most reasonable are the following:

1) The blue stragglers are representatives of a new generation of stars, born later than the majority of cluster members.

2) These stars are on (or very near) the main sequence for the second time. Possibly, a sufficient amount of the hydrogen in the envelope was transported to the interior during the helium flash to sustain a second (shorter) hydrogen-burning lifetime near the main sequence (see Rood 1970).

3) The blue stragglers are members of close-binary systems in which mass exchange has taken place (McCrea 1964; van den Heuvel 1968). On this picture, the present primary is believed to have an original mass less than the mass of stars at the turnoff, M_{to}. The mass of the *original* primary is slightly greater than M_{to}. As the original primary evolves, it fills its Roche lobe and begins to lose mass, most of which accretes on the surface of the secondary. As the secondary gains mass, it increases in luminosity and moves up the main sequence to its present location; the original primary in most cases becomes a white dwarf.

Each of these three hypotheses has one or more directly observable consequences. In hypothesis 1, the mass of the blue straggler, M_{BS}, corresponds to its location in the H-R diagram. For hypothesis 2, $M_{BS} \leq M_{to}$; whereas hypothesis 3 has the following consequences:

* Visiting Astronomer, Kitt Peak National Observatory, which is operated by the Association of Universitites for Research in Astronomy, Inc., under contract with the National Science Foundation.

† Alfred P. Sloan Fellow.

a) M_{BS} is identical with the mass of a main-sequence star which occupies the same position in the H-R diagram.

b) All blue stragglers are members of binary systems, some of which should have observable variations in velocity.

c) If the initial mass of the original primary is much greater than M_{to}, it is possible to form a blue straggler; however, a straggler formed from such a system would have evolved and not be visible as such today. Hence, the blue stragglers of highest mass must have had initial mass ratios near unity, and as a consequence, $M_{BS} \lesssim 2M_{to}$. Since $M_{BS} \lesssim 2M_{to}$, the luminosity of the blue stragglers in a cluster cannot exceed the turnoff luminosity by more than a factor of approximately 10.

In order to test these competing hypotheses, we chose to study the blue stragglers in the rich open cluster NGC 7789 (Burbidge and Sandage 1958). The number and brightness of the stragglers in this cluster were consistent with our goal of obtaining fairly extensive spectroscopic and photometric observations in a reasonable time. For each star, we obtained Strömgren four-color and Hβ photometry at the Kitt Peak National Observatory. Model-atmosphere calculations can be matched with these indices to predict the luminosity, T_{eff}, and mass for the blue stragglers. In order to test the binary hypothesis, a series of spectrograms of the four brightest blue stragglers was obtained with the KPNO Cassegrain image-tube spectrograph at dispersions of 50 and 35 Å mm^{-1}. These spectra permit us to check for variations in radial velocity.

II. THE OBSERVATIONS

a) *Membership*

NGC 7789 is located in a fairly crowded region of the Milky Way ($l^{II} = 115$, $b^{II} = -5°$). Hence, to avoid contamination from field interlopers, we felt that membership of the blue stragglers should be established on the basis of measured radial velocities. Unfortunately, to our knowledge, no published radial velocities are available for individual stars in NGC 7789.

To establish a value for the velocity of the cluster, we obtained spectrograms in the wavelength region 5000–7000 Å of K and M giants in NGC 7789 at a dispersion of 127 Å mm^{-1} with the KPNO image-tube spectrograph. The velocities were reduced by using the Grant measuring engine at the KPNO. The mean velocity deduced for three K giants is -40 ± 8 km sec^{-1}, which we adopt as the cluster velocity. In Table 1 we list for the blue stragglers, the mean values for radial velocity, the number of observations, and the mean error per observation. These values are based on image-tube spectrograms taken at dispersions of 50 and 35 Å mm^{-1}. An M in column (5) indicates those blue stragglers which we consider to be likely members. Of the twelve stars studied, eight are probable members. We note in this regard the photometric observations of Osváth (1960): He estimates from counts of blue stars within the cluster field and in a nearby comparison field that two-thirds of the blue stars in NGC 7789 are likely to be members, which is consistent with our results. We also indicate by MC and NC, respectively, those stars thought to be members and nonmembers by Cannon (1968) on the basis of a recent, unpublished proper-motion study.

b) *The Photometry*

In Table 2, we list the observed $(b - y)$, m_1, c_1, and β for all stars in our program, along with the number of observations and the mean error per single observation. Before comparing the photometry with model-atmosphere predications, it is necessary to correct the observed colors for the effects of interstellar reddening. From their photographic and photoelectric *UBV* observations of NGC 7789, Burbidge and Sandage (1958) derive a reddening value $E_{B-V} = 0.28$. Althoûgh these authors give no value for the expected error in this result, we estimate from their data that ±0.03 mag is a reasonable guess. We can also estimate the reddening from the spectral types derived from our observations. In Table 3, we present for each star the estimated spectral type, the unreddened $(B - V)$ for that type (Johnson 1963), the $(B - V)$ inferred from the observed $(b - y)$ (Crawford 1966), and the resulting color excess, E_{B-V}. From this procedure we obtain $E_{B-V} = 0.34 \pm 0.01$.

