2-1981

Four-Color and Hβ Photometry of the Galactic Cluster NGC 7790

Edward G. Schmidt
University of Nebraska at Lincoln, eschmidt1@unl.edu

THE ASTRONOMICAL JOURNAL VOLUME 86, NUMBER 2 FEBRUARY 1981

FOUR-COLOR AND Hβ PHOTOMETRY OF THE GALACTIC CLUSTER NGC 7790

EDWARD G. SCHMIDT[a)]
Department of Physics and Astronomy, University of Nebraska, Lincoln, Nebraska 68588
Received 6 October 1980; revised 13 November 1980

ABSTRACT

Observations have been obtained on the four-color and Hβ system of 16 stars in the field of NGC 7790. These represent virtually all of the stars which are in the B-star region of the cluster color-magnitude diagram. I discuss the membership of these stars and find three which are possibly field stars. The remaining stars indicate a true distance modulus of 11.98 ± 0.13 for the cluster and a color excess of $E(b-y) = 0.403$.

I. INTRODUCTION

The cluster NGC 7790 has been studied previously by Sandage (1958), who obtained *UBV* photometry, and by Kraft (1958), who obtained spectral types for eight stars in the cluster field. This cluster is of special interest because it contains three Cepheids (CE Cas a, CE Cas b, and CF Cas) and an eclipsing binary (QX Cas). Mavridis (1959) also suggested that NGC 7790 contains an M giant (star F in Sandage's notation). However, this star is nearly two magnitudes fainter than the Cepheids and is probably a foreground dwarf.

Two of the Cepheids, CE Cas a and CE Cas b, form a close visual binary (about 2.5″ separation). Smak (1966) and Sandage and Tammann (1969) have attempted the difficult task of obtaining separate light curves for the two stars. The presence of Cepheids in a cluster is useful for determining the luminosities of these stars, and the Cepheids in NGC 7790 have been included in a number of calibrations of the Cepheid period-luminosity-color (PLC) relation (Kraft 1961; Sandage and Tammann 1969; van den Bergh 1977; de Vaucouleurs 1978; Martin, Warren, and Feast 1979). Additionally, the presence of three such stars allows a discussion of their location relative to the evolutionary tracks in the color-magnitude diagram (Sandage and Tammann 1969).

The eclipsing binary, QX Cas, is composed of two similar stars of early spectral type (Sandage 1958) and has a period of 6 days. As pointed out by Sandage, this star is potentially useful for calibrations of effective temperature and mass if it is in fact a member of the cluster. Although it is outside of the main part of the cluster, Sahade and Davila (1963) list it as a certain member (for reasons which are not stated). Further observations of this star are clearly warranted.

NGC 7790 is located within the area of the sky covered by the Cas V association and appears to be at nearly the same distance as at least part of the association (Reddish 1961; Ampel 1964). This raises the interesting question of whether it is connected with the association. However, there is a large discrepancy between the inferred age of the association stars and that of the cluster (Ampel 1964).

For reasons discussed briefly in a previous paper (Schmidt 1980a), it is desirable to reobserve clusters with Cepheid members in the four-color and Hβ system. This is especially true of NGC 7790 since there has been only one previous photometric study and since it contains several interesting stars. This paper presents such data for this cluster.

II. THE OBSERVATIONS

The stars to be observed were selected using Sandage's (1958) *UBV* photometry. I have included all the stars in his list brighter than $V = 14$ and between $B-V = 0.2$ and $B-V = 0.48$ with only a single exception. Reference to Sandage's color-magnitude diagram shows that few, if any, potential cluster B stars have been eliminated by the color limits. The stars near my magnitude cutoff are late B stars. Thus, going to fainter limits would involve stars near the maximum of the hydrogen-line strengths, for which the B-star calibration is not applicable. In several clusters it has been found that the A stars do not obey the standard calibrations (Crawford and Barnes 1974; Crawford and Perry 1976; Schmidt 1978). Thus, extending my photometry to still fainter stars is not likely to increase confidence in the distance modulus and color excess derived for the cluster. This and the difficulty of obtaining accurate four-color and Hβ indices for faint stars led to the magnitude limit.

In Table I, I list the stars that were observed in NGC 7790. The designations and the V magnitudes are from Sandage (1958) and the spectral types are from Kraft (1958). The fourth, fifth, and sixth columns give the four-color indices, while the seventh column gives the number of nights on which they were measured. The Hβ indices are tabulated in the eighth column and the number of nights on which they were measured are in the ninth column. These observations were obtained with the

[a)] Visiting Astronomer, Kitt Peak National Observatory, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

 0004-6256/81/020242-04$00.90

TABLE I. Photometric data for stars in NGC 7790.

