PROCEEDINGS ITB Vol. 6, No. 3, 1972.

PHOTOGRAPHIC PHOTOMETRY OF NGC 6866*)

B. Hidajat and W. Sutantyo**)

R I N G K A S A N

Magnitudo dan warna dalam sistim UBV-photometri untuk 575 buah bintang disekitar NGC 6866 telah diukur setjara photographi-photometri. Excess warna, jang diturunkan dari diagram warna-warna, telah ditentukan sebesar 0.16 magnitudo.

Djarak gugus bintang tersebut diperkirakan 1336 pc. Dari kurva evolusi diketahui bahwa umur gugus tersebut 2.5 x 10^8 tahun.

A B S T R A C T

Magnitudes and colors in the UBV photometric system have been determined for 575 stars in and around NGC 6866. The color-color relation of the cluster stars provides an estimate of interstellar reddening of 0.16 mag.

The distance of cluster is found to be 1336 pc. The age, as determined from the evolutionary deviation curve, is approximately 2.5 x 10^8 years.

INTRODUCTION

The cluster NGC 6866 is situated at R.A. (1950) = $20^h\ 02^m.6$; Dec. (1950) = + 44°02' (l = 79°.4; b = +6°.8). According to Ruprecht (1966) the cluster belongs to the Trumpler class II2m. Inspection of Lynds' Catalogue of Dark Nebulae (1962) shows that the cluster is situated at the edge of a dark cloud. Photometric data for 25 stars by Hoag et al. (1961) in the cluster area shows that the color-magnitude diagram of the cluster resembles that of the intermediate-age cluster.

The purpose of the present study is to determine the angular extent of the cluster and to find any nonuniformity of the reddening across the cluster area. The investigation is based on the photographic photometry of 575 stars down to a limiting B-magnitude of $16^m.5$, in

*) Contribution from the Bosscha Observatory, No. 44, 1972.

**) Bosscha Observatory, Lembang, Java, Indonesia.

an area of 15' from the adopted center of the cluster. This area is considered large enough to include the possible intrusion of the dark cloud. In the present study only stars which are well separated were measured photographically.

PHOTOGRAPHIC PHOTOMETRY

The photometric material in the UBV system were collected with the Hamburg Schmidt Telescope. Table I gives the relevant data of the photometric plates. The photometric measurements was carried out with the Eichner astrophotometer of the Bosscha Observatory. It was tied

TABLE I

The Photometric Plates

Date	Plate No.	Color	Kodak Emulsion and Filter	Exp. in Minute	Observer
Oct. 9, '67	3858	U	103a-0 + UG 1	15	Hidajat
Oct. 9, '67	3865	U	"	30	"
Oct. 9, '67	3866	U	"	15	"
July 28, '68	4023	B	IIa-0 + GG 13	19	Lubeck
July 28, '68	4024	B	"	20	"
July 28, '68	4025	B	"	20	"
July 23, '68	4010	V	103a-D + GG 11	7	"
July 23, '68	4011	V	"	10	"
July 23, '68	4012	V	"	10	"

into the UBV-photometric system by means of photoelectric standards established by Hoag et al. (1961), the faintest of which reaches U = $16^{m}.5$; B = $16^{m}.4$ and V = $15^{m}.9$. Extrapolation of the calibration curves, no more than $0^{m}.3$ in each of the colors was justified because of the linearity of the calibration curves in the magnitude-intervals employed in the present study. The measurements of the standard deviations of the sequence stars from the calibration curves for a certain plate is used as a measure of the weight of the magnitudes determined from this particular plate. Using these weights the mean magnitudes and colors of the program stars are calculated. A comparison between the mean photographic and photoelectric data of the sequence stars was used as an estimate of the accuracy. The standard error from the mean of V, B-V and U-B obtained in this way are $0^{m}.06$, $0^{m}.08$ and $0^{m}.08$ respectively. It was observed that there is no appreciable systematic differences between the measurements carried out by each of us. The results of the photometric determinations are presented in the Appendix. The numbers correspond to the number in Plate 1.

