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THE NEARBY OPEN CLUSTER COLLINDER 140

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ABSTRACT

Photoelectric *UBV* data of 77 stars in the region of Cr 140, as well as β indices of 31 stars and DDO data of one red star, are reported and discussed. In addition, MK spectral types of the four brightest B stars in the region are also given. These data, together with existing radial velocity and proper motion measurements, show that Cr 140 is a real, dynamically stable, open cluster. Twenty-seven stars, including a red giant, appear to be cluster members. The average color excess, due to interstellar reddening, is $E(B-V)=0.05$ and the true distance modulus was found to be $V_0-M_v=7.78$. A nuclear age of 2.1×10^7 yr and a lower limit to the contraction age of 2.3×10^7 yr were also obtained for the cluster. Assuming that the metal content of the red giant member is representative of that of the whole cluster, then Cr 140 is slightly metal weak compared to the Hyades.

I. INTRODUCTION

Collinder 140 is presumably an open cluster located at $\alpha = 7^h 22^m$, $\delta = -31°56'$ (1950) ($l = 245\overset{\circ}{.}0$, $b = -8\overset{\circ}{.}0$). The cluster, illustrated in Fig. 1, does not appear on the sky as an outstanding group of stars, as happens with most of the well-known clusters. It is rather a poorly concentrated group of moderately bright stars lying in the constellation of Canis Major; hence Ruprecht (1966) placed it as belonging to class III3p. Collinder (1931) reported the cluster as containing about 14 or 16 stars spread out over a field of 42 arcmin in the sky. The most recent reference is from Williams (1967a) who derived a distance of 360 pc and an age of 2.3×10^7 yr from the *UBV* data of 26 stars in the cluster field. The distance found by Williams is considerably smaller than that quoted by Collinder (2650 pc).

In the present study, photoelectric *UBV* data of 77 stars in the cluster region are reported and discussed. In addition, Hβ photometry of 31 stars, DDO data of one red star, and MK spectral types of the four brightest B stars are also given. It is our purpose to reexamine the region, to verify the physical reality of Cr 140, and to determine the basic cluster parameters, particularly its distance, improving our knowledge of it.

II. PHOTOMETRIC AND SPECTROSCOPIC OBSERVATIONS

The *UBV* measurements were carried out at the Bosque Alegre Station of the National University of Cordoba (Argentina) and Cerro Tololo Inter-American Observatory (CTIO, Chile) during 1973 and 1975, respectively. The observations were made using the CTIO 41- and 61-cm telescopes equipped with pulse-counting refrigerated photometers, and with the Bosque Alegre 150-cm telescope provided with a conventional design photometer. The stars were measured using diaphragm apertures of 28, 20, and 15 arcsec in the three telescopes, respectively. Mean coefficients were employed in both observatories to correct for atmospheric extinction and nightly observations of about 12 E-region primary standards (Cousins 1972) were used to transform to the *UBV* system. The results of the *UBV* photometry are presented in Table I, where the column labeled n_1 refers to the number of nights each star was observed. An asterisk after the star number refers to a note at the end of Table I. Three stars were found to be variables (Clariá 1976a) and their mean values are given in Table I. Table II summarizes the external and internal mean errors of the *UBV* photometry for the different telescopes employed. As shown, there exists a small increase of the internal mean errors with the V magnitude. Besides this, it is apparently contradictory that the internal and external errors obtained with the 150-cm telescope are higher than those obtained with both the 61- and 41-cm telescopes. This contradiction is only apparent and disappears when taking into account the remarkable differences between the local sky conditions.

Twenty-six of the stars measured in the present study have been observed earlier in the *UBV* system by Williams (1967a). Figure 2 shows the differences (Williams minus present study) ΔV, $\Delta(B-V)$, and $\Delta(U-B)$, as a function of the observed colors. Omitting the $(U-B)$ values of stars 8 and 35 for which the two sets of observations do not agree, the average differences are $\Delta V = -0.01 \pm 0.02$, $\Delta(B-V) = -0.02 \pm 0.02$, and $\Delta(U-B) = 0.00 \pm 0.02$. As there is no evidence of noticeable systematic discrepancies, the agreement can be considered good. Williams observed stars 8 and 35 only once and twice, respectively, while we observed them during four and six nights using different telescopes. Therefore,

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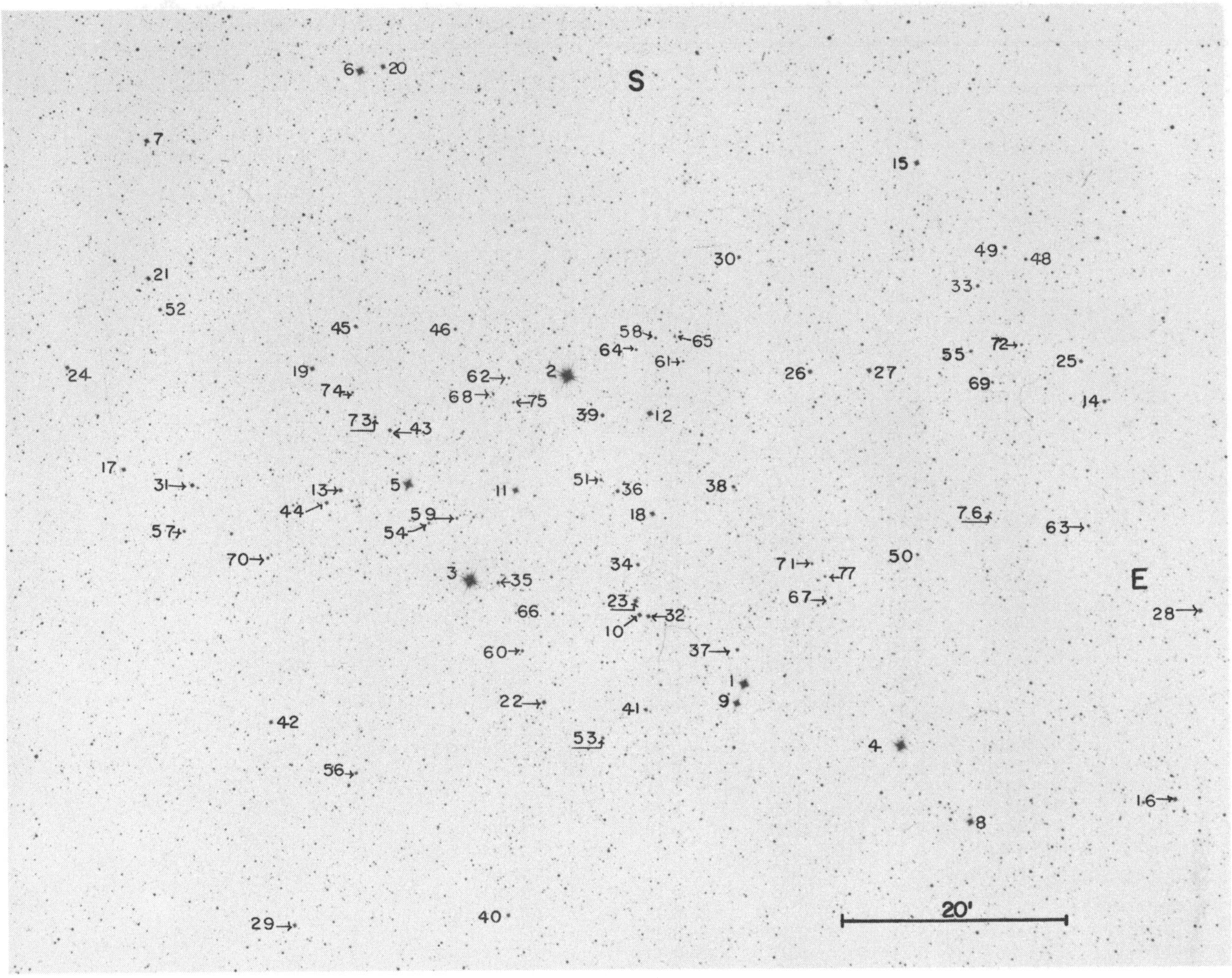