Finally, we obtain a reddening estimate from the observed β and $(b - y)$ values for the stars later than A0. However, because the $[\beta, (b - y)]$-relation is still quite sensitive to gravity for stars earlier than F0, this determination is of much lower weight. A value of $E_{b-y} = 0.22 \pm 0.03$ or $E_{B-V} = 0.32 \pm 0.04$ is deduced in this way. We adopt a weighted mean value of $E_{B-V} = 0.32$ mag for the reddening to NGC 7789.

TABLE 1

RADIAL-VELOCITY MEASUREMENTS FOR BLUE STRAGGLERS IN NGC 7789

Star (1)	N (2)	$\langle V \rangle$ (3)	Probable Error per Single Observation (4)	RV Member? (5)	PM Member? (6)
K144	1	−16	...	...	MC
K168	1	−21	...	...	MC
K197	1	−31	...	M	MC
K234	1	−26	...	M?	MC
K342	7	−45	±13	M	MC
K349	1	−34	...	M	MC
K371	4	−56	± 6	...	MC
K409	7	−20	±17	M?	MC
K453	8	−41	±19	M	MC
K799	12	− 2	± 7	...	NC
K1168	1	−49	...	M?	MC
K1211	8	−33	±18	M	MC

TABLE 2

STRÖMGREN FOUR-COLOR AND Hβ PHOTOMETRY FOR BLUE STRAGGLERS IN NGC 7789

Star	N(Four-Color)	$(b-y)$	m_1	c_1	N(Hβ)	β
			Members			
K197	2	0.304±0.019	0.118±0.005	1.118±0.029	3	2.867±0.061
K234	2	0.303±0.027	0.173±0.054	0.938±0.049	3	2.880±0.060
K342	5	0.191±0.018	0.063±0.026	1.057±0.040	6	2.872±0.021
K409	6	0.253±0.015	0.102±0.023	1.025±0.045	8	2.930±0.049
K453	9	0.227±0.019	0.040±0.027	0.913±0.021	11	2.792±0.042
K1168	2	0.271±0.020	0.193±0.000	0.992±0.047	2	2.927±0.051
K1211	13	0.157±0.015	0.065±0.019	0.628±0.027	14	2.718±0.018
			Nonmembers			
K144	3	0.276±0.018	0.082±0.030	1.215±0.002	3	2.902±0.027
K168	2	0.258±0.021	0.119±0.041	1.060±0.043	3	2.873±0.021
K371	6	0.277±0.017	0.119±0.021	1.115±0.040	7	2.914±0.054
K799	17	0.245±0.014	0.160±0.019	0.936±0.031	17	2.867±0.034

In Table 4 we present the mean values of $(b - y)$, m_1, and c_1 corrected for reddening for each star.

The distance modulus is computed from the data listed in Table 5. Here we present the spectral type and luminosity class, the absolute magnitude (Blaauw 1963) corresponding to this classification, the observed V-magnitude, and the apparent modulus. From this data we obtain $(m - M) = 11.9 \pm 0.1$ (m.e.). Burbidge and Sandage estimate $(m - M) = 12.2 \pm 0.2$ from the main-sequence slope and the location of the turnoff point. We regard the agreement between these determinations as satisfactory. With $E_{B-V} = 0.32 \pm 0.03$, we predict a true distance modulus $(m - M) = 11.0 \pm 0.15$.

TABLE 3

REDDENING DETERMINATION FOR NGC 7789

Star	Sp Type	$(B-V)_0$	$(B-V)$	E_{B-V}
		Members		
K197..........	A3–A5 V	+0.12	0.48	+0.36
K234..........	A3–A5 V	+0.12	0.48	+0.36
K342..........	B9–A0 V	−0.03	0.30	+0.33
K349..........	A3 V	+0.09	0.43	+0.34
K409..........	A1–A2 V	+0.04	0.40	+0.36
K453..........	B9–A0 V	−0.03	0.36	+0.33
K1168.........	A3 V	+0.09	0.43	+0.32
K1211.........	B8–B9 V	−0.07	0.25	+0.32
		Nonmembers		
K144..........	B8–B9 V	−0.07	0.44	+0.51
K168..........	B9–A0 V	−0.03	0.41	+0.44
K371..........	A3–A5 V	+0.12	0.45	+0.33
K799..........	A2p	+0.04	0.39	+0.35

