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THE OPEN CLUSTER NGC 2204

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ABSTRACT

Photoelectric photometry in the intermediate-band DDO system and the wideband Cousins *VRI* system is presented for representative giants in the old open cluster NGC 2204. The metal-poor character of the cluster, suggested by previous *UBV* photometry, is confirmed and an average cyanogen anomaly $\langle \delta \mathrm{CN} \rangle = -0.047 \pm 0.009$ mag (m.e.) is derived. There are several stars in NGC 2204 which may have unusual surface compositions.

I. INTRODUCTION

The study of metallicity in open clusters is astrophysically important for two primary reasons. First, the clusters serve as probes of the Galaxy's chemical structure, for evaluation of radial and axial gradients of metallicity expressed as [Fe/H] or Z. Abundance information from *UBV* or DDO photometry is currently available for some 40 open clusters (see Janes 1979a). Second, there is observational evidence for CNO or *s*-process-element enhancement (or depletion) in some globular cluster giants and in the very old open cluster NGC 188 (see, for example, Cannon and Stobie 1973, McClure and Osborn 1974, Zinn 1977, and McClure 1974), but the data for other open clusters suggest that when peculiarities in surface composition occur at all they are observed in only a few cluster members. Estimates of the physical conditions in such stars will aid our understanding of why such structural anomalies occur.

NGC 2204 is an old, moderately rich and diffuse open cluster (Trumpler class III 3m) located at $l^{\mathrm{II}} = 266\overset{\circ}{.}0$, $b^{\mathrm{II}} = -16°$. It belongs to a small group of old open clusters (including NGC 2420, NGC 2243, and Melotte 66) which occupy positions in the extreme disk, some 500–1000 pc from the Galactic plane. The only previous systematic photometry was by Hawarden (1976), who obtained *BV* photographic photometry for stars brighter than $V = 17.5$ and photoelectric *UBV* data for 33 of the brightest stars. The data lead to an age of about 3×10^9 yr and an ultraviolet excess $\delta(U - B) = 0.095 \pm 0.024$ mag, typical of a moderately metal-poor grouping (the other extreme-disk clusters have similar values).

At least two of the other members of the extreme-disk group contain peculiar stars: NGC 2420 has at least one horizontal-branch Ba II star (McClure, Forrester, and Gibson 1974); and Melotte 66 has two strong-CN stars in a location blueward of the upper end of its giant branch, which may be the asymptotic branch (Dawson 1978; Anthony-Twarog, Twarog, and McClure 1979). This information suggested that a similar search of NGC 2204 for peculiar stars might prove profitable.

II. THE OBSERVATIONS

Photoelectric data were obtained with the 91-cm and 1.5-m telescopes at the Cerro Tololo Inter-American Observatory during observing runs in March 1978 and February 1979. Observations in the David Dunlap Observatory (DDO) intermediate-band system (McClure and van den Bergh 1968) were obtained during both runs with cooled RCA 4516 (S-11) photomultipliers in pulse-counting configuration; in 1979 an RCA 31034A (GaAs) cell was added to a second channel to enable observing in the Cousins *VRI* system (see Bessell 1976 and 1979). The *VRI* filter set was kindly made available to the author by Dr. John Graham. CTIO filter sets 1 and 2 were used in 1978 and 1979, respectively, for the DDO observations.

Figure 1 is an adaptation of Hawarden's color-magnitude diagram for NGC 2204 indicating the stars for which photometry was obtained in this study. Program stars were chosen to give a representative sample of red giants (RGB), the "clump" or red horizontal branch (HB), and the region lying above the horizontal branch. Table I lists the mean observed color indices; the numbering system for the program stars follows Hawarden's convention. Errors of a single observation averaged ±0.011, ±0.015, ±0.019, ±0.016, ±0.020, and ±0.015 mag in $C(45\text{–}48)$, $C(42\text{–}45)$, $C(41\text{–}42)$, $C(38\text{–}41)$, $V - R$, and $R - I$, respectively.

