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UBVRI PHOTOELECTRIC PHOTOMETRY OF THE OPEN CLUSTER NGC 7790[1]

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RESUMEN

Reportamos la fotometría fotoeléctrica *UBVRI* de veinticuatro estrellas más brillantes que V $\sim$ 13.5 mag en el campo del cúmulo galáctico NGC 7790. Este cúmulo contiene a las cefeidas clásicas CE Cas a, CE Cas b y CF Cas.

Los valores del módulo de distancia y del enrojecimiento encontrados por varios autores, presentan grandes diferencias. Hemos estimado el enrojecimiento $E(B-V) = 0.59 \pm 0.05$. Puesto que no observamos estrellas más débiles que V $\sim$ 13.5 mag en la secuencia principal, no estimamos el módulo de distancia. Sin embargo, encontramos que el módulo de distancia $(V - M_V)_0 = 12.3 \pm 0.2$ de Pedreros, Madore and Freedman (1984) produce el mejor acuerdo entre las M_V's para las cefeidas y la predicción de tres calibraciones de la relación P-L-C.

ABSTRACT

UBVRI photoelectric photometry is reported for twenty-four stars brighter than V $\sim$ 13.5 mag in the field of the galactic cluster NGC 7790, which contains the classical cepheids CE Cas a, CE Cas b and CF Cas.

Discrepancies for the distance modulus and reddening found in the literature are discussed; we estimated $E(B-V) = 0.59 \pm 0.05$. As we only reached V $\sim$ 13.5 mag on the main sequence, we were not able to estimate the distance modulus, however we found that M_V's for the Cepheids are in good agreement with the predictions from three independent P-L-C relation calibrations if $(V - M_V)_0 = 12.3 \pm 0.2$ from Pedreros, Madore and Freedman (1984) is adopted.

Key words: **CLUSTERS-OPEN – PHOTOMETRY**

I. INTRODUCTION

The galactic cluster NGC 7790 has attracted the attention of several researchers in the past; mainly because it contains three classical cepheids: CF Cas, CE Cas a and CE Cas b, the latter two forming a physical system, separated by 2.5 arcseconds. These three Cepheids have been used in several works to calibrate the galactic period-luminosity (P-L) relationship (e.g., Sandage and Tammann 1969; Schmidt 1984). Smak (1966) and Sandage and Tammann (1969) undertook the difficult task of measuring the individual light curves of CE Cas a and CE Cas b. The first photometric study of the cluster was published by Sandage (1958), who reported *UBV* measurements for 33 stars in the field of the cluster. These 33 stars have served as calibrators for photographic work (Pedreros *et al.* 1984). Sandage found $(V-M_V)_0 = 12.8 \pm 0.15$ and $E(B-V) = 0.52 \pm 0.04$ for the true distance modulus and reddening, respectively. More recently Schmidt (1981) observed sixteen stars of NGC 7790 in the *uvby* Hβ system and reported $(V - M_V)_0 = 11.98 \pm 0.45$ and $E(B-V) = 0.54 \pm 0.03$. From photographic work, Pedreros *et al.* (1984) reported $(V - M_V)_0 = 12.3 \pm 0.2$ and $E(B-V) = 0.64 \pm 0.05$. The discrepancies for the distance modulus and reddening reported by different authors are larger than those which would be desired for such an important cluster. These discrepancies affect the estimated luminosities of the Cepheids and therefore the corresponding P-L relation calibration. Such discrepancies have already been noted by Pedreros *et al.* (1984), who suggest that systematic errors might exist in the original photoelectric photometry.