TABLE 4

UNREDDENED COLORS FOR BLUE STRAGGLERS IN NGC 7789

Star	$(b-y)_0$	m_1^0	c_1^0
	Members		
K197...........	+0.084	0.184	1.074
K234...........	+0.083	0.239	0.894
K342...........	−0.029	0.129	1.013
K409...........	+0.033	0.168	0.982
K453...........	+0.038	0.185	1.016
K1168..........	+0.051	0.259	0.953
K1211..........	−0.063	0.584	0.131
	Nonmembers		
K144...........	+0.056	0.148	1.171
K168...........	+0.038	0.185	1.016
K371...........	+0.052	0.185	1.071
K799...........	+0.024	0.226	0.892

III. INTERPRETATION

In Figures 1, 2, and 3, we indicate the location of the blue straggler members of NGC 7789 in the [β, $(b - y)$]-, [m_1, $(b - y)$]-, and c_1, $(b - y$]-planes. We superpose on these plots the observed location of luminosity class III–V stars as taken from Crawford's (1966) study. We note immediately that *almost without exception, the location of the blue stragglers in these plots appears to be consistent with that of normal main-sequence A and B stars*. The exceptions to this statement are (1) the location of K453 at $\beta = 2.792$ and $(b - y) = 0.038$ in the [β, $(b - y)$]-plot; the β is somewhat small for the $(b - y)$; (2) the location of K1168 and possible K234 in the [m_1, $(b - y)$]-plot.

The individual observations of K453 show a range of almost 0.15 in β. This range is larger than that found for blue stragglers of comparable brightness in our program. It is possible that the observed Hβ variation of K453 is real; and as a consequence, we have omitted this star from subsequent discussion.

TABLE 5

DISTANCE-MODULUS DETERMINATION FOR NGC 7789

Star	Sp Type	M_v	V	Apparent Modulus
		Members		
K197	A3–A5 V	+1.7	13.3	11.6
K234	A3–A5 V	+1.7	13.4	11.7
K342	B9–A0 V	+0.3	12.4	12.1
K349	A3–A5 V	+1.7	13.3	11.6
K409	A1–A2 V	+1.0	13.0	12.0
K453	B9–A0 V	+0.3	12.7	12.4
K1168	A3 V	+1.5	13.2	11.7
K1211	B8–B9 V	−0.3	11.5	11.8
		Nonmembers		
K144	B8–B9 V	−0.3	13.4	13.7
K168	B9–A0 V	+0.3	13.8	13.5
K371	A3 V	+1.5	12.9	11.4
K799	A2p	+0.8	11.8	11.0

Both K234 and K1168 are faint, and only two observations were obtained for each star. Since no spectral peculiarities were noted for these stars, we hesitate at this time to attribute any significance to the high m_1 values.

Although the location of the blue stragglers in the Strömgren four-color plots appears "normal," we must now interpret our observations quantitatively in order to estimate the range of stellar masses encompassed by the data. Chromey (1970) has recently computed, from model-atmosphere data, the expected variation of β with $(b - y)$ and with c_1 for A- and B-type stars of differing gravities. The theoretical [β, $(b - y)$]- and (β, c_1)-plots are shown in Figures 4 and 5, in which lines of constant $T_{\rm eff}$ and log g are indicated for reference. It is essential to note that these theoretical plots are useful primarily for estimating the *differential* variation of $T_{\rm eff}$ and g *between* groups of stars. Because of small errors in the models and adopted line-blanketing coefficients, we caution against using these plots for absolute determinations of these parameters.

For the range of late B stars, we find from this figure that a change of 0.01 mag in β corresponds to a change of 0.1 in log g, almost independently of c_1. We can apply this