The DDO photometry and published $B - V$ values were combined, following the calibration of Janes (1977), to yield reddening estimates. These values are listed in Table II with other quantities derived from the unreddened colors (discussed below). The stars for which photoelectric $B - V$ values are available (marked "pe"

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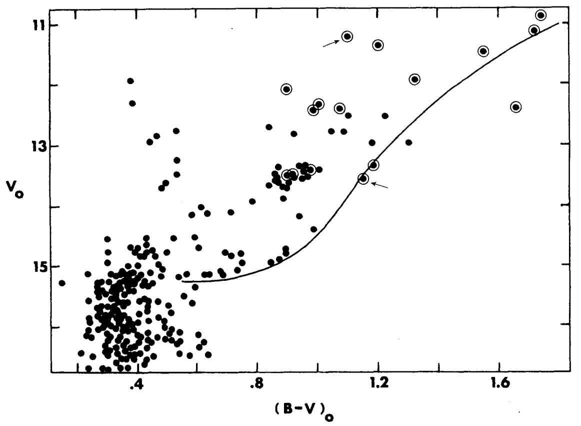

FIG. 1. The color-magnitude diagram of NGC 2204, adapted from the study by Hawarden (1976). The stars observed by the author are circled, and two stars which may be CN-strong are indicated by arrows.

in the table) yield the most consistent results: the average reddening derived from them is

$$E(B-V) = 0.08 \pm 0.01 \text{ mag},$$

which is identical to the value derived by Hawarden from the color-magnitude diagram; this value was adopted for the present work.

Photometric spectral classifications were obtained by comparing the unreddened colors with the mean colors of bright standard stars in the DDO and *VRI* systems. The spectral types are in excellent agreement, indicating that no large systematic errors exist.

The blue and violet cyanogen anomalies, δCN and δ3842, were obtained by comparison with the colors of nearby G–K giants. It is apparent from the preponderance of negative δCN values that NGC 2204 is moderately metal-poor. With the exclusion of the two most negative cases and stars with a positive anomaly (for reasons discussed below), an average value

$$\langle \delta\text{CN} \rangle = -0.047 \pm 0.009 \text{ mag (m.e.)}$$

is obtained. When CN is not abnormally strong, there is a good correlation between δCN and the iron-to-hydrogen ratio [Fe/H]; however, the zero point of this correlation is in dispute (Deming, Olsen, and Yoss 1977; Janes 1979b). The original calibration, viz.

$$[\text{Fe/H}] = 4.5\delta\text{CN} - 0.2\ (\pm 0.17),$$

shall be adopted for the present study inasmuch as it has been used with success in previous investigations. With this relation, an iron abundance [Fe/H] $= -0.41 \pm 0.19$ is derived (internal and external errors considered).

Observations in the DDO "38" filter were not obtained during the 1978 run; therefore, the violet anomaly is not available for all the program stars. However, the general trend of δ3842 values is also suggestive of moderate metal deficiency; again, excluding the two positive values and the most negative case, an average

$$\langle \delta 3842 \rangle = -0.042 \pm 0.020 \text{ mag (m.e.)}$$

is obtained.

It is also evident from Table II that several stars do not follow the general trend of CN strength. Two stars (1329 and 2222) appear CN-strong or otherwise peculiar, while two others (1129 and 3304) seem very metal-poor. To test the possibility that the anomalous colors might be due to observational errors, the following consistency tests were run: (1) the indices δCN and δ3842 should both reflect the presence of a real anomaly; (2) the DDO and *VRI* colors should both show blanketing effects; (3) the internal scatter among successive filter series (per star per night) should be low; and (4) the photometry should be reasonably consistent with the star's being a cluster member, i.e., M_v(DDO) should be similar to that predicted from the color-magnitude diagram, and the "distance modulus" $V - M_v$(DDO) should be similar to values previously published. Stars which consistently

TABLE I. Observed colors, NGC 2204 giants.

Star	Type	C(45–48)	C(42–45)	C(41–42)	C(38–41)	$(V-R)_c$	$(R-I)_c$	n
2120	AB[a]	1.281	0.993	0.278	−0.396	0.700	0.620	2
1129	AB[a]	1.321	1.013	0.170	−0.270	0.648	0.599	1
3207	AB[a]	1.218	0.860	0.182	−0.525	0.563	0.572	1
1320	AB[a]	1.234	0.902	0.182	−0.426	0.607	0.560	2
4212	AB[a]	1.173	0.848	0.095	−0.548	0.555	0.503	2
3304	AB[a]	1.360	1.095	0.213	−0.096	0.782	0.692	2
1329	AB[a]	1.235	0.967	0.318	—	—	—	2
4137	GB	1.419	1.306	0.275	−0.050	0.911	0.792	2
3325	GB	1.458	1.381	0.234	—	—	—	2
4132	GB	1.405	1.152	0.085	—	—	—	2
2222	GB	1.247	1.011	0.314	−0.363	0.688	0.583	1
1225	GB	1.174	1.371	−0.031	—	—	—	3
1133	HB	1.240	0.879	0.151	—	—	—	1
4210	HB	1.146	0.878	0.124	—	—	—	1
1330	HB	1.175	0.867	0.183	—	—	—	1
1224	field	1.156	0.773	0.170	−0.567	0.479	0.438	1
1136	var. (1979)							
	16 Feb.	—	—	—	—	1.373	1.659	
	1 Mar.	1.420	1.173	0.072	−0.013	1.554	1.700	

[a] Located above the horizontal branch and blueward of the red giant branch in the color-magnitude diagram.

