1968PASP...80..410F

THE OPEN CLUSTER NGC 6231*

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Received April 8, 1968

Photometric data are given for 34 stars situated in the position of the very young open cluster NGC 6231. Two Of and two Wolf-Rayet stars belong to the cluster according to their magnitudes and colors. If the high luminosity star HD 152236 (ζ^1 Sco) is a cluster member, its absolute magnitude is $M_v = -7.4$.

The open cluster NGC 6231, core of the association Sco OB 1, is a very unusual group of stars due to the presence of two Wolf-Rayet stars and two Of stars (Struve 1944; Holopov 1951). Several papers dealing with photoelectric data have been published (Brownlee and Cox 1953; Breckinridge and Kron 1963; Bok, Bok and Graham 1966). Struve (1944) measured radial velocities of 20 stars in and near the cluster, and later, Morgan, Code and Whitford (1953) and Houck (1956) classified some of them on the MK system.

Observations

The photoelectric observations were carried out with the 32-inch reflector of the La Plata Observatory, and with the 16-inch reflector of the Cerro Tololo Inter-American Observatory, during 1964-66. From a radius of around 20 minutes of arc of the center of the cluster, 34 stars were observed photoelectrically in the *UBV* system, and five stars also in the *RI* system (Feinstein 1966). The observational data are listed in Table I. Only 20 stars have spectral types in the MK system (Morgan, Code and Whitford 1953; Houck 1956). Also listed in Table I are the data (Feinstein 1968) for the very high luminosity supergiant HD 152236, which is 30 minutes of arc south of the center of the cluster. Spectroscopic binaries are indicated in the remarks column and footnotes. The stars which

Contributions from the Cerro Tololo Inter-American Observatory No. 42.

†Member of the Carrera del Investigador Científico, Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina.

††Operated by the Association of Universities for Research in Astronomy, Inc., under contract wit hthe National Science Foundation.

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TABLE I

Magnitudes and Color Indices of Stars in NGC 6231

No.	HD or CD or CPD	Sp. MK or (HD)	V	$B-V$	$U-B$	n	R	$R-I$	n	Remarks
1	151804	O8fp	5.22	0^m07	-0^m84	2				
2	152234	B0.5 Ia	5.51	0.15	−0.75	3				(*)
3	152408	O8fp	5.77	0.14	−0.75	2				
4	152248	O8	6.16	0.12	−0.82	2				(*) Var. 6.02–6.20
5	152424	O9 I	6.32	0.34	−0.59	2				(*) ?
6	152235	B1 I	6.38	0.46	−0.51	3				
7	152249	O9.5 Ia	6.43	0.20	−0.74	4				(†) Var. 6.34–6.50
8	152270	WC7+O8	6.50	0.18	−0.51	3	6^m63	0^m33	1	
9	151932	WN6	6.55	0.19	−0.68	3	6.04	0.39	3	Var. 6.51–6.61
10	152233	O6	6.63	0.12	....	5				Var. 6.55–6.68
11	152003	B0 Ia	7.08	0.33	−0.65	4				Var. 7.02–7.15
12	152247	O9.5 III	7.18	0.16	−0.74	3				
13	152147	B0 Ia	7.33	0.34	−0.63	3				
14	152218	O9.5 V	7.59	0.15	−0.77	4				(*)
15	152219	O9.5 IV	7.69	0.13	−0.79	4				
16	326331	O7	7.71	0.14	−0.75	2				Var. 7.62–7.80
17	−41°11037	cO9	7.74	0.17	−0.70	2				(*)
18	152314	O9.5 III	8.02	0.16	−0.69	2				Var. 7.91–8.12
19	152042	B0.5 III	8.18	0.09	−0.75	3				
20	−41°11042	....	8.36	0.20	−0.68	5	7.99	0.21	1	(*) Var. 8.12–8.43
21	152200	(B8)	8.42	0.12	−0.80	3				Var. 8.35–8.42
22	152076	B0 III	8.50	0.20	−0.72	3				
23	152269	(B9)	8.51	0.12	−0.43	2				
24	−41°11038	....	8.56	0.16	−0.69	2	8.58	0.09	1	
25	152199	(B0)	8.65	0.20	−0.70	3				Var. 8.58–8.70

