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The Open Clusters NGC 6613 (M18) and NGC 6716

U. Lindoff
Lund Observatory

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UBV-magnitudes have been determined for stars in the open clusters NGC 6613 and NGC 6716, using a combination of photoelectric and photographic photometry. Spectral classes for the brighter stars have been determined from slit-spectra and objective prism-plates.

The absorption has been determined to $1^m.4$ in front of NGC 6613 and to $0^m.4$ in front of NGC 6716. Their respective distances are 1250 pc and 600 pc. NGC 6613 is a young cluster, NGC 6716 is of medium age.

Key words: open clusters — *UBV* photometry — spectral classification

I. Introduction

NGC 6613 and NGC 6716 are two comparatively sparsely populated clusters in Sagittarius, included in the writer's programme on open clusters. The former is situated at $\alpha_{1950} = 18^h17^m.0$, $\delta_{1950} = 17°09'$ ($l = 14°.1$, $b = -1°.0$), right in the Sagittarius cloud. Though not very distinct, it has already been discovered by Messier and is also known as M 18. NGC 6716 is situated about 10° south of the galactic plane $\alpha_{1950} = 18^h51^m.7$, $\delta_{1950} = -19°58'$ ($l = 15°.4$, $b = -9°.6$), and contains few stars of rather poor concentration. The photographic material used for the clusters consists of three direct plates in each colour and objective prism-plates. They were taken by the writer in June-July 1969 with the Uppsala Schmidt telescope (50/65/175) at Mount Stromlo. The photoelectric sequences were taken partly with the 50″ telescope at Mount Stromlo, partly with the 16″ telescope of the Siding Spring Observatory in July-August 1969. The 100 cm telescope at La Silla in Chile was also used for a few stars in NGC 6613 (Feb. 1970). In March 1970, split spectra with a dispersion of 77 Å/mm were taken with the 152 cm telescope of La Silla for the MK-classification of four stars in NGC 6613 and three stars in NGC 6716.

Table 1. *Photoelectric standards in* NGC 6613

Star No.	Region	V	$B-V$	$U-B$	n	Sp.	Remarks
1	1	11.93	0.33	−0.18	3	B7	
2	1	13.47	0.44	0.18:	4		
3	1	13.46	2.30:	—	3		n.m.
11	1	12.02	1.26	1.07:	3		n.m.
12	1	10.39	0.22	−0.22	3	B5V	
13	1	9.25	0.48	0.43	3	A6V	n.m. HD 168353
15	1	8.65	0.32	−0.45	6	B2III	HD 168352
16	1	10.33	0.24	−0.40	3	B6:	
20	2	12.55	0.31	0.01	3	B9	
21	2	12.56	1.38	1.5:	3		n.m.
28	2	10.47	0.27	−0.44	2	B6	
38	2	9.38	0.28	−0.47	3	B3IV	HD 168368
47	3	10.60	0.70	0.32	2	F8	n.m.