STELLAR COUNTS

In order to determine the extent of the cluster a stellar-count as a function of the radius was performed. The area where the counts were made is 15' from the cluster's center. The cluster area was di-

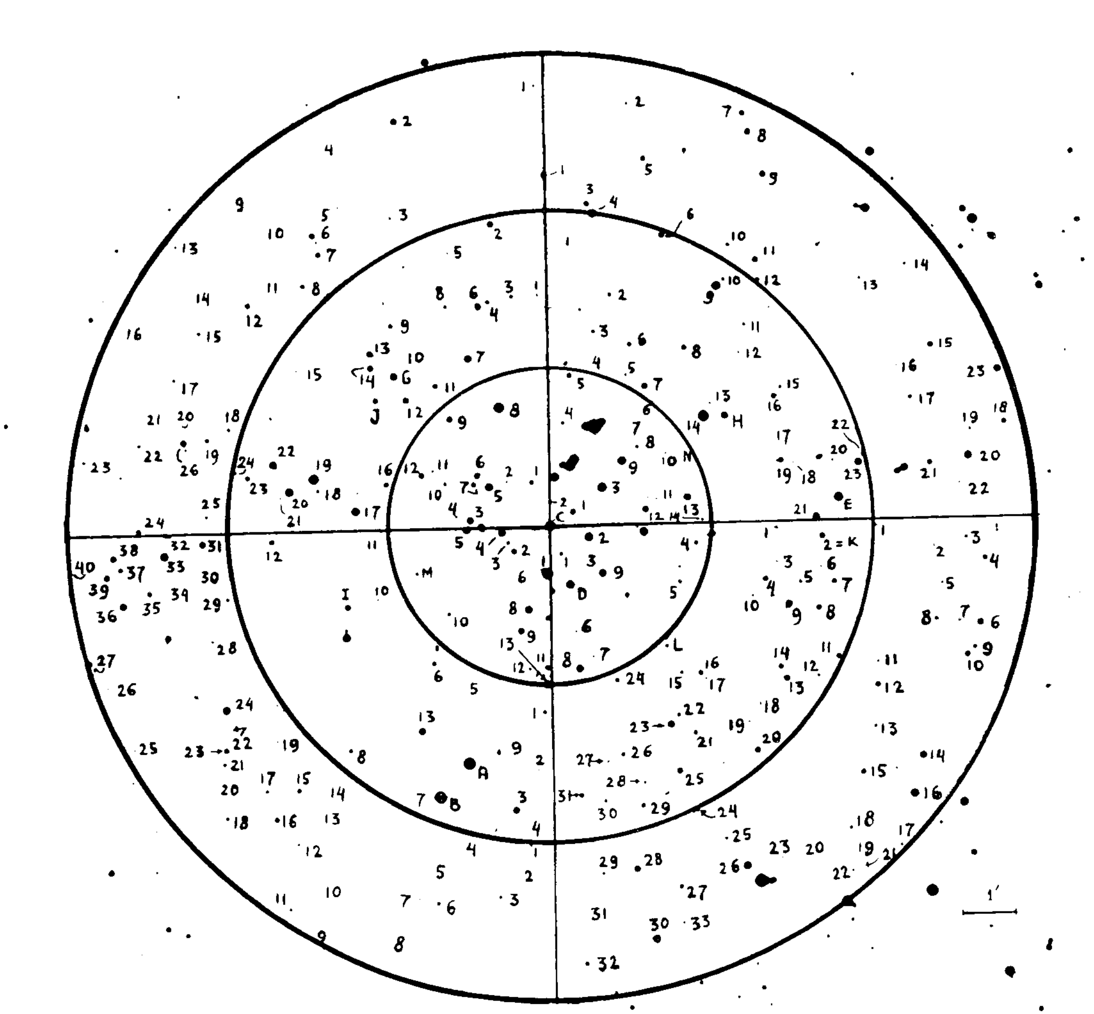


Plate 1 : Identification chart for stars in NGC 6866.

vided into 4 quadrants, defined more or less by the north-south and east-west directions. Concentric circles, whose radii differ by 3' of arc, were drawn upon the cluster area. All stars down to B=16.00 were then counted. The stars per unit area, which is the area of the innermost circle, are plotted as a function of the angular distance from the cluster. The result is shown in Fig. 1.

The error of the counts is proportional to the $\sqrt{n}$, where n is the number of stars in the particular ring in each quadrant. The mean of the counts for each ring can then be made, taking into account the errors of the counts. Solid lines are drawn through the means. It can be seen in Fig. 1 that the curve seems to level off at the end of ring 3, the radius of which is 9'. The figure also reveals that Quadrant IV consistently contains larger number of stars than that found in other quadrants. This trend is also observed in the stellar counts for stars brighter than visual magnitude of $15^{m}.8$. The "excess" of stars in Quadrant IV may be accounted for the possible existence of unequal absorption among the quadrant. This view may be supported by the result of the examination of the Palomar Sky Atlas. On the red plate, of the general direction of the cluster, there appears a trace of absorbing cloud covering part of Quadrant III.

INTERSTELLAR REDDENING AND DISTANCE

Separate color-color diagrams for stars in different quadrants suggest that quadrant III shows slightly higher reddening than that can be observed in other quadrants. However, in view of the accuracy of the present photometry, no attempt has been made to perform a separate investigations for each quadrant.