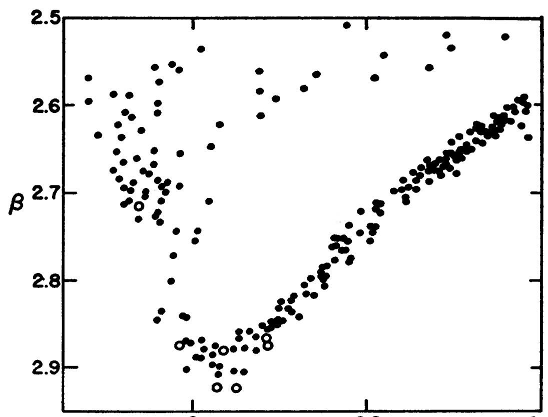

FIG. 1

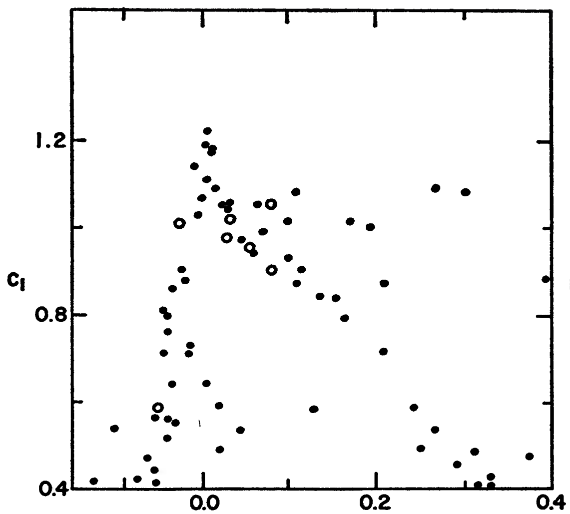

FIG. 2

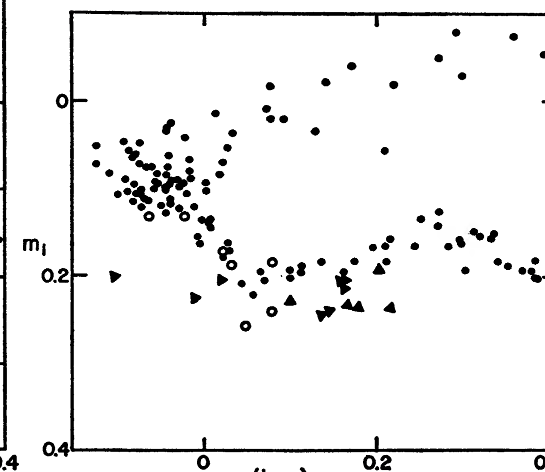

FIG. 3

FIG. 1.—Location of the blue stragglers (*open circles*) in the [β, $(b - y)$]-plane. For reference, the stars of luminosity classes III, IV and V as observed by Crawford (1966) are plotted. Note that, with the exception of K453, the stars fall near the lower part of the distribution, as expected for main-sequence stars.

FIG. 2.—Location of the blue stragglers in the (β, c_1)-plane. Notation is the same as in Fig. 1.

FIG. 3.—Location of the blue stragglers in the [m_1, $(b - y)$]-plane. Notation is the same as in Fig. 1 except that Am stars are plotted as filled triangles. Although K234 and K1168 appear to have high m_1 indices, the accuracy of the observations is insufficient to draw any significant conclusion as to abnormal metallicity.