Considering the importance of the cluster, the different values of the distance modulus and reddening and the fact that *RI* photometry of the cluster has never been

1. Based on observations collected at the Observatorio Astronómico Nacional of San Pedro Mártir, B.C., México.

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TABLE 1

STARS OBSERVED IN NGC 7790

Star	V	$(B-V)$	$(U-B)$	$(V-R)$	$(V-I)$	n
A	11.07	0.33	−0.72	0.037	0.18	4
B	12.29	0.38	−0.10	0.17	0.48	3
C	12.54	0.55	0.38	0.26	0.23	4
D	12.83	0.47	0.35	0.14	0.57	3
E	12.80	0.41	−0.05	0.09	0.25	3
F	12.66	1.75	1.03	1.38	2.75	1
I	13.11	1.31	0.75	0.71	1.37	2
J	13.25	0.50	0.38	0.27	0.58	1
M	13.37	0.37	−0.10	0.04	0.9	3
O	13.70	0.39	−0.04	0.38	0.60	2
Q	13.71	0.55	−0.21	0.33	0.68	1
R	14.08	0.44	0.08	0.30	0.63	1
V	14.51	0.49	0.08	0.46	1.01	3
X	14.30	0.58	0.02	0.14	1.01	2
Z	14.76	0.41	0.16	0.22	...	2
b	15.25	0.50	0.25	0.17	0.86	2
16	15.48	0.62	...	0.60	1.01	1
36	13.71	0.43	−0.01	0.36	1.19	2
52	13.00	0.45	−0.01	0.25	0.74	1
55	13.04	0.46	−0.02	0.21	0.80	1
62	13.23	0.50	0.00	0.37	0.36	1
87	13.90	0.39	−0.24	0.38	1.10	1
95	12.46	0.42	−0.25	0.25	0.52	1
CF Cas	11.14	1.30	0.86	0.71	1.43	3

undertaken, it was decided to perform *UBVRI* (Kron-Cousins) photometry on a group of stars in NGC 7790.

II. OBSERVATIONS AND REDUCTIONS

The observations were carried out using a pulse-counting photometer and an S20 photomultiplier coupled with the 1.5-m telescope at the Observatory at San Pedro Mártir, México during the nights of September 13 to 24 1985. The five filters used were those of the Kron-Cousins System *UBVRI*.

Twenty-four stars in the field of NGC 7790 were observed and reduced to the Kron-Cousins standard system using the Harris, FitzGerald and Reed (1981) reduction method. One of the advantages of this method is the flexibility it lends while observing, since it does not require the observation of extinction stars as such, due to the fact that the extinction information and the transformation to the standard system are both extracted from the same set of standard stars.

A total of 26 standard stars were observed during the season and were used to compute the transformation coefficients. These standard stars were selected from the work by Landolt (1983) within the ranges of −0.05 to 1.50 in $(B-V)$ and 9.4 to 12.0 in V.

One observation consisted of three to five ten-second integrations on each filter on the star and the near background. A diaphragm of 20-arcseconds was generally used, although on occasions, a 10-arcsecond diaphragm was needed in the more crowded regions of the cluster. Special attention was given to avoid the presence of other stars in the diaphragm. At least two independent observations were done of standard stars and the transformation coefficients for the season were computed from the entire set of standard stars.

The magnitudes and colors in the Kron-Cousins system for the twenty-four stars observed in NGC 7790 are listed in Table 1, where the star identifications are those of Sandage (1958). The number of independent observations for each of the stars is given in column seven.

The estimated uncertainties for a single observation are 0.035, 0.05, 0.029, 0.040 and 0.050 mag for V, $(U-B)$, $(B-V)$, $(V-R)$ and $(V-I)$ respectively. A comparison of our photoelectric photometry with that of Sandage (1958) was carried out for 16 stars in common. The mean differences (Sandage −this work) are $\Delta V = -0.008$, $\Delta(U-B) = -0.042$, $\Delta(B-V) = -0.020$. The differences with respect to photographic photometry of Pedreros *et al.* (1984) for 23 stars in common are (Pedreros *et al.* −this work) $\Delta V = -0.016$, $\Delta(U-B) = -0.001$ and $\Delta(B-V) = -0.001$.

In addition to the above, three observations of the Cepheid CF Cas were made and reduced in the same manner as the other cluster stars. The results are listed in Table 2. Figure 1 shows the agreement of these observations with the light curves reported by Sandage (1958).