FIG. 1. The region of Cr 140 reproduced from Kodak IIa-O plate of 15-min exposure time taken with the Curtis–Schmidt telescope at CTIO. The stars listed in Table I are indicated.

the $(U - B)$ values for both stars here reported should be considered more reliable than the previous ones.

In addition, Hβ photometry was also obtained for 31 stars in the cluster area, using the 61-cm telescope at CTIO. These observations were tied into the standard system defined by Crawford and Mander (1966). The external and internal mean errors of a single Hβ observation are 0.005 and 0.009, respectively. The β indices are given in Table I along with the number n_2 of individual observations per star.

Slit spectra were obtained of the four brightest B stars in the cluster region. The spectra were taken on Kodak IIa-O plates using the Cassegrain spectrograph (42 Å mm^{-1} at Hγ) on the Bosque Alegre 150-cm telescope. In addition, a set of MK standards was taken under the same conditions with the same equipment. They were picked out from a list furnished privately by Dr. Kennan. Unfortunately, the spectrograph has been found to be erratic for obtaining radial velocities (Buscombe 1965; Milone 1966; Clariá 1970). This seems to be caused by loss of collimation of the comparison arc source. Consequently, no attempt was made for measuring this parameter and thus the spectra were used only for classification purposes. The last column of Table I lists the spectral types taken from the HD catalog (given in parentheses) or the MK spectral types taken from (1) Harris (1976), (2) Buscombe (1969), (3) Hiltner *et al.* (1969), and (4) the present study.

III. PROPER MOTIONS AND RADIAL VELOCITIES

Twenty-six stars observed in the *UBV* system have their proper motions registered in the *Smithsonian Astrophysical Observatory Catalog* (SAO). Reliability of these data is only relative as their errors are quite large. Although the cluster does not present a large, characteristic proper motion which would allow us to discriminate between members and nonmember background stars, the available proper motions enable us to reject a few foreground stars.

TABLE I. Photometric and spectroscopic data of stars in the region of Cr 140. (An asterisk following a digit indicates that the next decimal place would be a 5.)