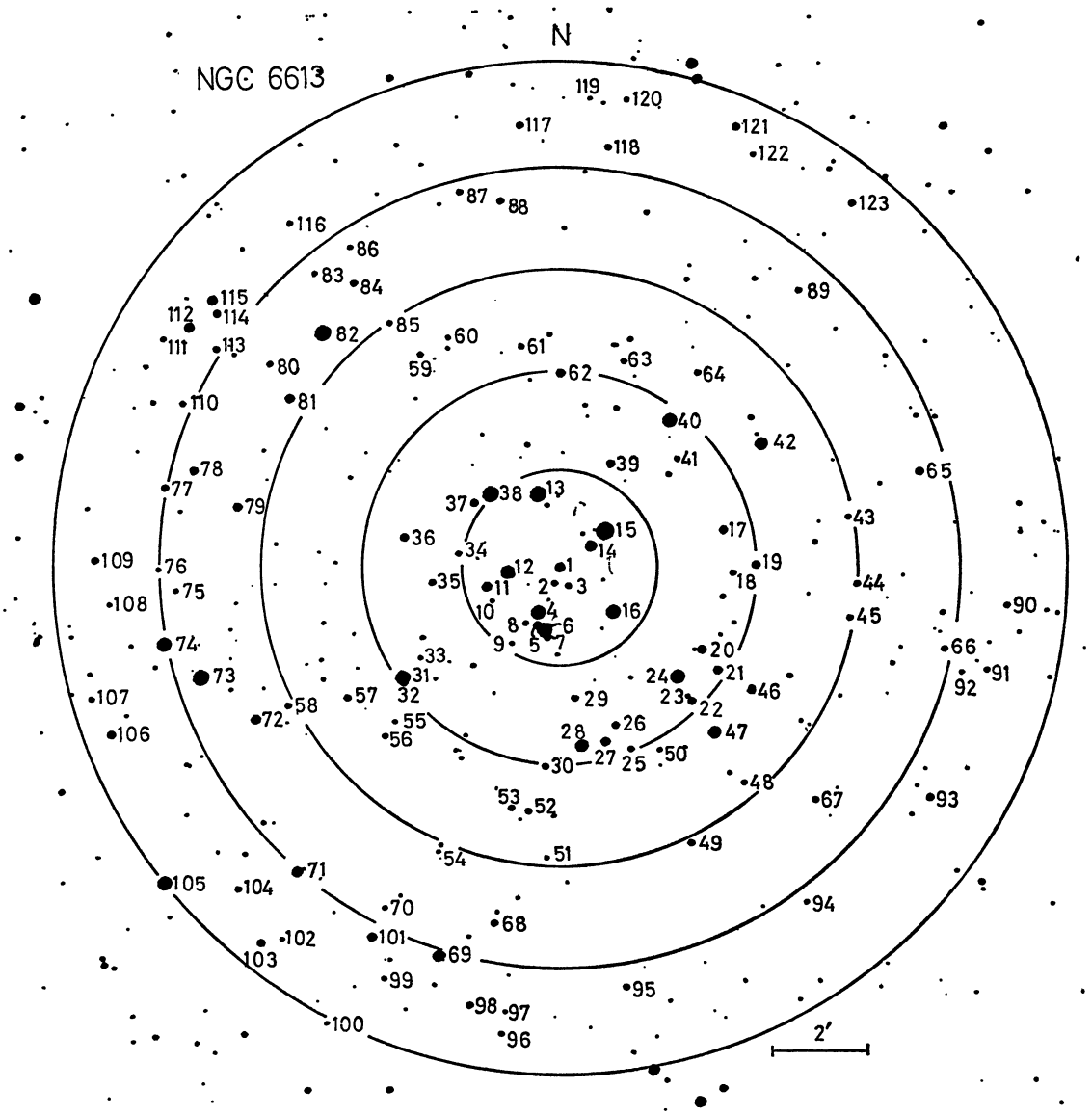

Fig. 1. Identification chart for NGC 6613

The photographic measurements have been made with the Eichner iris-diaphragm photometer of the Lund Observatory. The mean error in one measurement is about $0^m.06$.

In the Budapest Catalogue of Star Clusters and Associations (Alter *et al.*, 1970), these clusters have also been given the new notations OCl 40 and OCl 46, respectively.

II. NGC 6613

The only study more elaborated of this cluster was made by Alter in the m_p, m_{pg}-system (1943), when he found an apparent diameter of 9'.8 and a distance of 2070 pc. Other estimates according to the Budapest Catalogue (Alter *et al.*, 1970) show diameters ranging from 7' to 22' and distances from 680 pc to 4380 pc. According to Trumpler (1930)

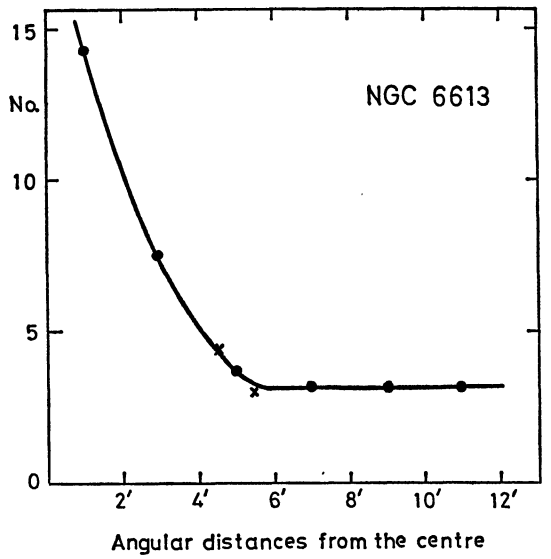

Fig. 2. Number of stars in circular regions of NGC 6613 per area equal to that of region 1. ($V \leqq 14^{m}.00$)

and Ruprecht (1966) the cluster belongs to class II 3 p.

The photoelectric sequence contains 13 stars, each star generally measured during three nights (n in Table 1). The mean error in a single photoelectric measurement is less than $0^{m}.015$ for stars brighter than the 13th magnitude. The photographic photometry, based on the photoelectric sequence and extrapolated about $0^{m}.5$, has been made in annular regions centered near star No. 1, their outer radii being 2′, 4′, 6′, 8′, 10′ and 12′. An identification chart of the 123 stars down to magnitude $V = 14^{m}$ in regions 1 to 5 is shown in Fig. 1. Star counts are illustrated in Fig. 2, which shows that the cluster diameter is about 10′ (regions 1, 2 and inner half of region 3), thus in good agreement with the value derived by Alter (1943). In the Catalogue the letters i and o after ring 3 signify "inner" and "outer".