TABLE 2

UBVRI OBSERVATIONS FOR CF CAS

HJD (2446000+)	V	$U-B$	$B-V$	$V-R$	$V-I$	φ[a]
321.895	11.317	0.932	1.331	...	1.507	0.165
324.761	11.030	0.853	1.216	0.678	1.416	0.753
330.207	11.080	0.793	1.361	0.774	...	0.870

a. Phase calculated with the ephemerides HJD = 2435668.931 + 4.87 φ from Sandage (1958).

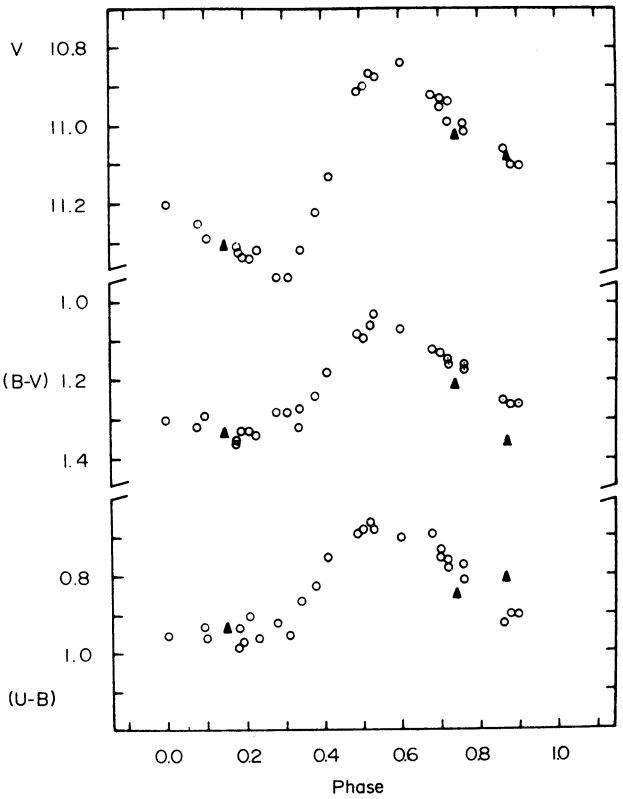

Fig. 1. Light and color curves for the cepheid CF Cas from Sandage (1958) (circles). Our three observations of the cepheid are represented by triangles.

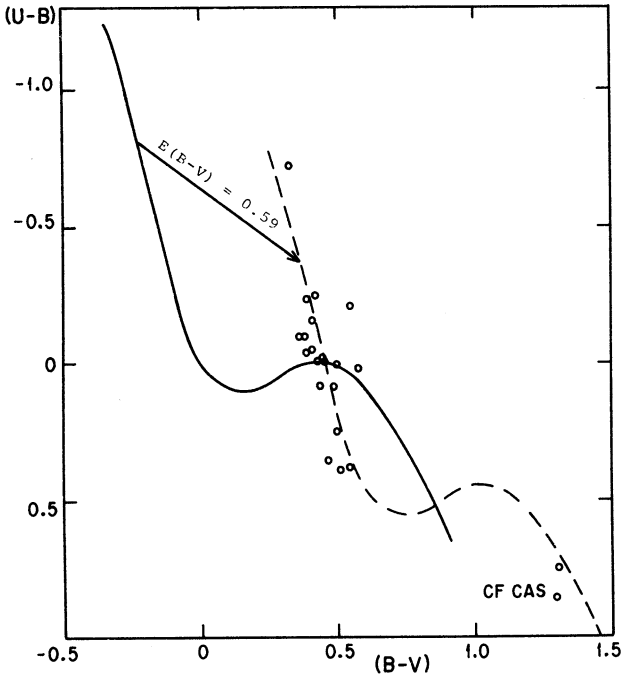

Fig. 2. Color-color diagram for the stars in NGC 7790. The continuous line represents the adopted main sequence. Broken line is the main sequence shifted by $E(B-V) = 0.59$. The position of the cepheid CF Cas in the diagram is shown.