1970ApJ...162..523S

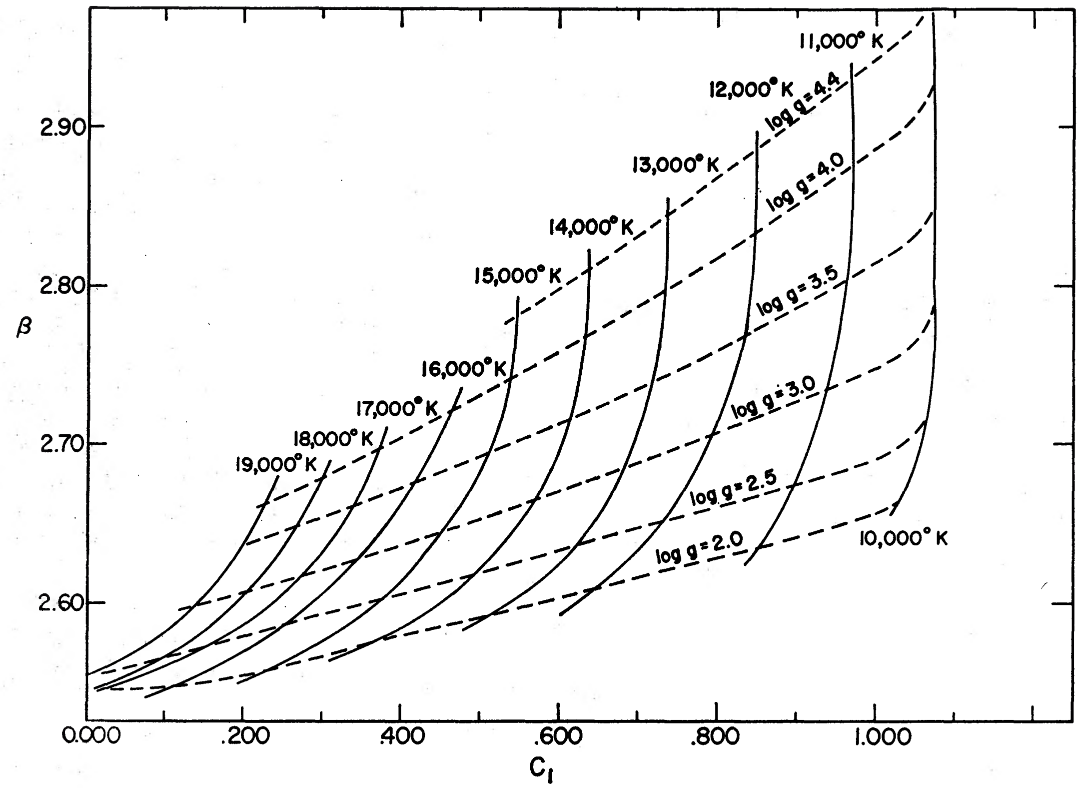

FIG. 4.—Theoretical (β, c_1)-plane as computed by Chromey (1970). Note that these plots should be used to make *differential,* as opposed to *absolute,* estimates of log g and T_{eff}.

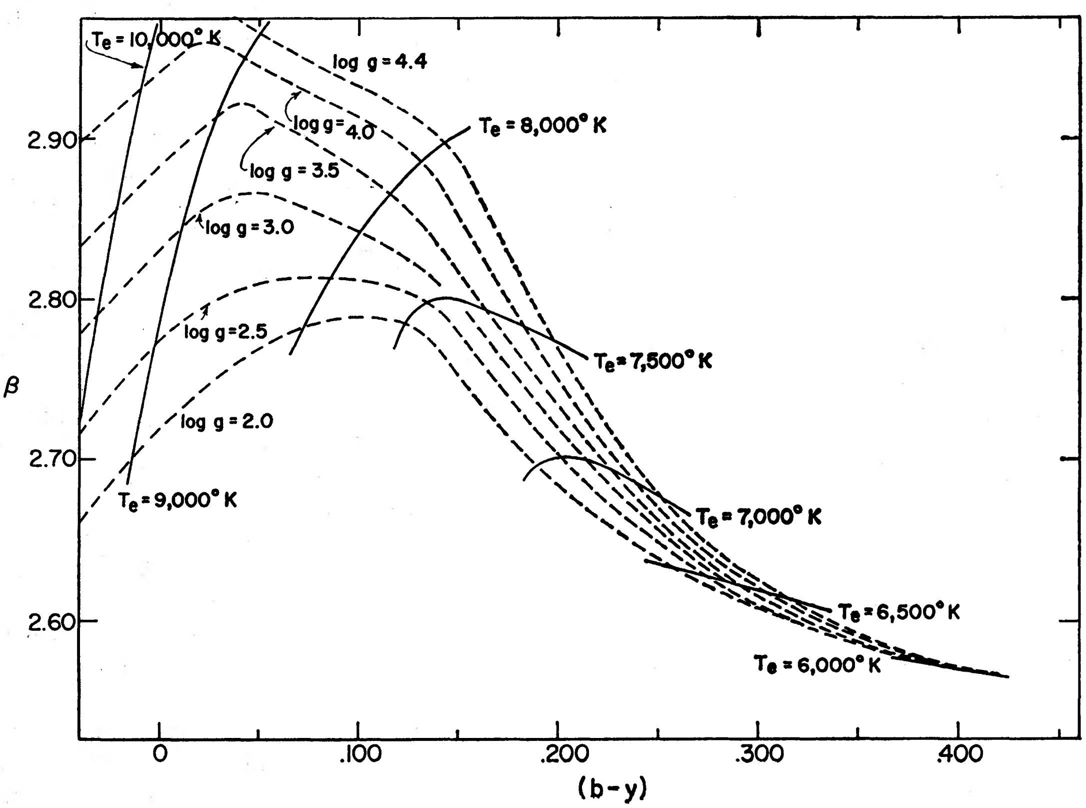

FIG. 5.—Theoretical [β, $(b - y)$]-plane as computed by Chromey (1970)