In the following, only stars within 9' from the adopted center of the cluster will be discussed. The color-color diagram for these stars is presented in Fig. 2. It is possible then to fit the two-color diagram of the unreddened main sequence stars (shown as solid line) as given by Johnson and Iriarte (1958) to the observed color-color plot of the cluster. If the reddening line is taken as 0.72 it can be found that the color excess E_{B-V} is $0^{m}.16$.

It is noted that there is a group of stars (14 in numbers) whose colors are centered around U-B = $-\ 0^{m}.2$ and B-V = $+\ 0^{m}.90$. These stars may not be cluster's members. If they were cluster's members they must have come from the upper part of the main sequence. This would give too large a reddening ($0^{m}.6$) for the cluster, which would contradict the reddening law found for the general direction of the cluster. As has been found earlier Fitzgerald (1968), Wehinger and Hidajat (1972), and Lindoff (1972), the reddening in the direction in this particular galactic longitude should not exceed $0^{m}.20$. Lindoff's study was based on the cluster NGC 6811. The group of stars mentioned here may form a group of early-type stars. Taking the ratio of the total to selective absorption equal to 3.0, we can then find the total absorption in front of the cluster is $0^{m}.48$.

Fig. 3 shows the color-magnitude diagram of the cluster. In this diagram the main sequence of the cluster can be identified. The spread of the points in this diagram is rather large which may be due to the uneveness of the absorption across the cluster area. The distance modulus of the cluster can be determined by fitting the zero-age main sequence given by Blaauw (1963) to the cluster's main sequence. This method yields an uncorrected distance modulus of $V-M_V = 11^{m}.10$.

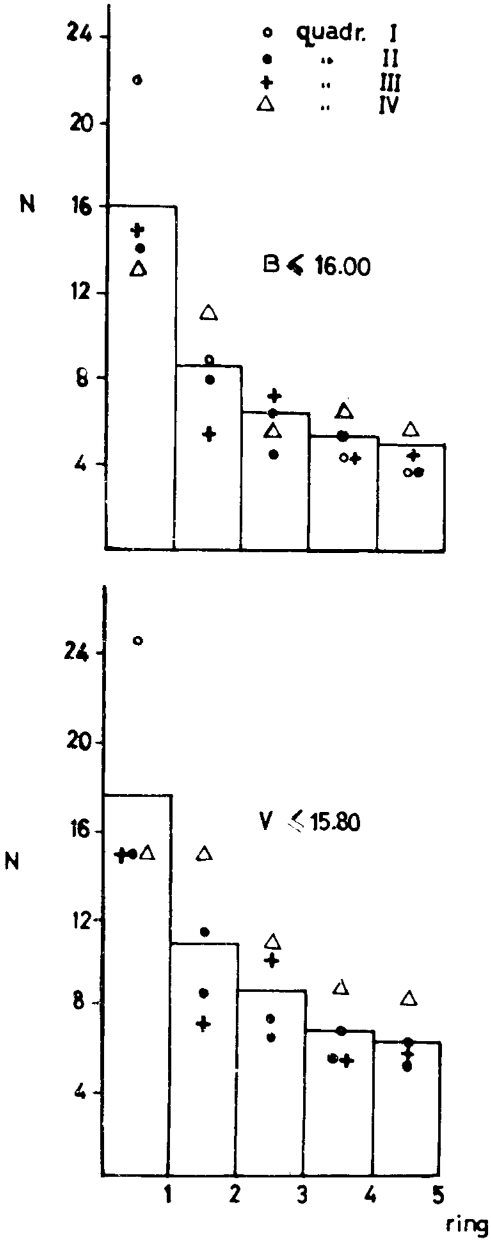


Fig. 1 : Surface density of stars in NGC 6866. N is the number of stars per unit area. The area of ring 1 is adopted as unit area.