III. REDDENING AND DISTANCE

a) *Reddening*

Color excesses $E(B-V)$ were individually calculated for each star by tracing each one back to the main sequence along its corresponding reddening line on the $(U-B)-(B-V)$ plane. The main sequence was adopted from Pedreros *et al.* (1984; Table 4.1). The adopted value for the color excess ratio was $E(U-B)/E(B-V) = 0.75$. The total-to-selective absorption ratio R_V was computed from the relationships given by Buser (1978), who derived expressions for this parameter as a function of the intrinsic color and the total reddening of a given star. Figure 2 shows the color-color diagram for the observed stars in the field of NGC 7790; the adopted main sequence is shown as a continuous line. The color excesses $E(V-R)$ and $E(V-I)$ in the Kron-Cousins system were calculated from the expressions:

$$E(V-R)/E(B-V) = E2 + E3\ E(B-V)$$

$$E(V-I)/E(B-V) = E4 + E5\ E(B-V)$$

with the parameters E2, E3, E4 and E5 given by Grieve (1983);

$$E2 = 0.6316 + 0.0713(B-V)_0$$

$$E3 = 0.0362 + 0.0078(B-V)_0$$

$$E4 = 1.3475 + 0.0806(B-V)_0$$

$$E5 = 0.0133 - 0.0010(B-V)_0.$$

The mean values of the extinction $A_V = R_V\ E(B-V)$ and the color excesses calculated as described above from 22 stars, including the Cepheid CF Cas, are listed in Table 3. The stars F and 16 were not considered and will be discussed below. For the sake of comparison, we searched for spectral types of the cluster stars. We found them for the stars A (B2 III-IV), D (B9 III), E (B5 IV), O (B9 IV) and 95 (B5, IV) (Kraft 1958). Using the spectral type – intrinsic color relations of Schmidt-Kaler (1982) we found $E(B-V) = 0.56 \pm 0.04$ in good agreement with the value found in Table 3. Transforming

TABLE 3

MEAN EXTINCTION AND COLOR EXCESSES OF NGC 7790

A_V	$E(U-B)$	$E(B-V)$	$E(V-R)$	$E(V-I)$
1.82	0.45	0.59	0.38	0.78
± 0.06	± 0.06	± 0.05	± 0.04	± 0.06

$E(V-R)$ and $E(V-I)$ in Table 3 from the Kron-Cousins system to the Johnson system (Fernie 1983), we found the ratios $E(V-R)/E(B-V) = 0.88$ and $E(V-I)/E(B-V) = 1.68$, in good agreement with the averages 0.83 and 1.59 respectively for the Perseus and Cepheus regions (Johnson 1966).

The mean value of the color excess $E(B-V) = 0.59 \pm 0.05$ in Table 3 can be compared with 0.52 ± 0.04 (Sandage 1958), 0.54 ± 0.03 (Schmidt 1981) and 0.64 ± 0.05 (Pedreros *et al.* 1984), i.e., we favor neither the low nor the high value of $E(B-V)$ as our value falls in between. We have used the values in Table 3 to de-redden the visual magnitude and the colors of each observed star in the field of NGC 7790. No evidence of differential reddening was found, in agreement with the results of Sandage (1958) and Pedreros *et al.* (1984).

The stars 16 and F were not considered in computing the mean values in Table 3 because for star 16 we do not have $(U-B)$ color while the position of star F in the color-color diagram of Figure 2 is rather anomalous (it does not appear in the diagram). The anomalous position of star F in the color-color diagram could be explained if it is a field star which is not physically connected to the cluster. The peculiarity of the F star has been noted by previous authors. It has been suggested that star F is an M giant (Mavridis 1959) and also that it might be a foreground dwarf (Schmidt 1981). The differences between our photometry of star F and that of Sandage (1958) are very large (Sandage –this work); $\Delta V = 0.16$ and $\Delta(B-V) = 0.23$; while relative to Pedreros *et al.* (1984) the differences are (Pedreros *et al.* –this work) $\Delta V = 0.01$ and $\Delta(B-V) = 0.45$. This indicates similar discrepancies between Pedreros *et al.* and Sandage. Unfortunately, we only have one measurement of this star. Clearly star F requires more observations to determine its photometric values, although intrinsic variations might also be present.