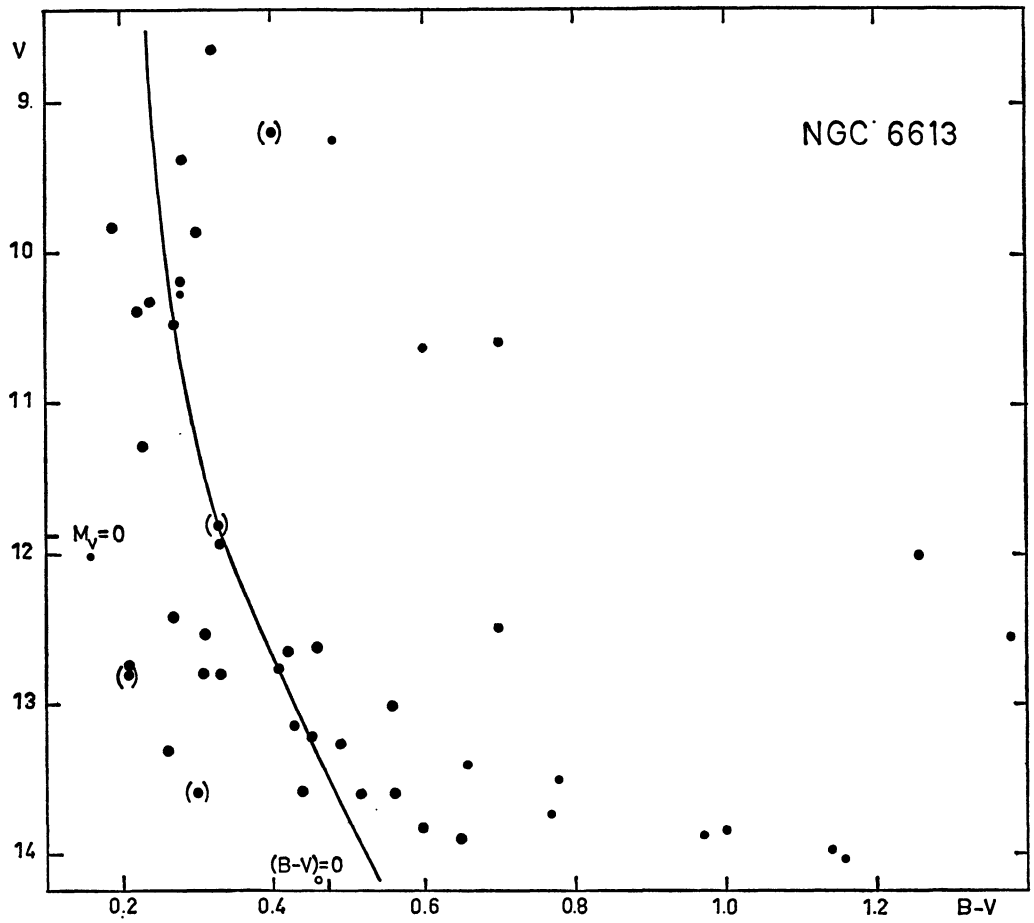

Fig. 3. Colour-magnitude diagram for stars in the cluster area of NGC 6613. Small dots indicate non-members. The magnitudes and colours of stars within brackets are considered very uncertain

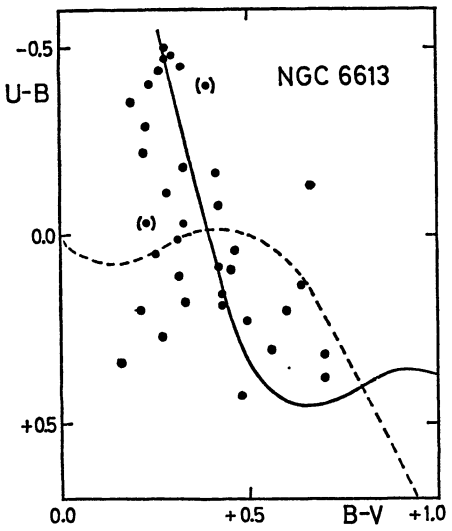

Fig. 4. Two-colour diagram for stars in NGC 6613

The colour-magnitude diagram of the stars in the adopted cluster area is illustrated in Fig. 3, showing a very clear main sequence, and the two-colour diagram is seen in Fig. 4.

As most of the brighter stars are early B-type stars, it is convenient to use for instance the nomogram given by Serkowski (1963) to determine the colour excess. Possible members with colours indicating spectral types about B9 and earlier give a colour excess $E_{B-V} = 0^{m}.47 \pm 0^{m}.03$, corresponding to an absorption of about $A_V = 1^{m}.4$, if $A_V/E_{B-V} = 3$ is accepted.

Figure 4 shows the unreddened two-colour diagram as a dashed curve and the reddened diagram (with $E_{B-V} = 0^{m}.47$) as a full-line curve.

For stars Nos. 12, 13, 15 and 38, slit-spectra were available from La Silla, showing the respective MK-classes B5V, A6V, B2III and B3IV (thus star No. 13 is not a member of the cluster). About 15 stars in the cluster area were one-dimensionally classified from four objective prism-plates, see Catalogue. An alternative method made it possible to determine the colour excess from these stars. The differences between observed and unreddened colours, derived from stars with given spectral classes, give $E_{B-V} = 0^{m}.44 \pm 0^{m}.03$, which is in good agreement with the above value.

The distance to the cluster has been determined by fitting a zero age cluster standard diagram to the colour-magnitude diagram. The full line in Fig. 3 shows the best fitting, corresponding to an observed distance modulus of $11^{m}.9$, which means (with the absorption given above) a distance of about 1250 pc. The distance to the cluster is thus smaller than was found in most of the earlier determinations. The distance modulus determined from spectral classes gives $11^{m}.8 \pm 0^{m}.2$.

Stars situated about more than $0^{m}.2$ from the adopted cluster main sequence and/or with deviating spectral type, are considered nonmembers. These stars are marked as small dots in Fig. 3 and denoted by n.m. in the Catalogue.

The age of the cluster has been determined according to a method of Lindoff (1968), which gives an age of $1.5 \cdot 10^7$ years. If we apply more modern values to the bolometric correction, as shown by Barbaro *et al.* (1969), a greater age is found, viz. $3 \cdot 10^7$ years.