result to K1211 which has a β approximately 0.05 mag smaller than the zero-age main sequence (ZAMS) value of β at $c_1 = 0.58$ (Crawford 1970, private communication). This means that K1211 has a gravity 0.5 in the log smaller than that for stars on the ZAMS near log $T_{\text{eff}} \sim 4.1$ We then estimate a value of log $g = 3.8 \pm 0.1$ for this star since B stars near the ZAMS have log $g = 4.3$ (Kelsall and Strömgren 1964; Iben 1967). From the calibration of spectral type with T_{eff} of Morton and Adams (1968), we deduce a log $T_{\text{eff}} = 4.1 \pm 0.03$ and a bolometric correction of 0.7 ± 0.2 mag. With the derived true distance modulus of $(m - M) = 11.0$, we compute the mass of K1211 as $M/M_{\odot} = 3.2$ $(+1.8, -1.2)$. This mass is completely consistent with the mass of a *normal* B8 star. The luminosity at the turnoff point in NGC 7789 is log $(L/L_{\odot}) = 1.0 \pm 0.1$, while log T_{eff} is 3.875 ± 0.015. From Iben's (1967) evolutionary tracks, the mass of stars at turnoff must be $M/M_{\odot} \sim 1.5$ with a cluster age of of $1.5 \pm 0.5 \times 10^9$ years. Thus the mass of K1211 is about twice the turnoff-point mass. As a test of the validity of our mass-determination procedure, we note that the gravity deduced from the observed Hβ index for Sirius is log $g = 4.36 \pm 0.1$ whereas the "observed" value is log $g = 4.30 \pm 0.01$. We regard this agreement in log g as excellent. The mass we deduce for Sirius is $M/M_{\odot} = 2.6$, which is entirely reasonable.

Next, we can obtain from the $[\beta, (b - y)]$-diagram (for the cooler blue stragglers) estimates of log g, differential with respect to the ZAMS. From this we can again compute

TABLE 6

MASS DETERMINATIONS FOR BLUE-STRAGGLER MEMBERS OF NGC 7789

Star	$[g]$	$[g/g_{\odot}]$	$[L/L_{\odot}]$	$[T_{\text{eff}}/(T_{\text{eff}})_{\odot}]$	$[M/M_{\odot}]$	$M/M_{\odot}$
K342.......	4.1±0.0	−0.35±0.1	1.84±0.1	0.242	+0.522	3.3 (+2.0, −1.2)
K409.......	4.2±0.1	−0.25±0.1	1.60±0.1	0.200	+0.55	3.5 (+2.1, −1.3)
K197.......	4.0±0.1	−0.45±0.1	1.40±0.1	0.161	+0.306	2.0 (+1.2, −0.7)
K234.......	4.1±0.1	−0.35±0.1	1.36±0.1	0.161	+0.366	2.3 (+1.4, −0.8)
K1168......	4.2±0.2	−0.25±0.2	1.44±0.2	0.181	+0.466	2.9 (+2.3, −1.3)

the mass. In Table 6, we summarize the mass determinations for the remaining blue stragglers in NGC 7789. Brackets denote logarithms of the indicated quantities. We also plot in Figure 6 the location of the blue stragglers relative to Iben's (1967) evolutionary tracks; this figure allows us to estimate masses from the apparent location of the blue stragglers in the H-R diagram. Although no individual mass determination in Table 6 is in itself convincing, our mass determinations for the six stragglers provides compelling evidence for the statement: ***The mass of blue stragglers is consistent with their observed location in the H-R diagram.*** This result would appear to rule out the possibility that blue stragglers are on the main sequence for the second time.

We next turn to the question of the binary character of the blue stragglers. The essential data are summarized in Table 1. We first note that the well-observed nonmember, K799, provides one estimate of the true mean error of a radial-velocity determination from a single plate, namely, ± 7 km sec^{-1}. A further check on the accuracy of the radial velocities is afforded by a comparison of our image-tube radial velocities with those derived by Trumpler (1930) for eleven B stars in NGC 2264. The comparison gives $(V_{\text{Strom}} - V_{\text{Trumpler}}) = -8 \pm 6$ km sec^{-1}; the error refers to the accuracy of an individual observation. Finally, we note that for five G-star members of M67, $(V_{\text{Strom}} - V_{\text{true}}) = 0 \pm 4$ km sec^{-1}. Hence, we believe that ± 7 km sec^{-1} is a conservative estimate of our *internal* error for radial-velocity determinations. It is clear immediately from Table 1 that the four well-observed blue stragglers have significantly higher errors per individual velocity determination. The most likely explanation for these greater errors is that these stars have variable radial velocities. While the velocity variations do not provide definite proof of the binary character of the blue stragglers, our data suggest strongly that *all blue stragglers studied are probably spectroscopic binaries.* We further expect the rotational velocities of the blue stragglers to be relatively small as a consequence of mass exchange and the close coupling between rotational and orbital angular momentum (van den Heuvel 1968) in the binary system. All blue stragglers in NGC 7789, with the exception of K453, have $v \sin i \lesssim 100$ km sec^{-1}, that is, less than the resolution of the image-tube spectrograms at 50 Å mm^{-1}. Spectrograms of K121, K409, and K342 were obtained at 35 Å mm^{-1}; and we estimate in these cases that $v \sin i \lesssim 70$ km sec^{-1}. The Ca II K-line and hydrogen-line widths in K453 appear to be variable on our spectrograms, as might be expected from the results of our Hβ photometry. This star may be a double-line binary; however, confirmation of this suspicion must await further observation. We conclude that none of the blue stragglers have rotational velocities greater than can be determined at our resolution. This observation is again consistent with the binary hypothesis.