Star	Spectral type	V	$b-y$	m_1	c_1	n	β	n	$E(b-y)$	V_0-M_0
A	B2III-IV	11.08	0.270	−0.029	0.091	9	2.630	12	0.385	12.12
B		12.16	0.364	−0.034	0.716	3	2.695	4	0.409	11.89
D[a]	B9III	12.59	0.330	0.056	1.073	3	2.835	4	0.350	10.84
E	B5IV:	12.79	0.354	−0.014	0.633	3	2.702	4	0.407	12.10
M		13.32	0.323	0.006	0.619	3	2.743	4	0.377	11.64
N[b]		13.48	0.399	−0.043	0.761	4	2.723	3	0.442	12.34
O	B9IV	13.54	0.356	−0.010	0.714	4	2.712	4	0.401	12.78
Q		13.72	0.385	−0.005	0.699	3	2.722	3	0.431	12.50
36		13.66	0.383	0.001	0.737	3	2.751	3	0.427	11.84
40	B8IV	13.07	0.356	0.004	0.558	3	2.701	4	0.406	12.20
41		12.60	0.400	−0.034	0.522	2	2.624	4	0.467	14.53
52		13.13	0.331	0.006	0.610	3	2.739	4	0.387	11.48
55		13.06	0.327	0.006	0.676	3	2.752	4	0.374	11.32
62		13.32	0.372	−0.031	0.854	3	2.698	3	0.412	13.35
95	B5IV	12.67	0.332	−0.004	0.474	3	2.683	4	0.403	12.26
99	B7IV:	13.34	0.347	0.024	0.742	3	2.770	4	0.391	11.31

[a] Double star; both components in diaphragm.
[b] In Sandage's region 3.

76-cm telescope at Behlen Observatory and with the 1.3 and 2.1-m telescopes at Kitt Peak National Observatory during the interval from August 1977 to November 1979. Most of the observations were obtained, however, in the runs of August 1977 and November 1979.

The observations were reduced to the standard system using stars from the following sources as standards: field stars from Crawford and Mander (1966) and Crawford and Barnes (1970); stars in the h Per cluster (Crawford *et al.* 1970); and secondary standards previously referred to the Crawford and Mander, and Crawford and Barnes standards. It has been shown that color-dependent terms can occur in the Hβ index (Muzzio 1978; Schmidt and Taylor 1979). During the run of November 1979 a carefully selected Hβ filter set was used which has no color terms. Comparisons of the previous photometry with the results of this run showed no significant differences. The observations from the various runs have therefore all been simply averaged. From the scatter among the multiple observations of each star, the following internal standard deviations for a single measurement were derived: $b-y$, 0.018 mag; m_1, 0.023 mag; c_1, 0.029 mag; β, 0.013 mag.

The location of the stars in the $[m_1]$-$[c_1]$ diagram was used to determine the approximate spectral type for each star. It was found that all of the stars in Table I are B stars with the exception of star D, which appears to be close to A0 in spectral type. The spectral types given in the table are consistent with this finding. Therefore, I have used the Crawford (1978) B-star calibration to determine the distance moduli and color excesses of the stars in Table I. In doing this, I have assumed a ratio of total to selective absorption of $A_V/E(b-y) = 4.46$, which corresponds to $A_V/E(B-V) = 3.3$. In the case of star D, I have also determined the distance modulus and color excess using the calibration derived by Claria (1974, quoted by Eggen 1980) for stars near spectral type A0. The resulting distance modulus, 11.02, and color excess, 0.324, are reasonably close to the values in Table I.

III. CLUSTER MEMBERSHIP AND THE DISTANCE MODULUS

In order to obtain the cluster distance modulus, it is necessary to remove nonmembers from the sample. This is accomplished by referring to various diagrams involving the photometric indices. Some of these are shown in Fig. 1, where possibly deviant stars are labeled. It can be seen that star A is near the cluster main sequence in all three diagrams and is unevolved in spite of being well above the other stars on the main sequence. Its distance modulus is in good agreement with the other cluster stars. This star may be a blue straggler and there seems to be no good reason to reject it as a member. Star B also lies away from the bulk of the stars in Fig. 1(b). However, its position is consistent with its simply being the most luminous main-sequence star (except for star A), and it is about a magnitude fainter than the Cepheids, as should be the case. Therefore, it is also retained as a cluster member. Star D is away from the rest of the stars in all of the diagrams. However, it has a nearby companion which could not be excluded from the diaphragm and which therefore affects the photometric indices in an unknown way. For this reason, I reject this star from the subsequent discussion. Star 41 has a β index which causes it to appear away from the bulk of the stars in Figs. 1(a) and 1(c). Since its position in Fig. 1(b) is reasonably close to the cluster sequence, this suggests that it may be an emission-line star. If this is the case, or alternatively, if it is not a member, it is not appropriate to use its distance in the cluster mean, and so I reject this star. Star 62 appears to have a normal β index for an unevolved cluster star [Fig. 1(c)] but the c_1 index is too large. This gives rise to a large evolutionary correction to the absolute magnitude and results in a distance