NGC 6613 is thus a young cluster, the spectral type of its brightest star being B2III. As shown by Becker (1964), young clusters are situated within

Table 2. *Photoelectric standards in* NGC 6716

Star No.	Region	V	$B-V$	$U-B$	n	Sp.	Remarks
1	1	12.94	1.08	0.88	3		n.m.
3	1	9.17	0.07	−0.25	2	B8V	HD 175091
4	1	11.12	0.21	0.05	2	A2	
8	1	13.79	1.89	—	2		n.m.
9	2	10.69	0.24	0.04	2	B9:	
20	2	13.12	0.63	0.06	4		
21	2	12.31	0.66	0.12	3		n.m. ?
22	2	12.66	1.11	0.67:	2		n.m.
27	2	9.81	−0.01	−0.33	1	B9	
46	3i	8.28	0.03	−0.40	5	B7IV	HD 175043
51	3o	10.56	1.66	1.69:	2	K5	n.m.
55	3i	9.24	0.04	−0.37	2	B8IV	HD 175141

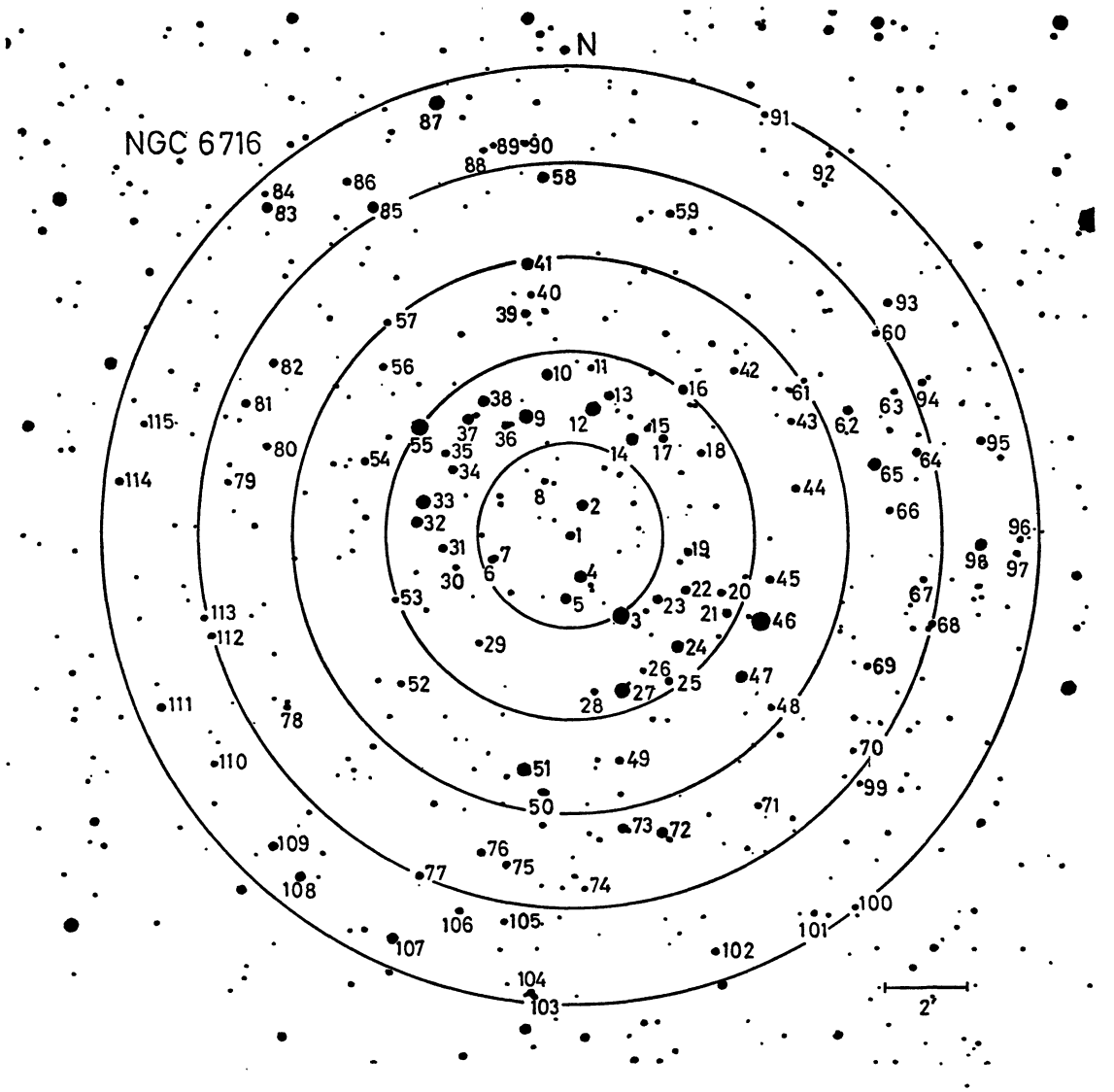

Fig. 5. Identification chart for NGC 6716

spiral arms, and NGC 6613 is located in the Sagittarius arm (−I), which approximately ranges from 1.2 kpc to 2 kpc in the galactic longitude in question.

III. NGC 6716

NGC 6716 is a small cluster in Sagittarius, situated far away from the galactic plane (10° south). It belongs to class II 3 p according to Trumpler (1930) and to IV 1 p according to Ruprecht (1966), the latter statement is in agreement with the writer's opinion.