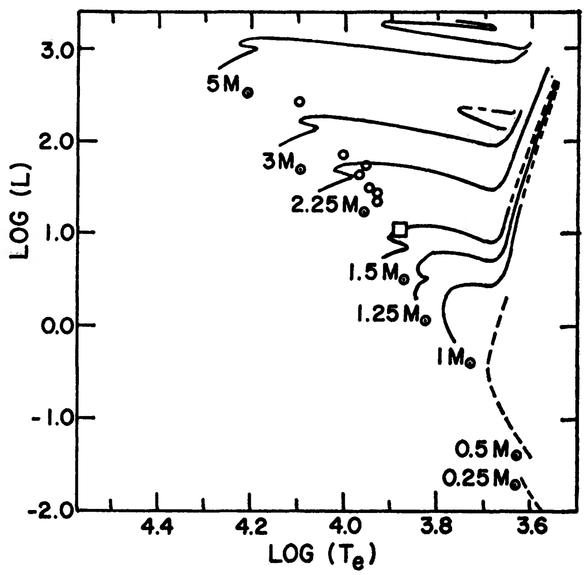

FIG. 6.—Location of the blue stragglers in the luminosity–effective temperature plane. For reference, the turnoff point of NGC 7789 is indicated as an open square. The tracks, as computed for stars of the indicated mass, are taken from Iben (1967).

To test whether we *expect* on the basis of the binary hypothesis to observe velocity variations for most blue stragglers in NGC 7789, we chose the most pessimistic case, that of K1211. From its location in the H-R diagram, we note that it is the most massive of the blue stragglers. Hence, its companion must presently be the *least* massive. As a consequence, we expect the observed variations in velocity for this star to be a minimum. As a plausible model for the initial configuration, we take $m_1{}^0 = 1.7\ M_\odot$ and $m_2{}^0 = 1.5_\odot$. For the final configuration, $m_1 = 0.5\ M_\odot$ and $m_2 = 2.7\ M_\odot$. Defining α as m_2/m_1, we can compute the ratio of the present to the initial period from (see van den Heuvel 1968) the equation

$$P/P_0 = \{\alpha_0/\alpha[(1+\alpha)/(1+\alpha_0)]^2\}^3 \,.$$

Adopting the above parameters, we obtain $P/P_0 \sim 6.7$. The total velocity amplitude, $2K_1$ in km sec^{-1}, is given by

$$2K_1 = \frac{208(m_1+m_2)^{1/3}\sin i}{P^{1/3}(m_2/m_1)^{1/2}}\,,$$

where i is the angle of inclination. If we adopt a mean value of sin i of 0.7, we find that for our limit of detection ($2K_1 \gtrsim 30$ km sec^{-1}), the present period P is less than about 27 days. Hence, the *initial* period of the binary must have been $P_0 \lesssim 4$ days. Approximately 25 percent of field binaries have periods in this range (Abt 1961). As an extreme example (see Refsdal and Weigert 1969) we choose $m_1{}^0 = 1.7\ M_\odot$ and $m_2{}^0 = 1.5\ M_\odot$; $m_1 = 0.3\ M_\odot$ and $m_2 = 2.9\ M_\odot$. For this case, the present period must be less than $\sim$13 days. For this pessimistic case, only a few percent of the initial binaries would be expected to have periods in this range. It would appear that, unless extreme conditions prevail, it is quite likely that a blue-straggler system similar to K1211 will be detected, given our sample and our observational accuracy.