No.	HD/CD	V	$B-V$	$U-B$	n_1	β	n_2	Sp. type
1[a]	58535	5.36	1.07	0.89	18			G8 II (1)
2	58286	5.38	−0.16	−0.71	18	2.643	3	B3 III–IV (4), B2 V (3)
3[b]	58155	5.41	−0.15	−0.72	5	2.555	3	B5 IIIn,e (4), B4 V_{np} (3)
4	58766	6.31	−0.16	−0.70	6	2.654	3	B3 V (4), B2 V (3)
5	58063	6.82	−0.16	−0.69	5	2.697	3	B5 V (2), B4 V (4)
6	57945	7.12	−0.04	−0.14	4	2.852	3	(A0)
7	57637	7.36	1.32	1.48	2			(K0)
8	58888	7.49	0.02	0.02*	6	2.867	2	(A2)
9*[c]	58534	7.59*	−0.09*	−0.48	8	2.760	2	(A0)
10	58394	7.89	1.45	1.85*	2			K4 III (1)
11	58216	8.26	−0.05	−0.40	3	2.788	3	(B8)
12	58398	8.33	0.01	−0.04	4	2.898	3	(B8)
13	57962	8.38	1.30	1.56*	3			K2 III (1)
14	59052	8.42	1.32	1.45	2			(K0)
15	58767	8.59	−0.06	−0.30	3	2.830	3	(A0)
16	59166	8.68	0.40	0.13	2			(F2)
17	57659	8.70	0.70	0.50	2			(F5)
18	58397	8.72	0.01	−0.15	4	2.867	3	(B9)
19	57912	8.83	−0.02	−0.21	2	2.890	2	(A0)
20	57963	8.89	0.12	0.10	2	2.928	2	(B9)
21[d]	57960	8.94	0.53	0.02	3			(F8)
22	58258	8.97	0.42	−0.03	3			(F2)
23	58395	8.99*	0.05	−0.02*	4	2.940	2	(B9)
24	57574	9.00	0.19	0.11	3	2.889	3	(A3)
25	−32° 4018	9.05	0.95	0.61	2			
26	58631	9.15	0.20	0.10	3			(A2)
27	58702	9.16	−0.13	−0.55	3	2.736	3	(B8)
28	59193	9.19	0.00	−0.14	1			(B9)
29	57943	9.28	0.14	0.11	2	2.868	2	(A2)
30	−32° 3976	9.31	0.90*	0.56	3			
31	57759	9.32	0.03	−0.04	2	2.929	2	(B9)
32	58396	9.34	0.02	−0.06	3	2.928	2	(A0)
33[e]	−32° 4008	9.37	1.01	0.80	2			
34	−31° 4466	9.38	0.90	0.61	3			
35	−32° 4443	9.47*	0.95	0.70	4			
36	−31° 4462	9.55	0.30	0.10	3	2.770	2	
37	−31° 4480	9.57	0.45	0.07	4	2.684	2	
38[f]	58513	9.57	0.22	0.11	2			(A5)
39	−31° 4460	9.59	0.15	0.11	3	2.887	2	
40	58233	9.61	0.13	0.09	2	2.892	2	(A0)
41	−31° 4470	9.65	0.52	0.00	2			
42	57867	9.71*	−0.07	−0.40	3	2.744	2	(A0)
43	−31° 4428	9.76	0.09	0.03	3	2.956	2	
44	57944	9.78	−0.02	−0.20	4	2.832	2	(A)
45	57991	9.83	0.10	0.05	2	2.930	2	(A)
46	−32° 3941	9.89	0.71	0.24	3			
47	−31° 4417		0.11	0.11	1			
48	−32° 4013	9.95	1.06*	0.91	2			
49	−32° 4011	10.00	0.01	−0.13	2	2.923	2	
50	−31° 4507	10.03	1.02	0.77	2			
51		10.09	1.25	1.10	4			
52	−32° 3913	10.12	0.21	0.12	2	2.882	2	
53	−31° 4461	10.15	0.17	0.09	2	2.890	2	
54	−31° 4432	10.24	1.48	1.67	1			
55	−32° 4007	10.25	1.24	1.10	2			
56	−31° 4426	10.26	0.22	0.14	4	2.881	2	
57	57945	10.44	0.12	0.15	2			
58	−32° 3964	10.46	1.04	0.83	2			
59	−31° 4435	10.62	0.86	0.50	2			
60	−31° 4448	10.70	0.11	0.10*	2			
61	−32° 3970	10.74	1.35	1.36	2			
62	−31° 4444	10.89	1.23	1.24	2			
63	−31° 4532	10.92	0.10	0.10	3			
64	−32° 3961	10.92*	0.55	0.08	2			
65	−32° 3968	10.95	1.60	1.92	2			
66	−31° 4452	10.97*	0.32	0.11	2			
67	−31° 4493	11.05	0.37*	0.09	3			
68	−31° 4442	11.10	0.88	0.46	2			
69	−31° 4520	11.12	0.36	0.06	1			
70	−31° 4409	11.14*	0.10	0.01	2			
71	−31° 4491	11.23	0.43	0.06	1			
72	−32° 4012	11.30	0.09	0.06*	3			
73		11.34	0.37	0.08	2			
74		11.41	0.12	0.09	1			

TABLE I (*continued*)

No.	HD/CD	V	$B-V$	$U-B$	n_1	β	n_2	Sp. type
75		11.48	0.64	0.08	2			
76	−31° 4519	11.62	0.08	0.02	2			
77		11.89	0.10	0.09	2			

Notes to Table I

[a] (1) Double star, ρ = 1.9 arcsec Δm = 5.5 (Jeffers *et al.* 1963); measured together. Eggen (1974) obtained *uvby* data for this star and considered it a class I cluster member.
[b] (3) H lines rather broad and diffuse; weak emission in Hβ.
[c] (9) Double star (Jeffers *et al.* 1963); measured together.
[d] (21) Double star (Jeffers *et al.* 1963); measured together.
[e] (33) Double star (Jeffers *et al.* 1963); measured together.
[f] (38) A companion has been detected at the telescope ($\rho \sim$ 3 arcsec).

Recently Harris (1976) obtained radial velocities of seven stars in the cluster region. In addition, Buscombe (1969) measured the radial velocity of HD 58063. These data are useful to obtain an approximate value of the cluster velocity as well as in excluding a few foreground stars. The available proper motions and radial velocities for Cr 140 are presented in Table III.

IV. ANALYSIS AND DISCUSSION OF THE DATA

a) The UBV,β Diagrams; Membership Criteria

The observed color–magnitude (C–M) diagrams resulting from the *UBV* photometry are presented in Figs. 3 and 4. Variable (v) and double stars (underlined) are indicated in the figures. Well-defined sequences are clearly seen in both diagrams which show that Cr 140 is really an open cluster. However, since the apparent members are spread out over a relatively large region in the sky, we must check if the space density of the group is sufficiently high, compared with the mean density of the galactic field, in order for these stars to be gravitationally bound.

Figures 5 and 6 are the color–color (C–C) diagrams for all the stars observed in the *UBV* system. For comparison, the unreddened sequences of Schmidt-Kaler (1965) for luminosity classes III and V (solid lines), as well as the reddening line with gradient 0.70, are also indicated. The cluster main sequence is now seen running parallel to the unreddened sequence in Fig. 5.

To discriminate between members and nonmembers of Cr 140, the following criteria have been used:

(1) The location of the star in the two C–M diagrams must correspond to the same evolutionary stage in the cluster. Since many effects contribute to the scatter in the C–M diagrams, a star located within 0.5 mag of the main sequence is considered to belong to it. With this criterion possible subdwarfs belonging to the cluster will be excluded. However, the incidence of subdwarfs in open clusters is extremely low, whereby this does not represent a serious restriction.

(2) Since the β index is a sensitive indicator of luminosity for main-sequence stars earlier than about A2, the

TABLE II. Mean errors of the *UBV* photometry.