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TABLE I (*Continued*)

No.	HD or CD or CPD	Sp. MK or (HD)	V	$B-V$	$U-B$	n	R	$R-I$	n	Remarks
26	326125	(M0)	8.84	1.94	2.31	5	7.14	1.44	2	Var. 8.76–8.99
27	−41°7730	....	9.10	0.19	−0.57	2				
28	152437	(A0)	9.15	0.13	−0.21:	1				
29	−41°7712	....	9.18	0.17	−0.68	2				
30	326351	B0 V	9.23	0.28	−0.62	4				Var. 9.12–9.35
31	151912	(A0)	9.49	0.25	0.25	3				
32	−41°7706	....	9.59	0.17	−0.63	1				
33	326305	(B3)	10.01	0.16	−0.65	3				
34	−41°7715	....	11.02	0.12	−0.47	1				
35	152236	B1.5 Ia+	4.72	0.48	−0.56	3				

*Spectroscopic binary, O. Struve, 1944
†Spectroscopic binary, F. J. Neubauer, 1930

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our observations suggest are variable are also indicated with their extreme magnitude values.

The star HD 152248 was classified as O8 by Morgan, Code and Whitford (1953) and as O8f by Houck (1956), but an inspection of spectrograms at the Cordoba Observatory in 1962, 1966, and 1968 by C. Jaschek and L. Milone, indicate no features present which characterize the Of stars.

Discussion

The color-magnitude and $(B-V)$, $(U-B)$ diagrams of the stars are depicted in Figures 1 and 2 respectively. The "zero-age" main sequence of Blaauw (1963) is also indicated in Figure 1.

The main sequence of the cluster is well defined. Four stars (Nos. 5, 6, 11, and 13) with visual apparent magnitude between 6.5 and 7.5 are 0^m3 more positive in $(B-V)$ than the cluster stars. The position of these four stars to the right of the main sequence may be explained by assuming that they have an additional interstellar absorption besides the mean absorption of the cluster, as Breckinridge and Kron (1963) have already pointed out.

Table II lists the absolute magnitude obtained from the spectral type (Blaauw 1963) for each star with known spectral types in the MK system, the intrinsic $(B-V)$ values and color excesses in $(B-V)$, the visual absorption from the relation $A_v = 3E(B-V)$, and the true distance modulus $V_0 - M_v$.

TABLE II

Distance Modulus of Stars in NGC 6231

No.	HD	M_v	$(B-V)_i$	E_{B-V}	A_v	V_0	V_0-M_v
2	152234	-6^m4	-0^m22	0^m37	1^m11	4^m40	10^m80
5	152424	−6.2	−0.28	0.62	1.86	4.46	10.66
6	152235	−6.2	−0.19	0.65	1.95	4.43	10.63
7	152249	−6.2	−0.27	0.47	1.41	5.02	11.22
10	152233	−5.5	−0.32	0.44	1.32	5.31	10.81
11	152003	−6.2	−0.24	0.57	1.71	5.37	11.57
12	152247	−5.4	−0.30	0.46	1.38	5.80	11.20
13	152147	−6.2	−0.24	0.58	1.74	5.59	11.79
14	152218	−4.6	−0.30	0.45	1.35	6.24	10.84
15	152219	−5.1	−0.30	0.43	1.29	6.40	11.50
16	326331	−5.4	−0.32	0.46	1.38	6.33	11.73
18	152314	−5.4	−0.30	0.46	1.38	6.64	12.04
19	152042	−4.7	−0.28	0.37	1.11	7.07	11.77
22	152076	−5.0	−0.30	0.50	1.50	7.00	12.00
30	326351	−4.4	−0.30	0.58	1.74	7.49	11.89