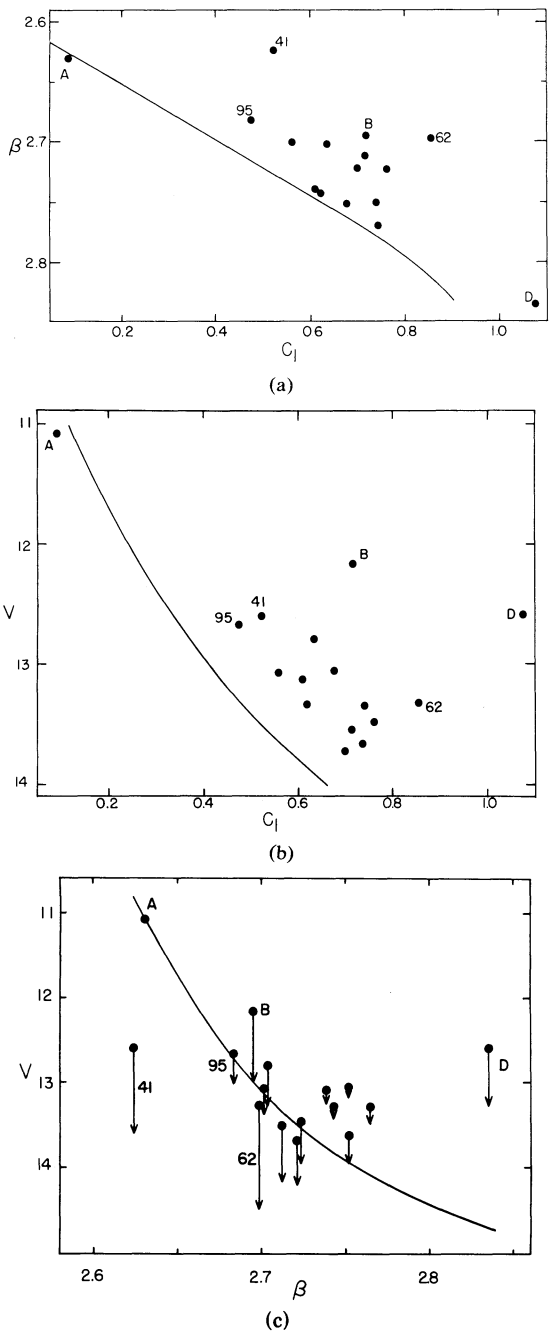

FIG. 1. Plots of the various photometric indices. The stars discussed in the text are labeled. The solid curve in each case is the zero-age relation from Crawford (1978) shifted to account for the apparent distance modulus of the cluster, 13.76, and the reddening, 0.081 in c_1. In Fig. 1(c) the measured apparent magnitudes are represented by circles, and the arrows show the evolutionary correction which needs to be applied to them according to the Crawford calibration.

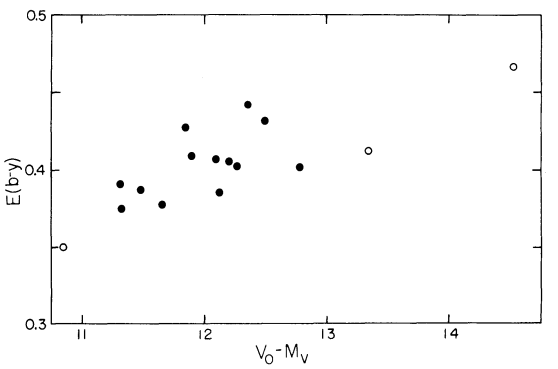

FIG. 2. The color excesses plotted against the true distance moduli. The three open circles represent stars D, 42, and 62, which are regarded as non-members.

modulus which is larger than any other star except star 41. Since this implies either that the calibration does not apply owing to some peculiarity of the star or that it is an evolved background star, I reject it. Star 95 is also away from the other stars in Fig. 1(a). However, its position in Figs. 1(b) and 1(c) seems to indicate that it is a likely member.