	V	$B-V$	$U-B$
	External mean errors		
41 cm	0.011	0.007	0.013
61 cm	0.009	0.007	0.011
150 cm	0.014	0.009	0.014
	Internal mean errors		
41 cm			
V < 9.0	0.010	0.007	0.009
9.0 ≤ V < 11.0	0.015	0.013	0.014
61 cm			
V < 10.0	0.008	0.009	0.011
10.0 ≤ V < 11.0	0.010	0.012	0.013
11.0 ≤ V	0.014	0.013	0.016
150 cm			
V < 9.0	0.013	0.010	0.012
9.0 ≤ V < 11.0	0.016	0.013	0.016
11.0 ≤ V	0.019	0.017	0.023

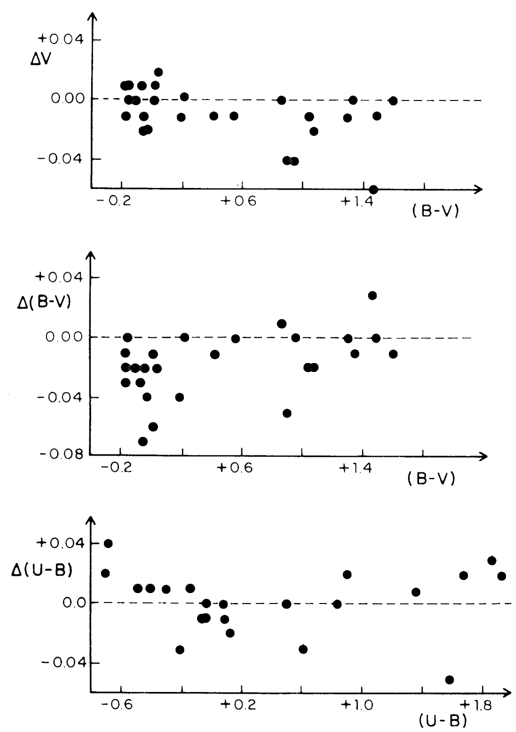

FIG. 2. Differences (Williams minus present study) for V, $(B-V)$, and $(U-B)$ plotted against the observed colors.

TABLE III. Existing proper motion and radial velocity data of stars in the cluster region.

No.	HD/CD	μ_α (0″.001)	μ_δ (0″.001)	ρ (km s^{-1})
1	58535	−30	+8	17.7
2	58286	−16	+2	11.0
3	58155	−22	+2	21.6
4	58766	−6	+5	10.0
5	58063	−4	+4	19.0
6	57945	0	+2	5.9
7	57637	−25	−6	
8	58888	−14	+1	
9	58534	−44	+3	
10	58394	−23	+8	111.0
11	58216	−30	−18	
12	58398	−5	+3	
13	57962	−53	+40	62.8
14	59052	+33	0	
15	58767	−56	−5	
16	59166	+6	+17	
17	57659	−30	−16	
18	58397	−20	−13	
19	57912	−35	−15	
20	57963	−14	−6	
22	58258	−35	−56	
24	57574	−36	−4	
26	58631	−27	−20	
31	57759	−3	−21	
36	−31° 4462	−68	−7	
38	58513	−18	−44	

β vs $(B-V)_0$ plot (Fig. 7) represents an unreddened H-R diagram for these stars. This criterion requires that the star position in Fig. 7 be consistent with its position in the two C–M diagrams, allowing for small differences due to accidental errors or differential reddening.

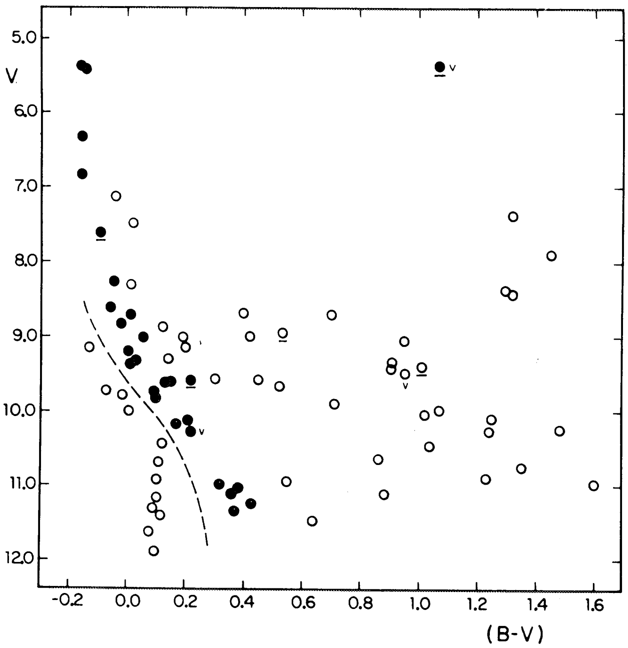

FIG. 3. The observed V vs $(B-V)$ diagram for stars in the region of Cr 140. Cluster members are represented by filled circles, the remaining stars by open circles. Variable (v) and double (underlined) stars are indicated. No corrections for duplicity have been made. Stars on the left of the dashed line are background field stars.

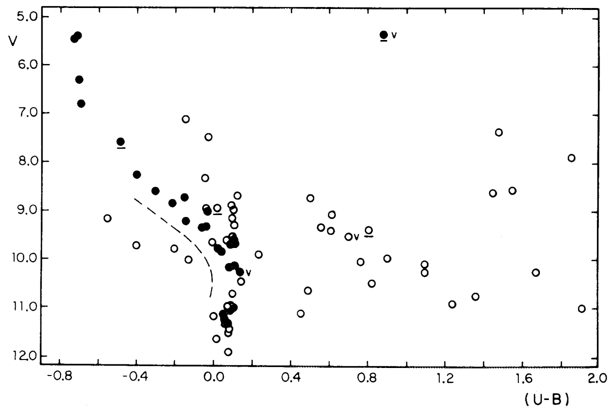

FIG. 4. The observed V vs $(U-B)$ diagram for stars in the region of Cr 140. Symbols are as in Fig. 3. No corrections for duplicity have been made.

(3) The third criterion is based on the existing proper motions and can be applied only to the stars of Table III. The μ_δ vs μ_α plot (Fig. 8) reveals an apparent concentration near $\mu_\alpha = -0\rlap{.}''024$, $\mu_\delta = -0\rlap{.}''008$. The circle represents a rough estimate of the limit beyond which proper motions are considered to be too large for membership, although, of course, many field stars undoubtedly fall within it. Therefore, we require, as a necessary (but not sufficient) condition for a star to be considered a member, that it lie within the circle.

The twenty-six stars that fulfill the above criteria have been represented by filled circles in Figs. 3–7. The probable membership of several red stars is discussed in Secs. V and VI.