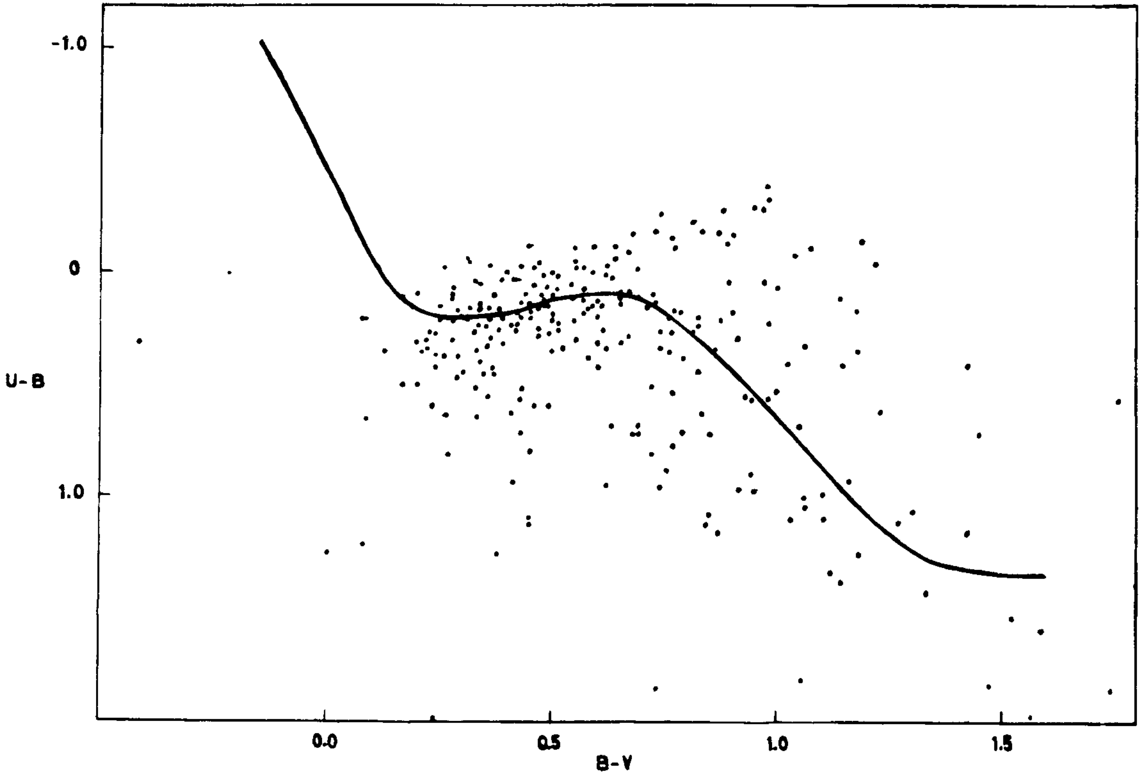
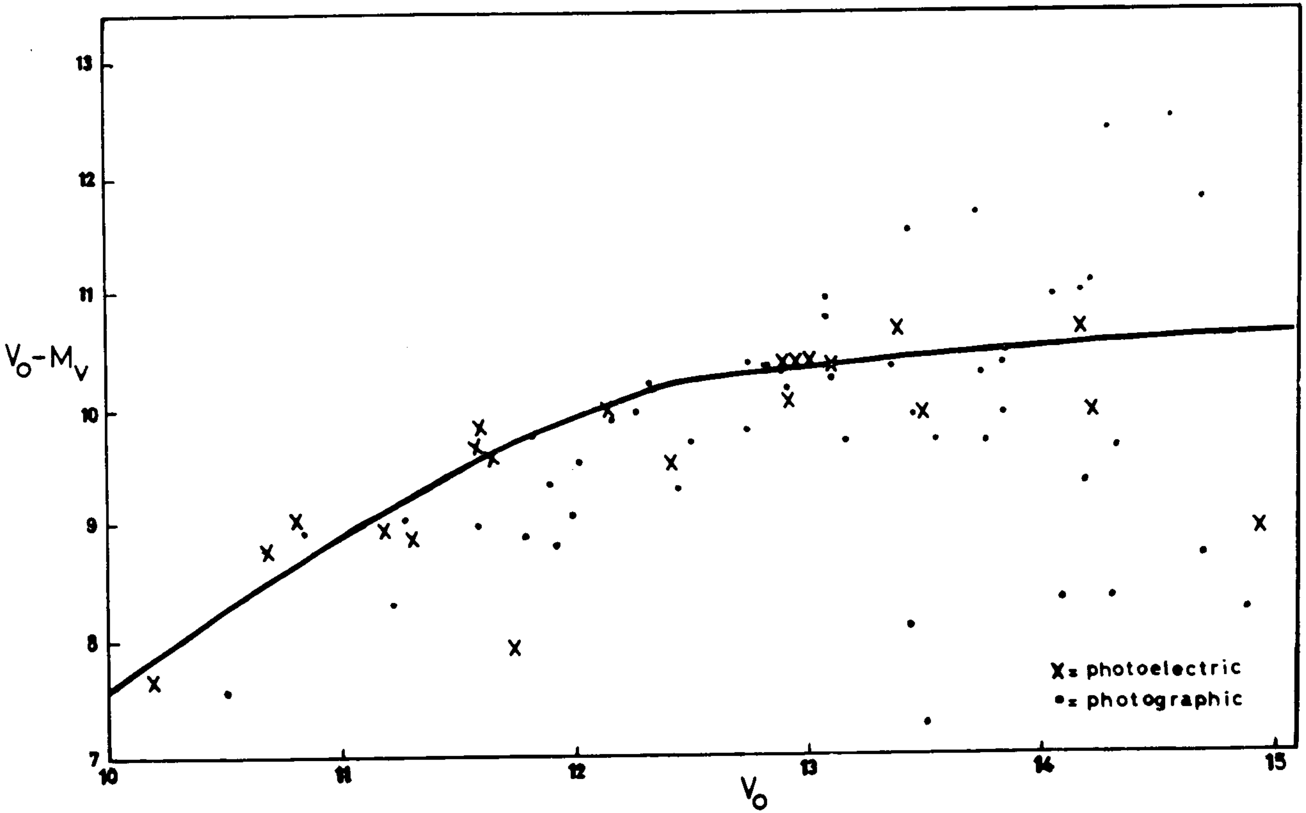