We can also check to see that the number of blue stragglers is consistent with the expected number of progenitor binary systems. We note first that all blue stragglers formed from systems with an initial primary mass greater than $\sim$1.7–1.8 $M_\odot$ would have evolved already and would now be in a later stage of evolution. Second, from the observed luminosities as well as our deduced masses, we note that the minimum mass of the blue stragglers is $\sim 2\ M_\odot$. On the assumption that a star of 1.7 $M_\odot$ is not likely to lose more than 1.4 $M_\odot$, the initial mass for the original secondary must be $\gtrsim 0.6\ M_\odot$. Hence, the initial mass ratio must be in the range $1.0 \lesssim \alpha \lesssim 3$. Approximately half the total number of binaries in NGC 7789 should have mass ratios in this range (van den Heuvel 1968). Furthermore, about half of these systems have appropriate initial separations (i.e., periods) for mass exchange to occur. If binary frequency in NGC 7789 is similar to that in the Hyades, approximately 25 percent of all stars are binaries. Consequently, 6 percent of all NGC 7789 members from the turnoff to approximately 2 mag ($M/M_\odot \sim 0.6$) below should form blue-straggler systems. If the survey of Burbidge and Sandage is reasonably complete, there are $\sim$330 stars occupying this region of the H-R diagram; as a result, we would expect approximately twenty blue stragglers. However, we estimate, using the luminosity function given in Allen (1963), that approximately 50 to 100 stars below the turnoff are probably field interlopers. This reduces the expected number of blue stragglers to the range 14–17. We observe eight blue stragglers to be certain members. Since we have not spectroscopically tested fourteen possible blue stragglers for membership, the total number must be in the range $8 < N < 21$. We consider this comparison to be reasonably consistent with the number of blue stragglers expected.

Finally, we note that Deutsch (1969) and Peterson (1970) have examined several stragglers in the open cluster M67. One of these stars has a definite period, while three others are radial-velocity variables. Hence, it appears reasonable to suggest that *most, if not all, blue stragglers are members of binary systems.*

IV. CONCLUSIONS

From our investigation we find that:

1. The masses deduced for blue stragglers from Strömgren four-color and Hβ photometry are consistent with their location along the main sequence in the H-R diagram.
2. All blue stragglers studied for radial velocity are velocity variables.

Conclusion 1 rules out the possibility that blue stragglers are on the main sequence for a second time during their evolutionary history. Conclusion 2 permits the following alternates:

a) The blue stragglers are a class of newly formed main-sequence stars, all members of which are binaries and all of which have relatively low rotational velocities.

b) The blue stragglers are produced as a result of mass exchange in close binaries. We believe the second of these alternatives to be the more likely.

Note added in proof.—Spectra of four additional K giants were obtained subsequent to the acceptance of this paper. The cluster velocity for NGC 7789 derived from a total of seven K giants is -45 ± 7 km sec^{-1}. As a consequence of this newly derived velocity, we now believe K371 to be a probable member. The photometry of this star predicts a mass consistent with its location along the main sequence, entirely in keeping with the conclusion of this paper.

We thank Dr. R. Lynds and Mr. J. deVeny of the Kitt Peak National Observatory for their valuable instruction and advice in using the Carnegie image-tube spectrograph. Miss N. Iraggi provided significant help in the preparation of this paper, and we thank her. We also acknowledge with gratitude the support of NASA grant NGR 22-024-001.

REFERENCES

Abt, H. A. 1961, *Ap. J. Suppl.*, **6**, 37.
Allen, C. W. 1963, *Astrophysical Quantities* (London: Athlone Press).
Blaauw, A. 1963, in *Basic Astronomical Data*, ed. K. Aa. Strand (Chicago: University of Chicago Press).
Burbidge, E. M., and Sandage, A. R. 1958, *Ap. J.*, **128**, 174.
Cannon, R. D. 1968, private communication.
Chromey, F. R. 1970, private communication.
Crawford, D. L. 1966, *I.A.U. Symposium No. 24*, p. 170.
Deutsch, A. J. 1969, private communication.
Heuvel, E. P. van den. 1968, *B.A.N.*, **19**, 326.
Iben, I., Jr. 1967, *Ann. Rev. Astr. and Ap.*, **5**, 571.
Johnson, H. L. 1963, in *Basic Astronomical Data*, ed. K. Aa. Strand (Chicago: University of Chicago Press).
Kelsall, T., and Strömgren, B. 1964, *Vistas in Astronomy*, Vol. **8**, ed. A. Beer and K. Aa. Strand (Oxford: Pergamon Press).
McCrea, W. H. 1964, *M.N.R.A.S.*, **128**, 147.
Morton, D. C., and Adams, T. F. 1968, *Ap. J.*, **151**, 611.
Osváth, I. 1960, *Abh. Hamburg-Bergdorf*, **5**, 129.
Peterson, D. M. 1970, private communication.
Refsdal, S., and Weigert, A. 1969, *Astr. and Ap.*, **1**, 167.
Rood, R. T. 1970, *Ap. J.* (in press).
Trumpler, R. J. 1930, *Lick Obs. Bull.*, **14**, 154.