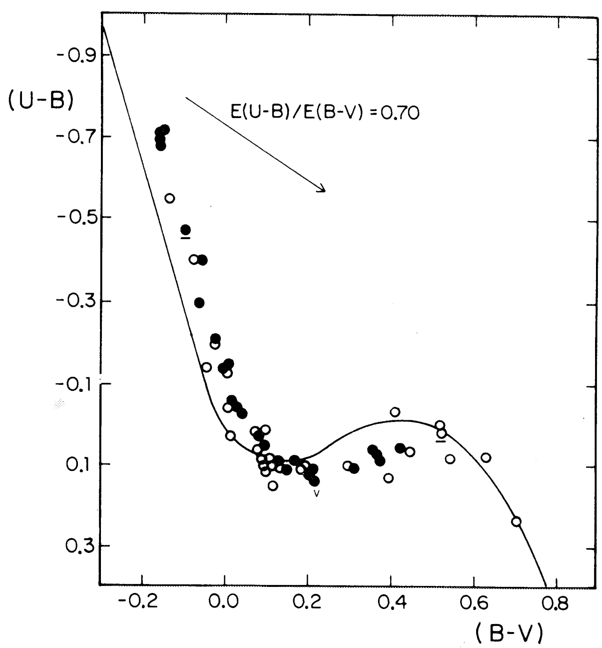

FIG. 5. The color–color diagram for stars in the region of Cr 140. The unreddened main sequence (solid line) of Schmidt-Kaler (1965) and the reddening line with gradient 0.70 are indicated. Symbols are as in Fig. 3.

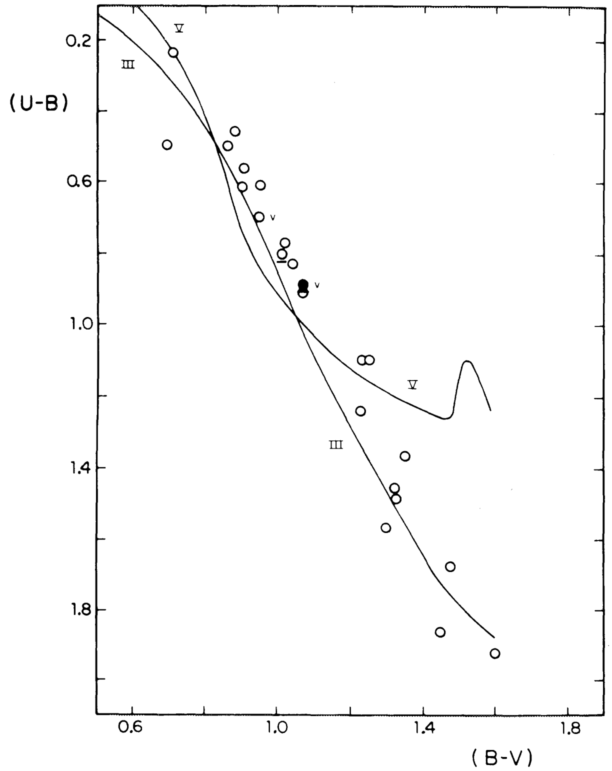

FIG. 6. The color–color diagram for the late-type stars observed in the region of Cr 140. The solid lines are the unreddened sequences of Schmidt–Kaler (1965) for luminosity classes III and V. Symbols are as in Fig. 3.

b) Interstellar Reddening

Figure 5 shows that the cluster members have nearly the same small reddening. From Clariá's (1973) Eqs. (1)–(3) one can derive the equations

$$E(B-V) = (B-V) - \frac{(U-B) - 0.70(B-V) - 0.05(B-V)^2}{3.012 - 0.05(B-V)}, \quad (1)$$

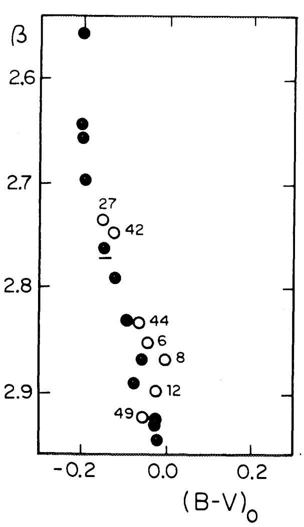

FIG. 7. The β vs $(B-V)_0$ plot for the observed stars with $(B-V) \leqslant 0.10$. Numbered open circles represent nonmembers from criterion 2 (see Sec. IV). Symbols are as in Fig. 3.

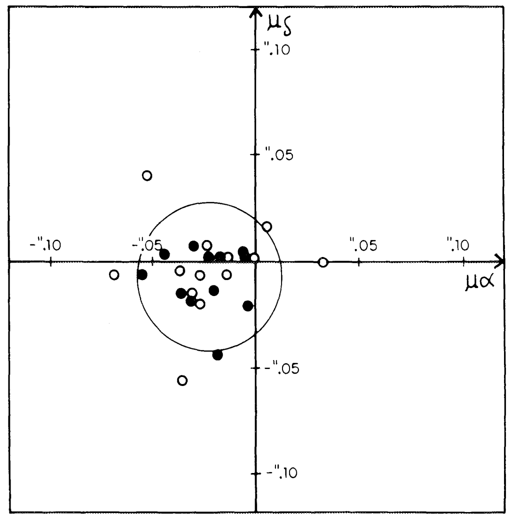

FIG. 8. A plot of the proper motions μ_δ vs μ_α. The circle is an estimate of the limit beyond which proper motions are likely too large for membership.

$$E(U-B) = 0.70E(B-V) + 0.05\,E^2(B-V), \quad (2)$$

from which the color excesses and intrinsic colors can be derived. These equations are strictly valid only for main-sequence stars earlier than about A2 but can also be used for objects as bright as class III without introducing appreciable errors. Assuming that the cluster members with $(B-V) \leqslant 0.10$ are earlier than A2, the average color excesses derived from Eqs. (1) and (2) are $E(B-V) = 0.05 \pm 0.01$ (s.d.) and $E(U-B) = 0.03 \pm 0.01$ (s.d.). Thus, the mean visual absorption amounts to $A_v = 0.15$, if the ratio $R = 3.0$ is accepted. The intrinsic colors for the members with $(B-V) > 0.10$ were determined adopting the above mean values for the cluster.

c) Absolute Magnitudes and Distance Modulus

The absolute magnitudes were determined in three different ways. A first estimate was made based on the intrinsic colors and Schmidt–Kaler's (1965) calibration, assuming the stars to be luminosity class V. This procedure was not applied to the blue giants HD 58286 and HD 58155. Second, for the stars where Hβ was measured the absolute magnitude was derived using Crawford's (1973) calibration. The β index of HD 58155 was not used to derive M_v, due to the emission detected in the Hβ line. Finally, for the B stars with available MK spectral types, Schmidt–Kaler's calibration of M_v as a function of spectral type was used. We have adopted for each star the average of the available estimates. The small mean difference $|M_v(UBV) - M_v(\beta)| = 0.2 \pm 0.2$ (s.d.) is not significant and therefore supports the conclusion that both the UBV and Hβ data yield consistent results. The derived quantities for all the stars with $(B$

TABLE IV. Derived quantities for all the observed stars with $(B - V) \leqslant 0.10$, as well as for cluster members with $(B - V) > 0.10$. (An asterisk denoted nonmembers.)