Fig. 2 : Two colour diagram of stars within radius of 9' from the adopted centre.



<u>Fig. 3</u> : Colour-magnitude diagram of stars within radius of ' from the adopted centre.

Using the absorption found above, the true distance modulus is found to be $10^{m}.62$, corresponding to a distance of 1330 pc.

Following Johnson (1960) we computed the corrected distance modulus of stars in the cluster. The average reddening, rather than reddening for individual stars, has been used to obtain the true distance modulus and corrected apparent magnitude. The intrinsic colors have been obtained by subtracting the reddening from the observed colors. These colors were then used to determine the absolute magnitudes by means of the color-magnitude relation calibrated by Blaauw (1963). Using the corrected distance modulus and the corrected apparent magnitude the evolutionary deviation curve can be conestructed. Fig. 4 shows the evolutionary deviation curve. Then, the evolved main sequence curve was fitted to both in modulus and in magnitude, as shown with solid line in Fig. 4. From the fainter, still unevolved stars a distance modulus of $10^{m}.64$ was obtained. The value corresponds to a distance of 1343 pc. Averaging the two estimates of distance we find the mean distance of the cluster is 1336 pc. Becker (1963) and Johnson et al. (1961), respectively found 1205 pc. and 1200 pc. for the distance of the cluster.

The turn-off point of the cluster provide the estimate of the age. Comparing with Lindoff (1968) the age of the cluster is estimated to be about 2.5 x 10^8 years.

ACKNOWLEDGEMENT

One of the authors (B.H.) would like to express his thanks to the Director of the Hamburg Observatory and to Dr. K. Lubeck who made the photometric plates available for this study. The present study is part of the author's program while he received the grant from the D.A.A.D. He should like to record his gratitude for the grant.

The authors are indebted to the Institut Teknologi Bandung for the PELITA-Fund that supported part of this study.

REFERENCES

Becker, W., 1963, Zf. f. Astroph., 57, 117.

Blaauw, A., 1963, Basic Astronomical Data, Ed. by K. Aa. Strand, p. 383. University of Chicago Press.

Fitzgerald, M.P., 1968, A. J., 73, 983.

Hoag, A.A., Johnson, H.L., Iriarte, B., Mitchell, R.I., Hallam, K.L., Sharpless, S., 1961, Publ. U.S. Naval Obs., XVII, 349.

Johnson, H.L., 1960, Lowell Obs. Bull., 5, 17.

Johnson, H.L., Hoag, A.A., Iriarte, B., Mitchell, R.I., Hallam, K.L., 1961, Lowell Obs. Bull., 5, 133.

Lindoff, U., 1968, Ark. f. Astr., 5, 1, 1968.

——————, 1972, Astron. Astroph., 16, 315.

Lynds, B.T., 1962, Ap. J. Suppl., 7, 1.

Ruprecht, J., 1966, Bull. Astron. Czech., 17, 33.

Wehinger, P.A. and Hidajat, B., 1972, To be published.