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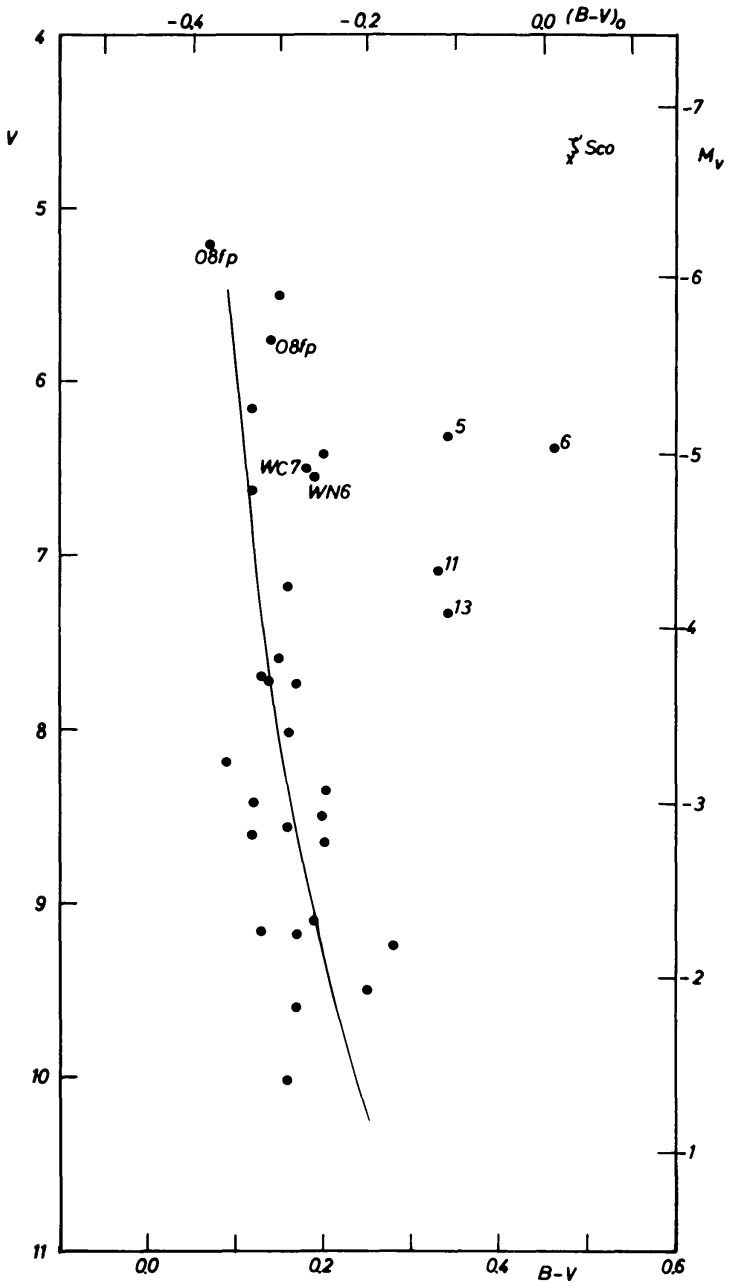

FIG. 1 — Color-magnitude diagram for the stars in NGC 6231. The star No. 26 is not included because it is too red ($(B—V) = 1^m94$). The zero-age main sequence given by Blaauw (1963) is indicated by the solid curve.

The mean color excess of all the stars is $E(B—V) = 0^m44$ which gives $A_v = 1^m32$, under the assumption $A_v = 3E(B—V)$. In computing this value we excluded the stars Nos. 5, 6, 11, and 13. The final mean distance modulus is $11^m4 \pm 0^m2$ which gives 1900