No.	$E(B - V)$[a]	M_V (adopted)	$V_0 - M_v$
2	0.04	−2.6	7.86
3	0.05	−2.2	7.46
4	0.04	−1.6	7.79
5	0.03	−1.1	7.83
6*	0.00	1.1	6.02
8*	0.02	1.4	6.03
9	0.04	0.0	7.48
11	0.07	0.3	7.75
12*	0.03	1.3	6.94
15	0.03	0.7	7.80
18	0.06	1.1	7.44
19	0.05	1.1	7.58
23	0.07	1.4	7.39
27*	0.02	−0.4	8.70
28	0.05	1.2	7.84
31	0.05	1.4	7.77
32	0.04	1.3	7.92
38	0.05	2.4	7.02
39	0.05	2.1	7.34
40	0.05	2.0	7.26
42*	0.05	0.1	9.47
43	0.05	1.8	7.81
44*	0.04	0.9	8.76
45	0.05	1.8	7.88
49*	0.06	1.2	8.62
52	0.05	2.3	7.67
53	0.05	2.2	7.80
56	0.05	2.3	7.81
66	0.05	2.8	8.03
67	0.05	3.1	7.80
69	0.05	3.0	7.97
70*	0.13	1.4	9.36
71	0.05	3.4	7.68
73	0.05	3.1	8.09
76*	0.09	1.5	9.85

[a] $E(B - V) = 0.05$ has been assumed for the cluster members with $(B - V) > 0.10$.

$- V) \leqslant 0.10$, as well as those for cluster members with $(B - V) > 0.10$, are presented in Table IV, whose columns are self-explanatory.

Omitting star 38, the average $\langle V_0 - M_v \rangle$ computed from the cluster members is 7.72 ± 0.22 (s.d.). In addition, fitting the cluster sequence to the zero-age main sequence (ZAMS) of Schmidt-Kaler (1965) in the two unreddened C-M diagrams [Figs. 9(a) and 9(b)] lead to $V_0 - M_v = 7.84$ and 7.88, respectively. Combining the three estimates, we obtain $\langle V_0 - M_v \rangle = 7.78$, equivalent to 365 pc, which has been adopted for the cluster. The ZAMS (continuous curve) and the absolute magnitude scale in Figs. 9(a) and 9(b), have been adjusted to the adopted cluster distance. Eggen (1974) obtained a somewhat larger value from *uvby*,β photometry of only four stars.

An estimate of the error in the distance determination can be obtained from the inaccuracies of the various quantities that enter in the distance calculation, using the classical equation for the propagation of errors. The variables that influence a $V_0 - M_v$ determination are the photoelectrically measured V and $(B - V)$ values of the star, the intrinsic color $(B - V)_0$, the absolute magnitude M_v that corresponds to the star, and the ratio of total to selective absorption for the region R. Thus, in our case the uncertainty of the distance modulus σ_μ can be written

$$\sigma_\mu = [\sigma_v^2 + 9.0\sigma_{B-V}^2 + 9.0\sigma^2{}_{(B-V)_0} + E^2(B - V)\sigma_R^2 + \sigma_M^2]^{1/2}, \quad (3)$$

where $R = 3.0$ has been assumed. The standard deviations of the photometry σ_v and σ_{B-V} were found to be about 0.01, while $\sigma(B - V)_0$ and σ_M were estimated as 0.015 and 0.16, respectively. Adopting $\sigma_R = 0.2$ (Sharpless 1963) and using the mean cluster reddening $E(B - V) = 0.05$ yields $\sigma_\mu = 0.17$. Therefore, the uncertainty in the distance estimate is found to be 29 pc.

Figure 10 illustrates the V_0 vs M_v (adopted) diagram for the cluster members. The continuous line corresponds to $V_0 = M_v = 7.78$, while the dashed lines represent shifts of 0.5 and 0.75 mag upward and downward, respectively, from the continuous line. One expects cluster members to define a linear sequence for the reasons given in a previous paper (Clariá 1976b). All of the stars that were considered to be cluster members define a linear sequence well within the allowed domain; that they form a physical group thus appears confirmed. It can be seen that the two double stars lie below the continuous line as expected.

d) *Age and Stability of the Cluster*

The two brightest stars classified as B3 III–IV and B5 IIIn,e, respectively, are both situated at about 1.5 magnitudes above the main sequence in Figs. 9(a) and 9(b), while the stars HD 58766 (B3 V) and HD 58063 (B4 V) represent the two brightest members on the main sequence. If we assume a chemical composition of $X = 0.70$, $Y = 0.27$ and adopt $(U - B)_0 = -0.75$ as the mean color of the two evolved stars, Kelsall and Strömgren's (1966) method yields a value of 2.1×10^7 yr for the time of evolution from the main sequence to their present position in the C-M diagrams. The cluster age in Sandage's (1957) scale derived from the turnoff point magnitude ($M_v \sim -1.2$) is somewhat greater.

Although there is no evidence of stars in the stage of gravitational contraction, a lower limit to the contraction age can be estimated from the expression given by Sandage (1958):

$$T_{cg} = 6.32 \times 10^7 \mathcal{M}/L\,R, \quad (4)$$

where $\mathcal{M}$, L, and R represent the mass, luminosity, and radius (all in solar units) of the lowest point on the main sequence. From Figs. 9(a) and 9(b) we adopt $M_v \sim +3.5$ for this point which, in turn, implies $\mathcal{M} = 1.23$, $L = 3.33$, and $R = 1.25$ (Arp 1958). Therefore, the contraction age result is 2.3×10^7 yr.