TABLE II. Reddenings, cyanogen anomalies, and photometric spectral classifications.

Star	Type	$E(B-V)_{DDO}$	δCN[a]	δ3842[a]	MK(DDO)	MK(RI)
2120	AB[b]	0.08 pe	−0.007	−0.096	K2–3III	K2–3III
1129	AB[b]	−0.06	−0.156	−0.123	K1–2II–III	K1–2III
3207	AB[b]	0.05	−0.037	−0.048	G9III	K0III
1320	AB[b]	0.01	−0.055	−0.000	K0III	K0III
4212	AB[b]	0.05	−0.048	−0.043	G9III	G7III
3304	AB[b]	0.09 pe	−0.143	+0.092	K3III	K3III
1329	AB[b]	0.07 pe	+0.094	—	K1–2III	—
4137	GB	0.11	−0.028	−0.026	K4–5III	K5III
3325	GB	—	—	—	M3III	—
4132	GB	—	—	—	M3III	—
2222	GB	0.09 pe	+0.080	+0.067	K2III	K2–3III
1225		0.00	—	—	M0V [foreground]	
1133	HB	0.00	−0.099	—	G8III	—
4210	HB	0.08 pe	+0.026	—	K1IV	—
1330	HB	0.09	+0.042	—	K0–1IV	—
1224	field	0.02 pe	−0.005[c]	−0.012[c]	G6III	G7III
1136	var.		1979 16 Feb.		—	M5III
			1 Mar.		M3–4III	M5.5III

[a] Computed using $E(B-V)=0.08$ mag.
[b] See footnote to Table I.
[c] Colors assumed to be unreddened.

violate these criteria either are nonmembers or have questionable observations.

A comparison of the two CN indices for stars with "38" observations suggests that 2222 and 1129 are really anomalous. The results for 3304 are ambiguous since all the data for this star show good internal agreement.

Figures 2 and 3 compare blanketing effects in plots of $C(45\text{–}48)$ vs $C(42\text{–}45)$ and $(B-V)-(V-R)$ vs $V-I$, respectively; the figures are oriented so that stars which are metal-poor relative to normal giants lie above the class III curve in Fig. 2 and below it in Fig. 3. The upper curve of Fig. 3 is the ridge line of bright standard stars from the data of Bessell (1979). In the figures, stars 1329 and 2222 appear to be enhanced in metals and 1129 looks metal-poor; it is questionable whether 3304 is anomalous.

Twarog (1980) has recently completed an analysis of image-tube spectra obtained at the 1.0-m Yale telescope at Cerro Tololo for the stars 2120, 1129, and 4212. Scans made with the Yale PDS microdensitometer reveal that star 1129 is apparently a normal, somewhat metal-poor giant, as are 2120 and 4212; radial velocities for the three stars are essentially the same (within the accuracy of the reduction) and are large enough (80–100 km/s) to indicate that all three are cluster members. It is, therefore, likely that the single measure for star 1129 is in error; the