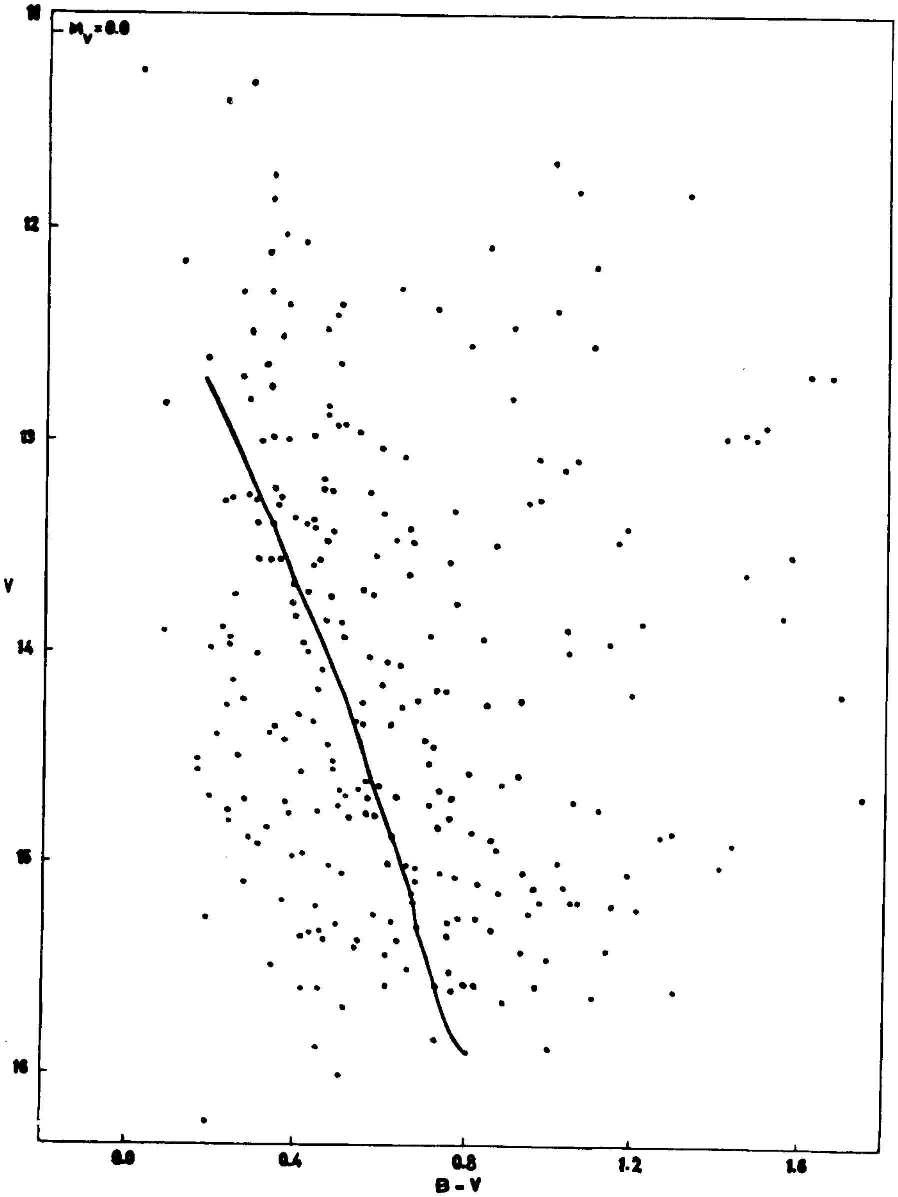


Fig. 4 : The evolution deviation curve of NGC 6866 for photoelectrically measured stars (taken from Hoag et al., 1961) and photographically measured stars in ring 1.

APPENDIX

MAGNITUDES AND COLOURS OF STARS IN NGC 6866

Quadrant I

	No.	V	B - V	U - B
Ring 1	1.	13.38	0.39	0.21
	2.	14.68	0.77	0.53
	3.	11.76	0.34	0.24
	4.	14.33	0.55	0.11
	5.	13.66	0.55	0.21
	6.	14.67	1.76	0.57
	7.	14.58	0.93	0.55
	8.	13.94	0.85	0.72
	9.	12.15	0.13	0.35
	10.	13.86	2.09	--
	11.	14.82	0.74	0.34
	12.	12.93	0.50	0.18
	13.	12.75	0.33	0.27
	14.	14.79	0.76	- 0.02
Ring 2	1.	14.90	1.45	0.72
	2.	13.56	1.50	1.09
	3.	14.24	0.86	0.34
	4.	15.00	1.42	0.41
	5.	14.76	0.57	0.12
	6.	14.02	0.58	0.16
	7.	13.41	0.45	0.20
	8.	13.73	0.59	0.15
	9.	12.12	0.33	0.35
	10.	13.85	1.23	0.62
	11.	15.17	0.38	1.26
	12.	15.17	0.69	- 0.02
	13.	14.57	0.82	0.44
	14.	11.25	- 0.03	- 0.25
	15.	14.61	0.57	0.18
	16.	13.70	0.48	0.35
	17.	15.21	1.22	- 0.04
	18.	15.18	1.08	- 0.11
	19.	13.40	0.35	0.45
	20.	13.55	2.00	--
	21.	12.38	1.02	1.26
	22.	12.91	1.52	1.54
	23.	11.83	1.33	1.43
Ring 3	1.	12.80	0.91	0.29
	2.	14.62	0.90	0.18
	3.	13.28	0.98	0.23
	4.	11.13	1.74	1.86
	5.	13.57	0.77	- 0.16
	6.	13.42	0.67	0.08
	7.	13.48	0.68	- 0.18
	8.	13.43	0.49	0.07
	9.	13.08	0.98	0.57
	10.	13.29	1.99	--
	11.	13.48	0.48	0.10