Adopting HD 58397 as the cluster center and assuming spherical symmetry, the angular radius of the cluster is about 46 arcmin. This value leads to a linear diameter of 9.8 pc, so that the stellar density amounts to

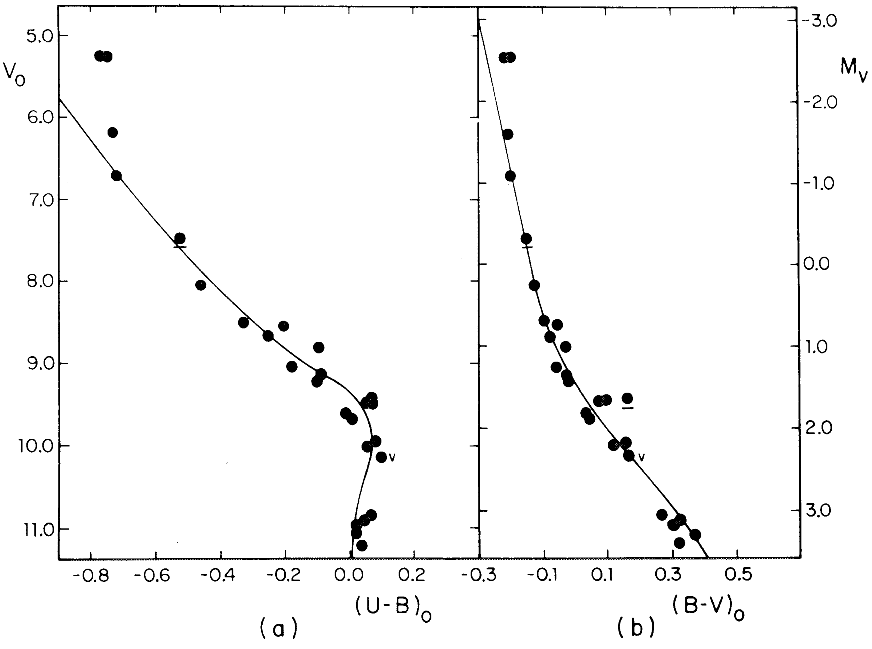

FIG. 9. The unreddened color-magnitude diagrams for the members of Cr 140. The red giant member HD 58535 has not been plotted. the ZAMS of Schmidt-Kaler (1965) and the absolute magnitude scale on the right-hand side of (b) have been adjusted to the adopted distance modulus $V_0 - M_v = 7.78$. Symbols are as in Fig. 3.

0.05 stars/pc^3. This low value casts doubts on the dynamical stability of the cluster. However, the total mass of Cr 140—including that of the red giant HD 58535 (see Sec. VI)—is found to be 103 $\mathcal{M}_\odot$, implying a space density of 0.21 $\mathcal{M}_\odot$ pc^{-3}. This is almost twice the density limit of all the matter in the solar neighborhood (Allen 1973). Furthermore, the space density derived greatly exceeds the limit of ~0.1 $\mathcal{M}_\odot$ pc^{-3} (Mineur 1939) beyond which a cluster is generally considered to be stable. We conclude that Cr 140 is a genuine, dynamically stable, open cluster.

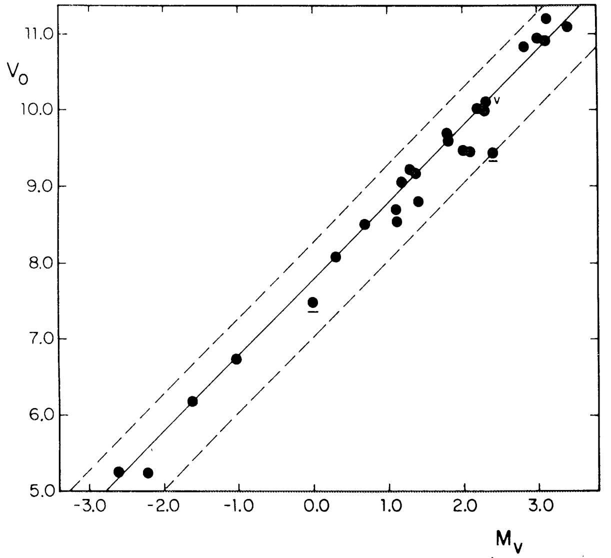

FIG. 10. The V_0, M_v (adopted) diagram for the members of Cr 140. The continuous line corresponds $V_0 - M_v = 7.78$, while the dashed lines represent shifts of 0.05 and 0.75 mag upward and downward, respectively, from the continuous line. Symbols are as in Fig. 3.

Cr 140 lies 50 pc below the Galactic plane in a region between the Sun and the Orion spiral arm. The possibility suggested by Williams (1967b) that NGC 2451 and Cr 140—with the possible addition of Cr 135 and Cr 173—are the remaining nuclei of an OB association which has broken up is still valid in view of the distance, age, and kinematical parameters here obtained for Cr 140.

V. RED STARS IN THE CLUSTER REGION

The C–M diagrams of Cr 140 show five bright stars which could be giant members. One of these (HD 58535) is about 2 mag above the main-sequence turnoff, while the others are 1–2 mag below it. Their positions in the C–C diagram (Fig. 6) are consistent with those of slightly reddened giants. The *UBV* criteria, however, are insufficient evidence of their physical connection with the cluster.

HD 58594: This star, K4 III according to Harris (1976), has been rejected as a probable member since its radial velocity of 111 km s^{-1} is too discordant with the fairly reliable cluster velocity of 15 km s^{-1} obtained from the brightest B members. Assuming for this star $E(B-V) = 0.05$, Schmidt-Kaler's calibration of M_v vs MK spectral type leads to $V_0 - M_v = 7.94$, in agreement with that of the cluster. There are two interpretations for this fact: This is either a nonmember star that has arrived by chance to the central region of the cluster, or else a member which has acquired a very different velocity. The first interpretation seems to us to be more reasonable.

HD 57637: This star has neither known radial velocity nor MK spectral type but the proper motion is remark-

TABLE V. Summary of results obtained for Cr 140 in the present study.