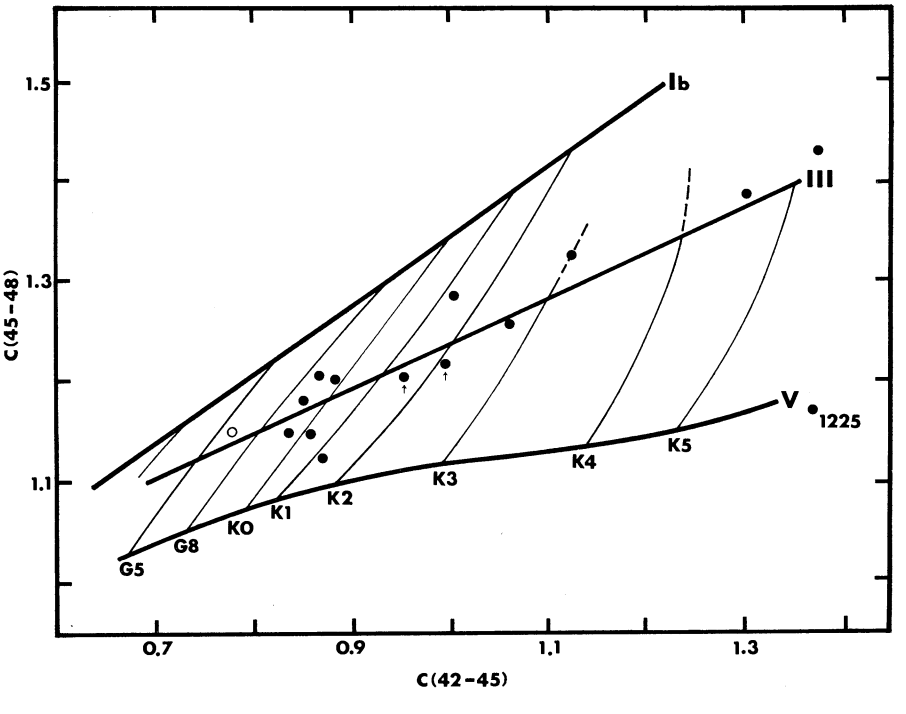

FIG. 2. Positions of NGC 2204 giants in the $C(45\text{–}48)$, $C(42\text{–}45)$ plane. The two stars suspected of being peculiar are indicated by arrows. The foreground giant 1224 is designated by an open circle; the foreground dwarf 1225 is numbered at the lower right.

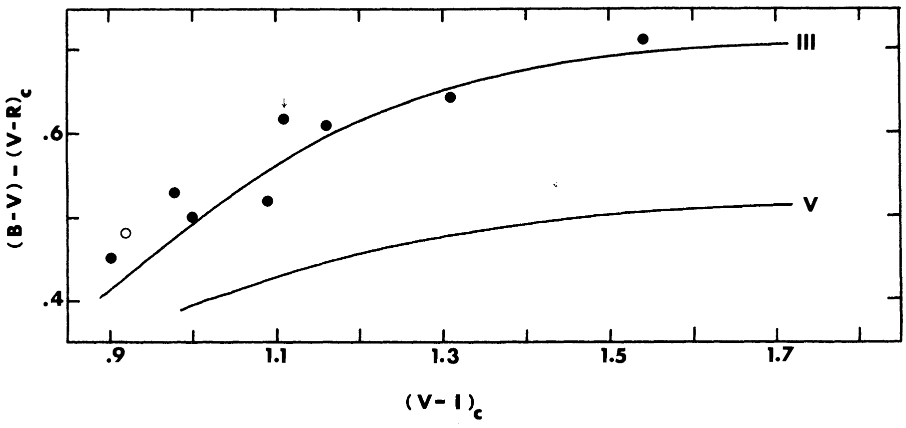

FIG. 3. Positions of NGC 2204 giants in a plot of $(B-V)-(V-R)$ vs $V-I$. The ordinate is blanketing-sensitive while the abscissa is largely blanketing-independent. The peculiar star 2222 is indicated by an arrow.

photometry of the two other stars agrees with the spectroscopic results.

Two stars on the horizontal branch, 4210 and 1330, have colors which are not consistent with cluster membership. However, observational errors cannot be ruled out as affecting the single observations of each.

One star on the RGB is a definite nonmember: the DDO photometry of star 1225 indicates that it is an M0 dwarf in the foreground. Hawarden did not have U photometry for this star when he examined NGC 2204 and thus could not make the luminosity distinction.

Star 1136, lying below the top of the RGB, was observed twice during the 1979 run because of its suspected variability. The *VRI* data confirm the variation, with the largest color amplitude in $V-R$. The nature of the variation is of course still uncertain.

III. PHYSICAL CONDITIONS

The calibrations of effective temperatures, gravities, and other parameters with DDO (Janes 1975; Osborn 1979) and *VRI* photometry (Bessell 1979) were used to obtain the data listed in Table III. $R-I$, which is relatively insensitive to metal-line blanketing, was the source of wideband effective temperatures; T_{eff} and other physical conditions were obtained from the DDO photometry after blanketing the unreddened colors for [Fe/H] = −0.41.

The $R-I$ effective temperatures are consistently about 200 K higher than those obtained from the DDO colors. The DDO temperature calibration was developed from the work of Schlesinger (1969); more recent determinations coupled with theoretical models that more completely treat line blanketing indicate that Schlesinger's T_{eff} scale is 200–300 K too low (see Cohen, Frogel, and Persson 1978 and McClure 1979). If allowance is made for this zero-point shift, the DDO and *VRI* determinations are in quite good agreement.