b) *Distance Modulus*

An attempt was made to apply the main sequence fitting method to estimate the distance modulus for the cluster. The calibrated main sequence adopted on the $V_0 - (B-V)_0$ plane was that of Pedreros *et al.* (1984). The color magnitude diagram for the observed stars in the field of NGC 7790 was constructed with the dereddened magnitudes and colors using the color excess found in the previous subsection. However, the main sequence of NGC 7790 for $V < 13.5$ mag on the color-magnitude diagram is too steep to give a definitive value for the true distance modulus.

In Figure 3 we have plotted the position of the adopted main sequence corresponding to the true distance moduli of Sandage (1958), Schmidt (1981) and Pedreros *et al.* (1984) on the observed color-magnitude diagram; the position of the cluster member Cepheid CF Cas is shown. Given the dispersion in Figure 3 and the fact that we only reached $V \sim 13.5$ mag, we do not deem it advisable to assign any preference to any of the three fits from this graph. We shall however, in the following section, favor one distance modulus based on the agreement of the three Cepheids' absolute magnitudes with the predictions of the Period-Luminosity-Color relationship. CCD photometry of the

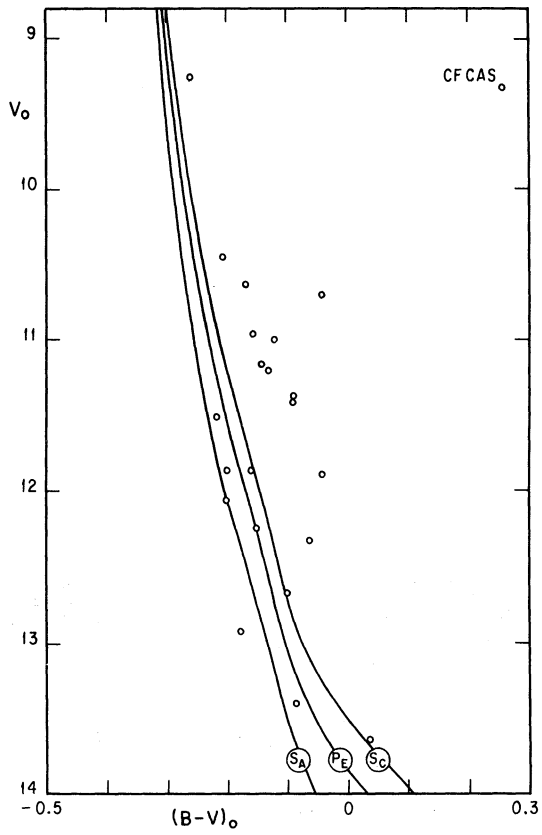

Fig. 3. Color-magnitude diagram for the dereddened stars in NGC 7790. The continuous lines represent the adopted main sequences corresponding to the distance modulus of Sandage (1958) (S_A). Schmidt (1981) (S_C) and Pedreros *et al.* (1984) (P_E).

TABLE 4

TRUE DISTANCE MODULUS AND REDDENING OF NGC 7790 FROM DIFFERENT AUTHORS

Author	$(V-M_V)_0$	$E(B-V)$	Photometric technique
Sandage (1958)	12.80 ± 0.15	0.52 ± 0.04	Photoelectric (*UBV*)
Schmidt (1981)	11.98 ± 0.45	0.54 ± 0.03	Photoelectric (*uvby*)
Pedreros *et al.* (1984)	12.30 ± 0.20	0.64 ± 0.05	Photographic (*UBV*)

TABLE 5

ABSOLUTE MAGNITUDE FOR THE THREE CEPHEIDS IN NGC 7790 CALCULATED FROM THE COLOR EXCESS 0.59 ± 0.05 AND THE ADOPTED DISTANCE MODULUS 12.3 ± 0.20 AND THREE P-L-C RELATIONS[a]