In Fig. 2, I plot the color excesses of the stars against their distance moduli. Open circles denote stars D, 41, and 62, which were rejected. The mean color excess of the remaining stars is $E(b-y) = 0.403 \pm 0.021$ (standard deviation of a single star). The scatter is slightly larger than one would expect from the photometric errors (perhaps ± 0.01). There is no obvious trend in the color excesses with position in the cluster but there might still be a small variation in the reddening which contributes to the scatter. The mean distance modulus for the 13 stars regarded as members is $V_0 - M_V = 11.98 \pm 0.45$ (standard deviation for one star). The rejection of three stars from the sample has had only a small effect on the distance modulus. Since the rejection seems justified, as discussed above, I adopt 11.98 ± 0.13 (standard error of the mean) as the best estimate of the distance modulus.

IV. DISCUSSION

My mean color excess for the stars in this cluster, $E(b-y) = 0.403$, corresponds to $E(B-V) = 0.545$. This is in excellent agreement with the value of $E(B-V) = 0.555$ for CF Cas which Kraft (1961) derived from the *UBV* photometry of Sandage (1958) and his own Γ photometry of the Cepheid. Unfortunately, all three of the Cepheids in the cluster are to the northwest of the B stars and there are no suitable stars in this region for four-color and Hβ photometry. In view of the possibility of slightly variable reddening in this region, there is an uncertainty of perhaps 0.02 mag in my estimate of the reddening of the Cepheids.

There are a number of values for the distance modulus of NGC 7790 in the literature. All are based on the photometry of Sandage (1958) and they range from about 12.5 (Becker and Fenkart 1971) to 12.8 (Sandage 1958; Cogan 1978). The present value lies outside of this

range. This agrees with the trend found previously for smaller distance moduli from the four-color and Hβ photometry than had been obtained from the *UBV* photometry (Schmidt 1980a,b). Clearly, whether this trend is significant depends on the reliability of the absolute magnitude calibration and on whether there are any differences among various clusters which can introduce systematic errors. These questions are being investigated and a full discussion is deferred until the data for more clusters with Cepheid members are analyzed.

The author is grateful to J. Barnes and D. Hayes for help in using the three-channel, the Mark I, and the Mark II photometers at Kitt Peak. This work was supported by the National Science Foundation under Grant No. NSF AST 77-17520. Some of the equipment used in this work was purchased with funds provided by a Cottrell Research Grant from the Research Corporation.

REFERENCES

Ampel, R. (1964). Acta Astron. **14,** 52.
Becker, W., and Fenkart, R. (1971). Astron. Astrophys. Suppl. **4,** 241.
Claria, J. J. (1974). *Elementos de Fotometria Estelan* (Instituto Venezolanode Astronomia, Merida, Venezuela).
Cogan, B. C. (1978). Astrophys. J. **221,** 635.
Crawford, D. L. (1978). Astron. J. **83,** 48.
Crawford, D. L., and Barnes, J. V. (1970). Astron. J. **75,** 978.
Crawford, D. L., and Barnes J. V. (1974). Astron. J. **79,** 687.
Crawford, D. L., Glaspey, J. W., and Perry, C. L. (1970). Astron. J. **75,** 822.
Crawford, D. L., and Mander, J. (1966). Astron. J. **71,** 114.
Crawford, D. L., and Perry, C. L. (1976). Astron. J. **81,** 419.
de Vaucouleurs, G. (1978). Astrophys. J. **223,** 351.
Eggen, O. J. (1980). Astrophys. J. **238,** 919.
Kraft, R. P. (1958). Astrophys. J. **128,** 161.
Kraft, R. P. (1961). Astrophys. J. **134,** 616.
Martin, W. L., Warren, P. R., and Feast, M. W. (1979). Mon. Not. R. Astron. Soc. **188,** 139.
Mavridis, L. N. (1959). Astrophys. J. **130,** 626.
Muzzio, J. C. (1978). Astron. J. **83,** 1643.
Reddish, V. C. (1961). Mon. Not. R. Astron. Soc. **123,** 27.
Sahade, J., and Davila, F. B. (1963). Ann. Astrophys. **26,** 153.
Sandage, A. (1958). Astrophys. J. **128,** 150.
Sandage, A., and Tammann, G. A. (1969). Astrophys. J. **151,** 683.
Schmidt, E. G. (1978). Publ. Astron. Soc. Pac. **90,** 157.
Schmidt, E. G. (1980a). Astron. J. **85,** 158.
Schmidt, E. G. (1980b). Astron. J. **85,** 695.
Schmidt, E. G., and Taylor, D. J. (1979). Astron. J. **84,** 1193.
Smak, J. (1966). Acta Astron. **16,** 11.
van den Bergh, S. (1976). "Decalages vers le rouge et expansion de l'univers," in *Evolution des Galaxies et ses Implications Cosmologiques,* IAU Colloquium No. 37, Paris, September 1976, edited by C. Balkowski and B. E. Westerlund (Edition du Centre National de la Recherche Scientifique, Paris), p. 13.