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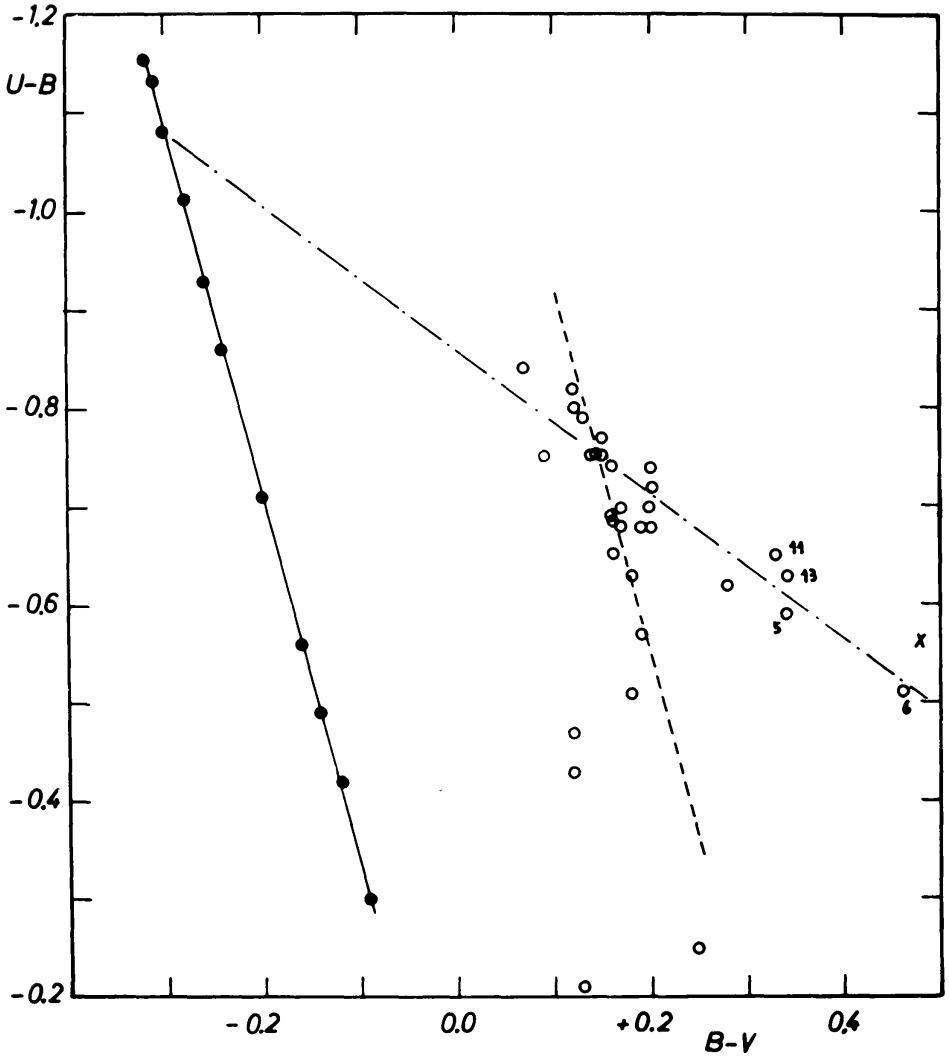

FIG. 2 — The $(B-V)$, $(U-B)$ diagram of stars in NGC 6231.

parsecs with an estimated error of ± 150 parsecs. This compares with 1800 parsecs quoted by Bok, Bok, and Graham (1966).

The star ζ^1 Scorpii (HD 152236) which is plotted as a cross in the color-magnitude and $(B-V)$, $(U-B)$ diagrams may be a member of the cluster. This star was classified by Code and Houck (1958) as a superluminous star of type B1.5 Ia$^+$. Its place to the right of the main sequence in the color-magnitude diagram is the same as stars Nos. 5, 6, 11, and 13, which are all south of the cluster center. The star HD 152236 which is in the same region in the sky as stars 5, 6, and 13 may also suffer an additional interstellar absorption.

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The intrinsic color index of a B1.5 star according to Johnson (1963) is $(B-V)_0 = -0^m18$ and thus the additional color excess of HD 152236 would be $E(B-V) = 0^m22$. The absolute magnitude obtained from the color-magnitude diagram, $M_v = -6^m7$, must be corrected for this extra absorption. Thus it would be around $M_v = -7^m4$. The position of this star off the main sequence is in agreement with its luminosity class. Code and Houck (1958) have estimated $M_v = -9^m0$ for this star.

Reddish (1967) has pointed out that the brightest stars of many clusters, surrounded by obscuring clouds, are frequently reddened more than the other stars of the cluster.

Of and Wolf-Rayet Stars

The position of the two Of and the two Wolf-Rayet stars in the color-magnitude diagram indicate they are members of the cluster. The absolute magnitudes of the Of stars are between -6^m2 and -5^m8 and the two Wolf-Rayet stars are $M_v = -5^m0$. Two other galactic open clusters contain Of stars; these are IC 1805 and NGC 6871 which have Of stars with absolute magnitudes around $M_v = -4^m5$. Both clusters are situated in Cygnus.

One of us (A.F.) appreciates the facilities provided by the Cerro Tololo Inter-American Observatory.

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