No.	V	B - V	U - B
12.	14.18	0.76	0.35
13.	15.03	0.95	- 0.30
14.	14.92	0.89	- 0.13
15.	13.71	0.43	0.13
16.	15.23	0.97	- 0.28
17.	13.89	1.05	0.68
18.	13.35	0.61	0.14
19.	14.63	0.60	0.20
20.	12.71	0.28	0.11
21.	13.74	0.49	0.06
22.	15.16	0.04	0.60
23.	12.64	0.64	--

Quadrant II

	No.	V	B - V	U - B
Ring 1	1.	13.93	0.24	0.37
	2.	15.07	0.28	0.30
	3.	12.48	0.46	0.60
	4.	14.67	0.51	0.26
	5.	12.38	0.37	0.10
	6.	12.99	0.43	0.52
	7.	13.58	0.33	0.52
	8.	11.32	0.28	0.10
	9.	13.23	0.34	0.16
	10.	12.24	0.55	0.30
	11.	14.79	0.24	0.42
	12.	13.57	0.31	0.20
Ring 2	1.	15.04	0.50	0.10
	2.	13.25	0.57	- 0.02
	3.	13.90	0.08	1.22
	4.	14.41	0.37	0.43
	5.	15.59	0.45	- 0.12
	6.	13.07	0.65	0.14
	7.	12.19	1.10	1.00
	8.	14.72	0.38	0.16
	9.	13.42	1.18	1.26
	10.	15.48	0.34	0.05
	11.	13.14	1.03	1.11
	12.	13.29	0.30	0.20
	13.	13.00	0.37	0.45
	14.	13.20	0.31	0.21
	15.	15.83	0.73	- 0.18
	16.	13.09	1.06	1.05
	17.	12.31	0.33	0.04
	18.	14.25	0.23	0.60
	19.	11.41	0.22	0.31
	20.	12.04	0.36	0.21
	21.	14.75	0.45	0.80
	22.	12.09	0.85	1.08
	23.	13.89	0.22	0.34
	24.	13.96	1.14	1.39

	No.	V	B - V	U - B
Ring 3	1.	14.78	0.52	0.34
	2.	13.28	0.36	0.17
	3.	14.97	0.39	0.22
	4.	15.05	1.19	- 0.14
	5.	15.34	0.41	0.63
	6.	13.40	0.30	0.45
	7.	13.69	0.39	0.03
	8.	13.47	1.16	0.94
	9.	15.68	0.51	0.02
	10.	15.28	0.76	0.27
	11.	15.60	0.77	0.18
	12.	13.55	0.58	0.38
	13.	14.66	0.74	0.26
	14.	15.34	0.76	0.20
	15.	14.70	0.28	0.22
	16.	15.20	1.15	0.42
	17.	14.65	0.50	0.35
	18.	14.44	0.47	0.29
	19.	13.86	0.50	0.11
	20.	15.00	1.02	0.41
	21.	15.87	0.45	0.14
	22.	14.33	0.43	0.57
	23.	14.50	0.26	0.38
	24.	13.78	0.39	0.32
	25.	14.88	0.29	0.47
	26.	13.28	0.24	0.27

Quadrant III

	No.	V	B - V	U - B
Ring 1	1.	10.53	0.36	0.55
	2.	13.40	0.42	0.25
	3.	14.22	0.27	0.64
	4.	12.51	0.36	0.30
	5.	12.41	0.49	0.15
	6.	15.20	0.45	1.10
	7.	13.85	0.47	0.25
	8.	12.64	0.32	0.16
	9.	13.23	0.46	0.06
	10.	13.09	1.86	2.56
	11.	13.59	0.44	0.10
	12.	14.55	0.49	0.59
	13.	11.69	1.00	0.53
Ring 2	1.	14.40	0.21	0.35
	2.	15.09	0.84	1.12
	3.	13.28	0.24	0.20
	4.	15.57	0.83	0.62
	5.	15.49	0.77	- 0.11
	6.	13.93	0.51	0.23
	7.	14.19	1.20	2.22
	8.	12.98	1.49	2.14
	9.	15.57	0.98	- 0.38
	10.	15.36	0.55	- 0.11
	11.	15.30	0.87	- 0.18