The photoelectric sequence consists of 12 stars (see Table 2), each star generally measured during two nights.

As in NGC 6613, measurements were made in six annular regions with outer radii from 2′ to 12′, and Fig. 5 gives an identification chart of the innermost five regions. All stars down to at least $V = 13^{m}.75$ have been measured.

Star counts (see Fig. 6) show that the cluster dimension is about 10′, somewhat greater than in earlier estimates (cf. the Budapest Catalogue, 1970). From Figs. 5 and 6 it is obvious that the greatest concentration appears in region 2, which might indicate that NGC 6716 is something like a stellar ring according to the definition of Isserstedt and Schmidt-Kaler (1968).

Table 3. *Photographically measured stars in* NGC 6613 (M 18)

Star No.	Region	V	$B-V$	$U-B$	Sp.	Remarks
4	1	9.86	0.19	−0.36	—	
5	1	11.85:	0.33:	−0.03:	—	
6	1	9.2::	0.4::	−0.5::	—	
7	1	12.8::	0.2::	—		
8	1	13.68	2.7	—		n.m.
9	1	13.85	1.00	—		n.m.
10	1	14.12	1.61	—		n.m.
14	1	11.29	0.23	−0.29	B5	
17	2	12.81	0.33	−0.03	—	
18	2	13.50	0.78	—		n.m.
19	2	12.66	0.42	0.08	—	
22	2	12.43	0.27	0.27	B8:	
23	2	13.98:	1.14:	—		n.m.
24	2	10.20	0.28	−0.50	B5	
25	2	13.15	0.43	0.16		
26	2	12.82	0.31	0.11	—	
27	2	12.02	0.16	0.34	—	n.m. ?
29	2	13.36	0.26	0.05		
30	2	13.55	1.98	—		n.m.
31	2	9.85	0.30	−0.48	B3	
32	2	13.6::	0.3::	—		
33	2	13.88	0.97	—		n.m.
34	2	13.61	0.56	—		
35	2	13.23	0.45	0.09		
36	2	12.69	0.46	0.04	—	
37	2	12.76	0.21	0.20	B8	
39	2	12.78	0.41	−0.17	—	
40	2	10.28	0.28	−0.11	B9	n.m. HD 168327
41	2	13.83	0.60	—		
42	3i	10.68	0.60	0.20	B9	n.m. HD 168303
43	3o	13.68	0.56	—		
44	3o	13.31	0.84	—		n.m.
45	3o	13.64	0.85	—		n.m.
46	3i	12.48	0.70	0.38	—	n.m.
48	3o	13.78	0.84	—		n.m.
49	3o	13.08	1.47	—		n.m.
50	3i	13.89	0.65	—		
51	3o	13.98	0.57	—		n.m.
52	3i	13.27	0.49	0.23		
53	3i	13.42	0.66	−0.13		n.m.
54	3o	13.95	0.47	—		n.m.
55	3i	14.05	1.16	—		n.m.
56	3i	13.73	0.77	—		n.m.
57	3i	13.04	0.56	0.30		
58	3o	13.00	0.42	−0.08		n.m.
59	3i	13.60	0.52	—		n.m.
60	3o	13.98	0.68	—		
61	3i	13.70	0.80	—		n.m.
62	3i	12.29	0.64	0.14	B9:	n.m.
63	3i	13.61	0.93	—		n.m.
64	3i	13.52	1.12	—		n.m.
65	4	12.63	0.35	−0.13	B9	n.m.
66	4	13.18	0.68	—		n.m.
67	4	13.51	1,01	—		n.m.
68	4	13.12	0.87	—		n.m.

Table 3 (continued)

Star No.	Region	V	$B-V$	$U-B$	Sp.	Remarks
69	4	10.75	0.39	0.37	A2	n.m.
70	4	14.01	0.69	—		n.m.
71	4	11.29	1.89	—	K5:	n.m.
72	4	12.37	0.38	0.36	A3	n.m.
73	4	9.37	0.25	−0.57	B6	n.m. HD 168448
74	4	9.86	0.07	−0.49	B7	n.m. HD 168463
75	4	13.74	0.79	—		n.m.
76	4	13.92	0.87	—		n.m.
77	4	12.89	1,53	—		n.m.
78	4	12.41	0.31	−0.08	—	n.m.
79	4	12.30	0.88	0.23		n.m.
80	4	13.64	1.14	—		n.m.
81	4	12.30	1.67	—		n.m.
82	4	9.48	0.25	−0.25	B5	n.m. HD 168418
83	4	13.58	0.41	—		n.m.
84	4	12.95	0.76	0.17		n.m.
85	4	13.66	0.82	—		n.m.
86	4	13.80	0.59	—		n.m.
87	4	13.26	0.91	—		n.m.
88	4	13.01	0.81	−0.02		n.m.
89	4	13.55	0.83	—		n.m.
90	5	13.57	0.84	—		n.m.
91	5	13.23	0.65	—		n.m.
92	5	13.73	0.44	—		n.m.
93	5	12.48	0.47	0.27	A1	n.m.
94	5	13.57	0.67	—		n.m.
95	5	13.04	0.50	0.24		n.m.
96	5	13.68	0.80	—		n.m.
97	5	13.84	1.14	—		n.m.
98	5	12.96	0.92	—		n.m.
99	5	13.70:	1.00:	—		n.m.
100	5	13.98:	1.46:	—		n.m.
101	5	11.78	0.27	−0.35	B7	n.m.
102	5	13.90	0.85	—		n.m.
103	5	12.64	1.13	−0.24		n.m.
104	5	13.23	0.34	0.14		n.m.
105	5	9.97	2.02	2.16	K5:	n.m.
106	5	12.33	1.71	—		n.m.
107	5	13.23	0.85	−0.10		n.m.
108	5	13.96	1.02	—		n.m.
109	5	12.82	0.87	0.27		n.m.
110	5	13.57	0.95	—		n.m.
111	5	13.57	0.56	—		n.m.
112	5	11.61	2.05	—		n.m.
113	5	13.46	0.09	0.38		n.m.
114	5	12.52	0.81	0.31		n.m.
115	5	11.65	0.27	−0.16	B5	n.m.
116	5	13.42	0.74	—		n.m.
117	5	13.03	0.65	0.28		n.m.
118	5	13.24	0.47	0.21		n.m.
119	5	13.97	0.81	—		n.m.
120	5	13.61	0.72	—		n m.
121	5	12.80	1.34	—		n.m.
122	5	13.76	1.01	—		n.m.
123	5	13.19	0.35	0.13		n.m.