Cepheid	P[b] (days)	This work M_V	Sandage and Tammann (1969) P-L-C	Caldwell (1983) P-L-C	Schmidt (1984) P-L-C	V[c]
CE Cas a	5.14	−3.33	−3.43 (0.10)	−3.48 (0.15)	−3.34 (0.01)	10.92
CE Cas b	4.47	−3.26	−3.42 (0.16)	−3.31 (0.05)	−3.33 (0.07)	10.99
CF Cas	4.87	−3.13	−3.32 (0.19)	−3.42 (0.29)	−3.22 (0.09)	11.12

a. The values between parentheses are the differences column 3 − column 4, 5 or 6, respectively.
b. Periods taken from Sandage and Tammann (1969).
c. Visual magnitude taken from Sandage and Tammann (1969).

cluster should, however, very easily reach V ∿ 16 mag and hence help discriminate between the three distance moduli.

IV. DISCUSSION

The results obtained by other authors for the reddening and the true distance modulus of the open cluster NGC 7790 are summarized in Table 4. The dispersion of the values for the true distance moduli found by Sandage (1958) (12.8 ± 0.15), Schmidt (1981) (11.98 ± 0.20) and Pedreros *et al.* (12.30 ± 0.20) is rather high. For the color excess $E(B-V)$, there is also a discrepancy between the values of Sandage (1958) (0.52 ± 0.04) and Schmidt (1981) (0.54 ± 0.08) and that of Pedreros *et al.* (1984) (0.64 ± 0.05). Our result $E(B-V) = 0.59 \pm 0.05$, however, falls halfway between the two results and hence does not support either case.

For the purpose of this discussion, let us adopt the modulus $(V - M_V)_0 = 12.30 \pm 0.20$ from Pedreros *et al.* (1984). The absolute magnitudes of the cluster Cepheids CE Cas a, CE Cas b and CF Cas, can be derived from our value of the color excess (0.59 ± 0.05) and the adopted true distance modulus. The results reduced to mean luminosity are listed in column 3 of Table 5. We have made a comparison of these results for M_V for the Cepheids and those predicted by three P-L-C relationship calibrations using the periods of Sandage and Tammann (1969). These results are listed in Table 5. The differences are in general less than 0.2 mag. Considering that the dispersion of the P-L-C relations given by these authors is between 0.1 and 0.2 mag, the agreement is good.

In Table 6 we have compared the value of M_V obtained from the distance moduli and from P-L-C relation calibrations in the following way: first the distance modulus and reddening determination from Sandage (1958) and Schmidt (1981) respectively (column 2) were used and then the P-L-C relationship calibrations of Sandage and Tammann (1969) and Schmidt (1984) (column 3) were applied. The differences encountered

TABLE 6

M_V FOR THE CLUSTER CEPHEIDS, CALCULATED FROM THE DISTANCE MODULUS AND REDDENING, AND FROM P-L-C RELATIONS OF SELECTED AUTHORS

Cepheid	M_V (Modulus)	M_V (P-L-C)	ΔM_V
	Sandage (1958)	Sandage and Tammann (1969)	
CE Cas a	−3.440	−3.180	0.26
CE Cas b	−3.370	−3.170	0.20
CF Cas	−3.240	−3.075	0.16
	Schmidt (1981)	Schmidt (1984)	
CE Cas a	−2.695	−3 143	−0.45
CE Cas b	−2.625	−3.129	−0.50
CF Cas	−2.495	−3.027	−0.53

(column 4) are large and show the inconsistency of these distance moduli and reddening determinations with the respective calibrations of the P-L-C relation. We conclude that better agreement for the luminosities of three Cepheids in NGC 7790 with three independent calibrations of the P-L-C relation is found if a true distance modulus $(V - M_V)_0 = 12.3 \pm 0.20$ (Pedreros *et al.* 1984) is used; these results appear in Table 5. CCD photometry of NGC 7790, should be able to provide a better and highly desired estimate of the cluster distance, as it reaches lower into the main sequence.

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