	No.	V	B - V	U - B
	12.	12.98	1.42	1.17
	13.	12.96	0.54	0.05
Ring 3	1.	15.24	0.59	- 0.11
	2.	15.49	0.67	- 0.09
	3.	14.22	0.94	0.90
	4.	15.64	0.90	- 0.17
	5.	15.14	0.68	0.72
	6.	14.22	0.69	0.71
	7.	15.32	0.44	0.09
	8.	15.39	0.55	- 0.04
	9.	14.84	1.30	1.07
	10.	15.56	0.81	- 0.22
	11.	14.90	0.31	- 0.06
	12.	14.95	0.42	0.23
	13.	15.32	0.46	0.06
	14.	15.28	0.50	0.21
	15.	12.96	1.47	1.84
	16.	14.00	0.31	- 0.04
	17.	14.76	0.39	0.25
	18.	14.38	0.34	0.40
	19.	14.44	0.73	1.86
	20.	15.42	0.62	0.01
	21.	14.68	0.20	0.10
	22.	15.36	0.65	0.31
	23.	13.63	0.67	0.28
	24.	12.36	0.50	0.00
	25.	15.04	0.51	0.08
	26.	14.52	0.72	0.81
	27.	12.55	0.81	0.26
	28.	13.82	1.56	1.98
	29.	14.18	0.74	0.95
	30.	15.58	0.74	- 0.27
	31.	13.19	0.46	- 0.02
	32.	15.29	- 0.03	0.75
	33.	11.82	1.06	1.01
	34.	15.08	0.69	0.11
	35.	12.68	1.67	2.43
	36.	12.38	0.73	0.13
	37.	13.28	0.95	0.97
	38.	13.26	0.29	0.17
	39.	13.04	0.60	0.13
	40.	14.73	1.12	1.34

Quadrant IV

	No.	V	B - V	U - B
Ring 1	1.	14.25	0.65	0.09
	2.	12.07	0.41	0.03
	3.	15.40	1.14	0.12
	4.	14.04	0.61	0.26
	5.	14.33	0.62	0.95
	6.	15.18	0.98	- 0.32
	7.	14.20	1.70	--
	8.	12.81	0.28	0.07
	9.	12.82	0.08	0.21

	No.	V	B - V	U - B
Ring 2	1.	14.67	0.64	- 0.12
	2.	13.56	0.45	0.12
	3.	14.85	1.27	1.12
	4.	12.67	1.62	2.51
	5.	14.76	0.59	0.00
	6.	15.10	0.97	0.04
	7.	13.48	0.87	1.17
	8.	13.83	0.40	0.00
	9.	13.32	0.77	0.77
	10.	15.29	0.69	0.69
	11.	13.76	0.78	0.18
	12.	14.86	0.63	0.02
	13.	13.55	0.36	- 0.03
	14.	13.99	0.43	0.20
	15.	14.68	0.57	0.07
	16.	13.97	0.20	0.31
	17.	15.24	0.79	0.71
	18.	15.05	0.79	0.39
	19.	15.03	0.75	0.88
	20.	13.55	0.36	0.16
	21.	14.04	0.65	0.11
	22.	14.54	0.17	0.50
	23.	12.83	0.47	- 0.04
	24.	14.13	0.60	0.32
	25.	13.72	0.25	0.15
	26.	14.17	0.45	0.17
	27.	14.87	0.87	0.21
	28.	14.55	0.82	0.24
	29.	13.91	0.72	0.50
	30.	14.63	0.55	- 0.02
	31.	14.12	0.25	0.21
Ring 3	1.	15.12	0.89	0.04
	2.	15.24	0.83	- 0.19
	3.	13.53	1.58	1.60
	4.	14.07	0.46	0.15
	5.	15.09	1.04	- 0.07
	6.	12.54	1.10	1.11
	7.	14.84	0.82	0.20
	8.	13.61	1.47	2.12
	9.	14.28	0.41	0.23
	10.	13.46	0.63	0.68
	11.	15.25	0.63	0.02
	12.	13.94	0.24	0.27
	13.	15.58	- 0.42	0.32
	14.	12.98	0.34	0.14
	15.	13.95	0.42	0.19
	16.	12.61	0.19	0.15
	17.	14.99	0.62	0.34
	18.	14.41	0.71	0.16
	19.	14.70	1.06	--
	20.	15.44	1.00	0.07
	21.	16.21	0.20	0.50
	22.	15.34	0.47	0.15
	23.	15.57	0.62	- 0.03
	24.	15.17	1.06	0.33
	25.	15.00	0.48	- 0.12

No.	V	B - V	U - B
26.	12.48	0.29	0.38
27.	14.34	0.35	0.24
28.	13.23	0.48	0.15
29.	14.71	0.72	0.10
30.	12.63	0.50	0.01
31.	15.40	0.94	0.57
32.	14.50	0.17	0.11
33.	15.82	0.60	--

(Received 29th May 1972)