Table 4. *Photographically measured stars in* NGC 6716

Stars No.	Region	V	$B-V$	$U-B$	Sp.	Remarks
2	1	11.81	0.36	0.15	—	
5	1	12.20	0.28	0.17	A3:	
6	1	13.1::	1.5::	—		n.m.
7	1	13.7::	0.8::	0.2::		
10	2	11.95	1.19	0.90		n.m.
11	2	13.71	0.61	0.23		
12	2	9.99	0.04	−0.25	B8	
13	2	12.47	0.35	0.23		
14	2	11.15	0.20	−0.05	A1	
15	2	13.69	0.39	0.43		n.m. ?
16	2	12.29	0.42	0.07		
17	2	12.91	0.60	0.11		
18	2	13.22	0.74	0.00		
19	2	13.00	1.79	—		n.m.
23	2	12.38	0.41	0.16		
24	2	11.20	1.68	1.74		n.m.
25	2	13.02	0.74	−0.02		
26	2	13.90	0.77	0.05		
28	2	13.56	1.51	—		n.m.
29	2	13.87	0.75	0.11		
30	2	13.66	0.67	0.17		
31	2	12.93	1.99	—		n.m.
32	2	11.21	0.10	0.23		
33	2	9.97	−0.08	−0.39	B8	
34	2	12.66	1.37	1.11		n.m.
35	2	13.49	0.62	0.08		
36	2	12.92	0.57	0.17		
37	2	11.81	0.32	0.19	A1	
38	2	11.77	0.35	0.06	A2	
39	3i	12.61	1.39	—		n.m.
40	3o	13.45	1.59	—		n.m.
41	3o	11.33	0.25	−0.05	B9	n.m.
42	3o	13.53	1.15	—		n.m.
43	3o	13.53	1.62	—		n.m.
44	3i	13.08	1.68	—		n.m.
45	3i	12.81	1.54	—		n.m.
47	3i	11.62	0.22	0.01	A1	
48	3o	13.55	1.96	—		n.m.
49	3i	12.86	1.97	—		n.m.
50	3o	13.0::	1.4::	—		n.m. double
52	3i	13.47	1.20	0.47		n.m.
53	3i	13.79	1.58	—		n.m.
54	3i	13.26	0.57	0.02		
56	3o	13.29	1.61	—		n.m.
57	4	13.29	2.29	—		n.m.
58	4	11.69	1.13	0.50		n.m.
59	4	12.96	0.90	0.11		n.m.
60	4	13.58	1.58	—		n.m.
61	4	13.91	1.46	—		n.m.
62	4	12.38	1.71	—		n.m.
63	4	13.79	1.18	—		n.m.
64	4	12.64	0.53	0.19		n.m.
65	4	10.86	0.09	−0.07	B8	n.m.
66	4	13.39	0.62	0.06		n.m.
67	4	13.55	1.98	—		n.m.

Table 4 (continued)