By combining the Stefan–Boltzmann relation with the definition of surface gravity and eliminating R as an independent variable, one can estimate stellar masses. Inserting solar values of M_{bol}, T_{eff}, and g, and expressing $M_{\mathrm{bol}} = M_v + \mathrm{BC}$, one ultimately obtains

$$\log[M/M_{\odot}] = \log g - 0.4(M_v + \mathrm{BC}) - 4\log T_{\mathrm{eff}} + 12.49.$$

TABLE III. Derived physical properties.

Star	Type	T_{eff}(DDO)	$T_{\mathrm{eff}}(RI)$	log*g*	M_V(DDO)	BC(DDO)	BC(*RI*)	Mass(DDO)	Mass(*RI*)[a]	V_0-M_V
2120	AB[b]	4220	4330	1.8	−0.1	−0.64	−0.54	1.23	1.01	11.5
1129	AB[b]	4170	4380	1.6	−1.1	−0.66	−0.53	2.04	1.49	13.6
3207	AB[b]	4600	4480	2.1	+0.3	−0.43	−0.49	0.97	1.16	12.1
1320	AB[b]	4480	4500	2.1	+0.4	−0.49	−0.49	1.06	1.04	12.0
4212	AB[b]	4640	4860	2.9	+1.8	−0.43	−0.33	1.50	1.13	11.7
3304	AB[b]	3980	4150	1.5	−1.1	−0.83	−0.67	2.29	1.69	13.1
1329	AB[b]	4290	—	2.3	+1.2	−0.60	—	1.05	—	10.0
4137	GB	3570	3990	1.3	−0.8	−1.20	−0.63	2.40	0.90	12.3
3325	GB	3440	—	—	−1.9 (est.)	—	—	—	—	13.1
2222	GB	4180	4420	2.2	+1.2	−0.65	−0.50	0.97	0.67	12.4
1133	HB	4550	—	1.9	−0.5	−0.46	—	1.37	—	14.0
4210	HB	4560	—	[3.5]	[+3.5]	−0.46	—	[1.36]	—	[10.0]
1330	HB	4580	—	2.8	+2.0	−0.46	—	1.06	—	11.5
1224	field	5040	4940	2.2	−0.5	−0.25	−0.28	1.51	1.68	8.3
(G7III: DDO calibration)		5070		2.7	+0.6	−0.27		1.70		

[a] Temperatures derived from $R-I$ are used in the log mass equation, entering as T_{eff} and the bolometric correction.
[b] See footnote to Table I.

The largest differences in derived mass between results using T_{eff}(DDO) and $T_{eff}(RI)$ occur for the cool star 4137 and for the two stars which are "metal-poor" candidates. Otherwise the two sets of determinations are in good agreement and the average derived log mass is in adequate agreement with that predicted (about 1.4 solar masses) from Iben's (1967a,b) red giant models.

The last column of Table III lists the "distance modulus" derived from V, A_v [$=3.3E(B-V)$], and M_v(DDO). The derived moduli are not intended as definitive indicators of membership (except for extreme cases), because of the uncertainty in M_v(DDO); rather, they serve as a final consistency check. On this basis, the two questionable HB stars cannot be rejected without also removing star 1329; this may be an argument for observational error in the HB-star observations. The average distance modulus for those stars not exhibiting abnormal color indices is $(m-M)_0 = 12.48 \pm 0.26$ mag, somewhat less than Hawarden's value of 13.0; with this modulus, NGC 2204 lies about 3100 pc distant and some 870 pc from the Galactic plane.

IV. DISCUSSION

The present study indicates that NGC 2204 is moderately metal-poor, in confirmation of previous work. Inspection of the abundance data does not indicate any systematic difference in metallicity between the red giants and those stars lying blueward of the RGB, at least at the level of observational errors. More horizontal-branch observations are desirable for completeness and in view of the small sample of this work.

At least two stars, 1329 and 2222, are candidates for being intrinsically peculiar. Star 1329 was noted as being possibly peculiar by Hawarden because of its ultraviolet defect; and its location in the color-magnitude diagram (similar to that of the two CN-strong stars in Melotte 66) is suggestive of a common mixing mechanism.

If star 1329 and the two CN-strong stars in Melotte 66 are in the asymptotic-branch evolutionary stage, a logical source of mixing is the convection accompanying sudden changes in the luminosity of the helium-burning shell, although the M_{bol} of star 1329 is slightly fainter than that at which He shell flashing is thought to become important (Gingold 1974, 1975). The mixing scenario for star 2222 is difficult to envision, although the convective envelope should still be fairly deep at that point in its RGB evolution; perhaps this is a case of mixing in a star which has just passed the helium-core ignition stage and has returned along the giant branch prior to looping blueward.

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