Coordinates α,δ (1950) l,b	7^h22^m, 31° 56′ 245.°0, 8.°0
Mean angular diameter	1° 32′
Distance	(365 ± 29) pc
Linear diameter	9.8 pc
Distance below the Galactic plane	50 pc
Number of members	≥27
Evolved members	≥3
Mean color excess $E(B-V)$	0.05 ± 0.01 (s.d.)
Total mass[a]	≥103 $\mathcal{M}_\odot$
Mean space density	≥0.21 $\mathcal{M}_\odot$ pc^{-3}
Nuclear age	2.1×10^7 yr
Contraction age	≥2.3×10^7 yr
Mean cluster radial velocity[b]	(15 ± 6) km s^{-1}
Mean proper motion[c] (μ_α,μ_δ)	−0.″0.24, − 0.″008
U,V,W	+8, −7, −39 km s^{-1}
Iron to hydrogen ratio[d] [Fe/H]	−0.1
Apparent integrated visual magnitude V_0^T	3.66
Integrated intrinsic colors $(B-V)_0$ and $(U-B)_0$	0.02, − 0.57

[a] The quoted value includes the mass of the red giant HD 58535.
[b] Cluster radial velocity defined by the four brightest B members.
[c] Mean proper motion of 12 members.
[d] The [Fe/H] value corresponds to the red giant HD 58535.

ably similar to that of the cluster. Although it lies at about 1° from the cluster center, we retained it as a probable member.

HD 57962 and HD 59052: Both proper motion and radial velocity data indicate that these two stars do not belong to the cluster.

VI. HD 58535: A RED GIANT CLUSTER MEMBER

HD 58535 has proper motion and radial velocity consistent with membership. In addition, this star was observed with the four primary filters of the DDO intermediate-band system (McClure and van den Bergh 1968; McClure 1976) using the 91-cm telescope at CTIO. The observed quantities are $C(45-48) = 1.212$, $C(42-45) = 0.884$, $C(41-42) = 0.253$, and $m(48) = 5.756$. Using McClure and Racine's (1969) method, the color excess result is $E(B-V) = 0.03$, which agrees well with the cluster reddening. The observed DDO indices were corrected for reddening using the color excess ratios given by McClure (1973) and the location of HD 58535 in the two classical DDO color–color diagrams indicates a normal K0 II–III object, consistent in both diagrams. Harris (1976) classified it as a G8 II, so its luminosity is compatible with membership in either case.

Information on the ratio [Fe/H] can now be obtained for HD 58535. In fact, Janes (1975) has tabulated the average of the $C(41-42)$ index as a function of $C(45-48)$ and $C(42-45)$ and has shown that the cyanogen anomaly δCN is well correlated with [Fe/H] by the equation

$$[\mathrm{Fe/H}] = 4.5\ \delta\mathrm{CN} - 0.2. \quad (5)$$

In computing δCN we have used the individual reddening $E(B-V)_{\mathrm{DDO}} = 0.03$ and the mean cluster reddening $E(B-V) = 0.05$, resulting, respectively, in $\delta\mathrm{CN} = 0.02$ and 0.03, both being weaker than the Hyades giants [$\delta\mathrm{CN} = 0.06$ (Janes 1974)]. If we assume the metal abundance of HD 58535 to be representative of that of the whole cluster, then the mean [Fe/H] = −0.09 value derived from Eq. (5) makes the cluster slightly metal weak compared to the Hyades {$[\mathrm{Fe/H}]_{\mathrm{Hyades}} = +0.1$ (Parker *et al.* 1961)}.

Finally, the calibration given by Osborn (1973) of the intrinsic DDO colors as a function of effective temperature and surface gravity leads to $T_{\mathrm{eff}} \approx 4770$ K and log $g \approx 2.2$. Therefore, the absolute bolometric magnitude of this star is $M_{\mathrm{b}} = -2.4$ (Schlesinger 1969) and the mess we derive from the following equation of Osborn and Clariá (1975):

$$\log \mathcal{M}/\mathcal{M}_\odot) = \log g - 4 \log T_{\mathrm{eff}} - 0.4\, M_{\mathrm{b}} + 12.49. \quad (6)$$

This amounts of 9 $\mathcal{M}_\odot$. The age of Cr 140 allows us to classify the cluster as belonging to group III of Harris (1976) and, although the mass of the red giant seems to be rather high, its value is not inconsistent with that expected for the above group.

VII. SUMMARY AND CONCLUSIONS

The present study shows that Cr 140 is a genuine open cluster situated in Canis Major at a distance of 365 ± 20 pc from the Sun and 50 pc below the Galactic plane. Therefore, it lies in a region intermediate between the Sun and the Orion spiral arm. From the UBV,Hβ analysis and the existing kinematical data, we conclude that the cluster contains at least 27 definite members (two being variables), mostly main-sequence B- and A-type stars, and one probable member. Among these, we recognize two blue giants and only one red giant.

Assuming an angular diameter of about 1.°5 a linear diameter of about 10 pc results, so that the stellar density is only 0.05 stars/pc^3 In spite of this small value, the cluster appears to be dynamically stable since the computed total mass (≥ 103 $\mathcal{M}_\odot$) implies a lower limit to the space density of 0.21 $\mathcal{M}_\odot$ pc^{-3} and this value greatly exceeds the limit beyond which a cluster is generally considered to be stable.

A nuclear age of 2.1×10^7 yr was derived while a lower limit to the contraction age of 2.3×10^7 yr was also obtained for the cluster. Contrary to the result found by Williams (1967a), Cr 140 appears to be uniformly reddened with $E(B-V) = 0.05$. The cluster radial velocity defined by the brightest B members is 15 ± 6 km s^{-1}, while the average proper motion from 12 cluster members results $\mu_\alpha = -0.″0.24$ and $\mu_\delta = -0.″008$. The possibility suggested by Williams (1967b) that NGC 2451 and Cr 140—with the possible addition of Cr 135 and Cr 173—are the remaining nuclei of an OB association which has broken up, still holds in view of the basic parameters here derived for Cr 140.

Finally, from the DDO data of the red giant HD

58535, we conclude it is a normal K0 II–III cluster member. In addition, we obtain for this star: $E(B-V) = 0.03$, $\delta CN = 0.02$, $[Fe/H] = -0.09$, and $\mathcal{M} \approx 9\, \mathcal{M}_{\odot}$. Therefore, if we assume the metal content of HD 58535 to be representative of that of the whole cluster, then Cr 140 is slightly metal weak compared to the Hyades.

Table V summarizes the basic parameters of Cr 140 derived in the present study.

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