Star No.	Region	V	$B-V$	$U-B$	Sp.	Remarks
68	4	13.12:	0.62:	0.11:		n.m.
69	4	13.17	1.58	—		n.m.
70	4	13.81	0.92	—		n.m.
71	4	13.41	0.40	0.29		n.m.
72	4	11.51	0.19	0.10	B9	n.m.
73	4	11.93	0.31	0.06	—	n.m.
74	4	13.76	1.47	—		n.m.
75	4	13.16	0.67	0.00		n.m.
76	4	12.78	1.54	—		n.m.
77	4	12.79	0.53	0.10		n.m.
78	4	13.39	0.52	0.13		n.m.
79	4	13.44	2.19	—		n.m.
80	4	13.03	0.77	0.04		n.m.
81	4	12.62	1.67	—		n.m.
82	4	12.53	1.66	—		n.m.
83	5	11.77	0.32	−0.01	A8	n.m.
84	5	13.65	1.45	—		n.m.
85	5	11.49	0.61	0.05		n.m.
86	5	13.21	1.66	—		n.m.
87	5	9.86	0.61	0.02	G2	n.m.
88	5	13.50	1.59	—		n.m.
89	5	13.41	1.86	—		n.m.
90	5	13.22	2.04	—		n.m.
91	5	13.42	2.07	—		n.m.
92	5	13.65	0.58	0.33		n.m.
93	5	12.81	1.98	—		n.m.
94	5	12.93	0.59	0.00		n.m.
95	5	12.72	1.38	0.74		n.m.
96	5	13.37	1.10	0.69		n.m.
97	5	13.26	2.02	—		n.m.
98	5	11.34	0.86	0.11	K	n.m.
99	5	13.50	1.82	—		n.m.
100	5	13.47	0.77	−0.08		n.m.
101	5	13.54	0.84	0.16		n.m.
102	5	12.94:	0.56:	0.07:		n.m.
103	5	13.2::	2.3::	—		n.m.
104	5	12.44:	1.99:	—		n.m.
105	5	13.54	1.51	—		n.m.
106	5	12.82	0.72	0.02		n.m.
107	5	11.69	0.29	0.10	A3	n.m.
108	5	11.51	1.99	1.70		n.m.
109	5	12.18	1.25	0.87		n.m.
110	5	13.38	2.28	—		n.m.
111	5	12.51	0.47	−0.04		n.m.
112	5	13.38	0.71	−0.10		n.m.
113	5	13.49	0.90	0.57		n.m.
114	5	12.51	1.72	—		n.m.
115	5	13.30	2.13	—		n.m.

The colour-magnitude diagram for the cluster area, shown in Fig. 7, gives a well defined cluster sequence. The two-colour diagram (see Fig. 8) shows that most stars are of late B- and A-types, and it is difficult to use the Serkowski nomogram (1963) to derive the colour excess for the stars in the cluster. A direct displacement of the unreddened two-colour diagram (dashed curve in Fig. 8) along the reddening

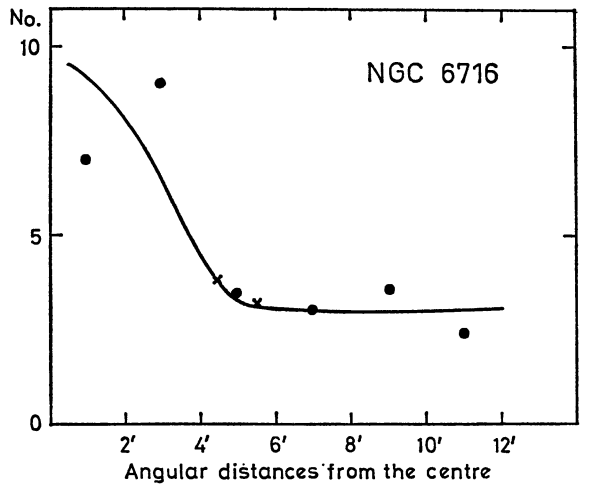

Fig. 6. Number of stars in circular regions of NGC 6716 per area equal to that of region 1. ($V \leqq 13^{m}.75$)

line gives the best adaptation (full line in Fig. 8) to $E_{B-V} = 0^{m}.13$, corresponding to $A_V = 0^{m}.4$. By comparing the colour-magnitude diagram with a standard zero age diagram, the apparent distance modulus to the cluster has been determined to $9^{m}.3$ (full line in Fig. 7). With the above absorption it means a distance to NGC 6716 of about 600 pc. Previous estimates range from 760 pc to 1320 pc.

For stars Nos. 3, 46 and 55, slit-spectra from La Silla were available, showing the respective MK-classes B8V, B7IV and B8IV. An objective prism-plate covering the cluster area made it possible to classify about 15 objects. An alternative estimate of the colour excess and the distance was made possible by using spectral classes. The derived values, $E_{B-V} = 0^{m}.20 \pm 0^{m}.03$ and 750 pc, are in fair agreement with the values derived from magnitudes and colours.

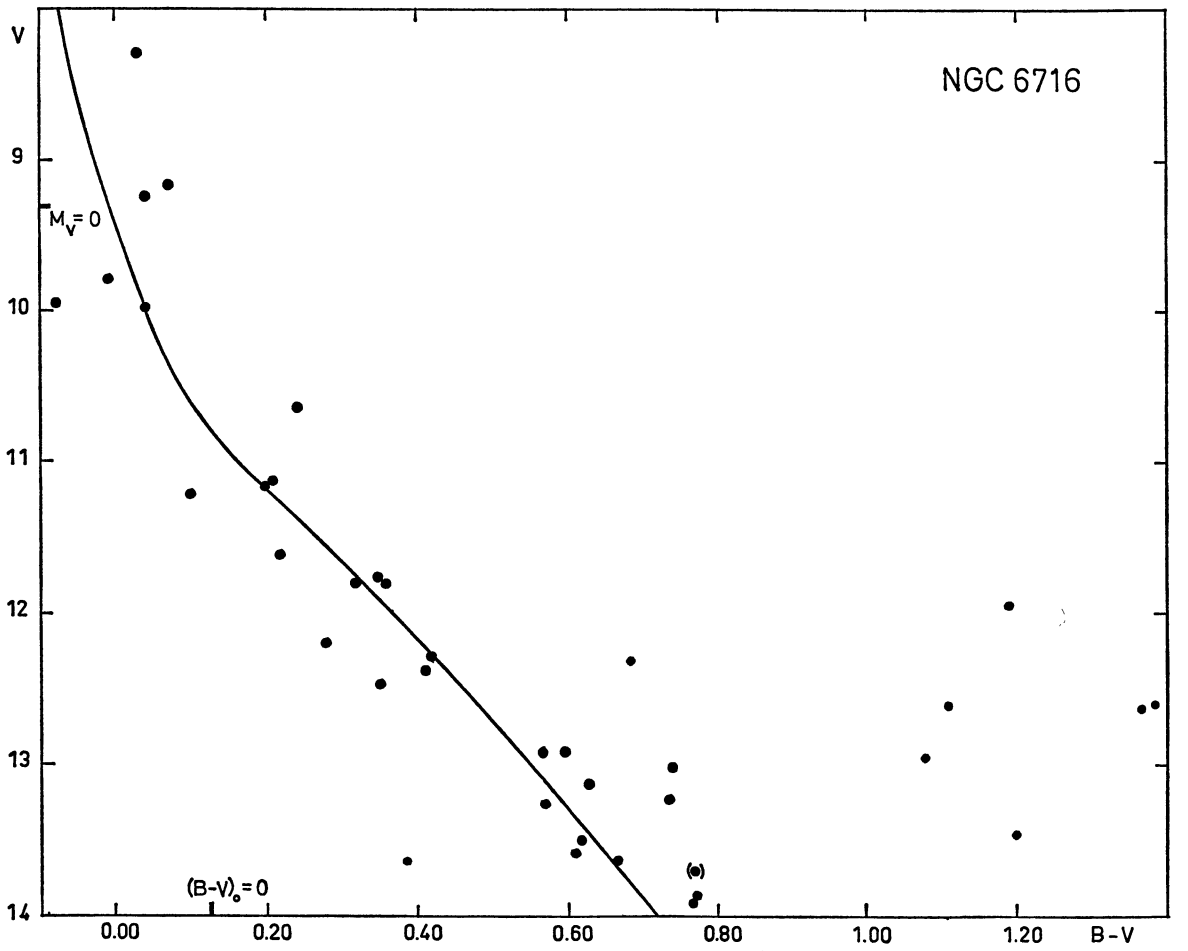

Fig. 7. Colour-magnitude diagram for NGC 6716

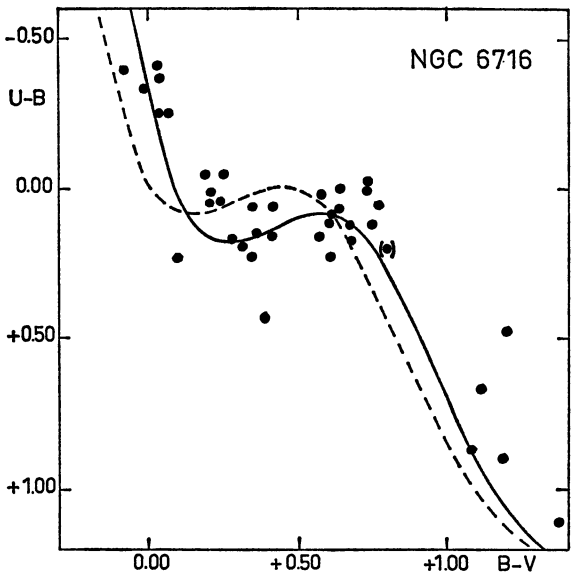

Fig. 8. Two-colour diagram for NGC 6716

The age can be estimated to $8 \cdot 10^7$ years according to the writer's method (1968). With other values for the bolometric correction according to Barbaro *et al.* (1969), the age is somewhat greater, viz. $1.5 \cdot 10^8$ years.

It is of interest to make some further comparisons with the disputed stellar rings (Isserstedt, Schmidt-Kaler, 1968). According to these authors, the minor axis is very close to 7.1 pc. In NGC 6716, with a concentration in region (ring) 2, a diameter of about 1 pc has been derived, significantly smaller than the Isserstedt value. On the other hand, NGC 6716 is a fairly old object ($1.5 \cdot 10^8$ years), while the stellar rings are very young, less than $2 \cdot 10^6$ years. Although reminding of a stellar ring, NGC 6716 is not the type of object indicated by Isserstedt and Schmidt-Kaler.

IV. Summary of Results

	NGC 6613	NGC 6716
Apparent diameter	10′	10′
Absorption	$1^m.4$	$0^m.4$
Distance	1250 pc	600 pc
Linear diameter	3.5 pc	1.8 pc
Limiting apparent magnitude (V)	$14^m.0$	$13^m.75$
Limiting absolute magnitude	$+2^m.0$	$+4^m.5$
Estimated number of cluster members brighter than the limiting magnitude	30	25
Distance from galactic plane	22 pc	100 pc
Spectral type of the brightest main sequence member	B2 III	B7 IV
Possible giant members	0	0
Absolute magnitude of the brightest member	$-3^m.3$	$-1^m.2$
Mean member density of stars brighter than the limiting magnitude (stars per pc^3)	1.3	6
Age	$3 \cdot 10^7$ years	$1.5 \cdot 10^8$ years
Apparent total magnitudes (prob. member only) V_{tot}	$7^m.1$	$7^m.0$
Integrated colours of all possible members $(B-V)_{tot}$	$0^m.35$	$0^m.07$

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U. Lindoff
Lunds Observatorium
S-222 24 Lund
Sweden