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IS NGC 1938 AND NGC 1939 A BINARY CLUSTER?

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Abstract

The close pair of cluster NGC 1938 and NGC 1939 with a centre-to-centre separation of $0.6'$, which belong to the galaxy Large Magellanic Cloud, has been studied in order to establish its binarity. The observed dynamical parameters of the cluster have been derived by means of star counts whereas the stellar content of the cluster by means of low resolution objective UK Schmidt prism spectra. The integrated spectra of the clusters have shown a common origin and an intermediate age for each cluster whereas their dynamical study has shown that they are gravitationally interacting. Comparing the age of their stellar content with their dynamical and relaxation times it has been found that these clusters are physically associated, are relaxed by stellar encounters and maybe are up to be merged.

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1. Introduction

Double cluster systems in Large Magellanic Cloud (LMC) has been surveyed by authors of Refs. [1, 2] who have identified 64 probable double clusters with a centre-to-centre separation of less than $\approx 1'.3$ ($\approx$ 18 pc). A statistical study of close pairs of clusters in the LMC led to the conclusion that the LMC cluster population constitutes a statistically significant sample of binary clusters [1].

An investigation of several pair of clusters in LMC by [13] reveals that both clusters in most pairs have stellar population of the same age and appear physically bound.

The existence of physical pairs of clusters has important implications in understanding the formation and evolution of star cluster. It would appear possible that at least some of the observed cluster pairs may have originated in Giant Molecular Clouds (GMCs) as part of complexes [5] and consequently the two components of any pair would be expected to have similar ages and metallicities.

The dynamical evolution of cluster pairs has interesting implications: clusters that interact gravitationally in a pair would be expected to merge or get tidally disrupted over time-scales of a few periods. The problem of physical association of cluster pair, the common origin of their stellar population and the evidence of gravitational interaction in the cluster NGC 1938 and NGC 1939 is the subject of this investigation (Fig. 1).

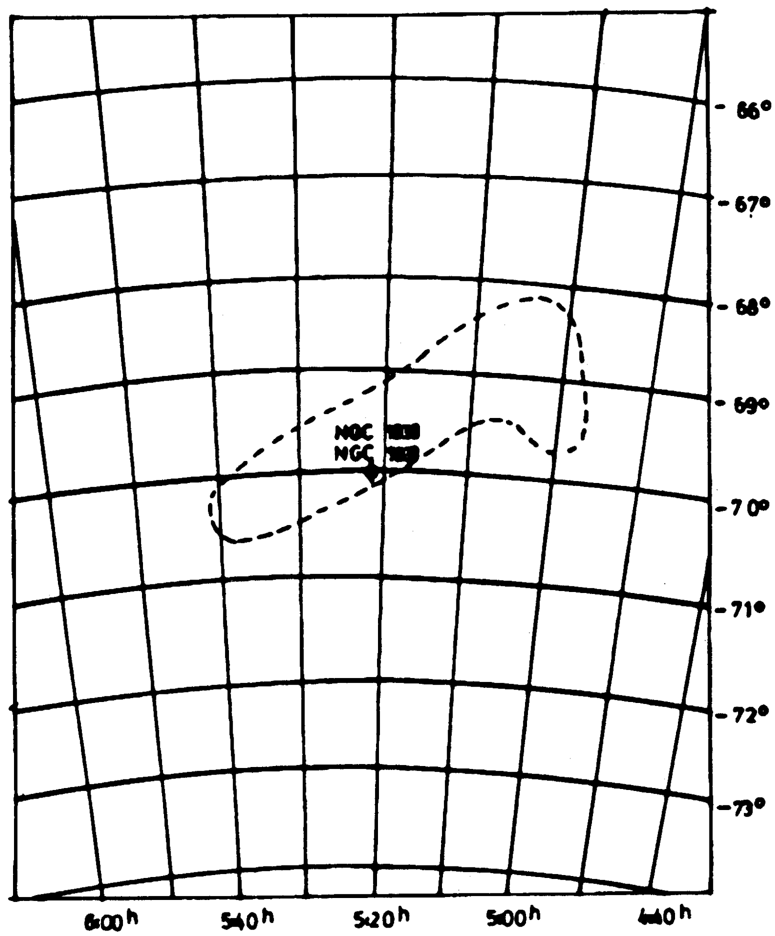

Fig. 1. Location of the clusters of our investigation in LMC.

2. Observations

A high quality film copy of photographic plate taken with the 1.2 m UK Schmidt telescope was used to perform star counts around the clusters in order to define their dynamical parameters and density profiles. The counts were carried out on a J plate of long exposure where the limit of detection for the plate is $V = 22.00$ mag. The emulsion–filter combination is IIIa+GG393.

The spectral classification of stars around the centre of each cluster of the pair has been carried out on low dispersion (2440 A mm^{-1} and 830 A mm^{-1} at H_γ) objective prism plate of the 1.2 m UK Schmidt telescope. For stars as faint as $V = 18.5$ mag the low dispersion objective prism plate provides an accuracy of the order of one spectral type.

3. Dynamical parameters and reductions

The dynamical structure of each cluster has been investigated in order to detect evidence for gravitational interaction traced in their density profiles due to the presence of a companion star cluster. Star counts have been carried out to derive the density profile and dynamical parameters of each cluster.

The star counts were carried out on the screen of a magnifying system on a circular réseau with angular separation of 0.155 arcmin for the first 10 circles and beyond this of double separation because the number of stars decreases considerably.

The circular réseau was centred by eye on each cluster and the counts were conducted inside an approximately semicircular area opposite the assumed gravitational centre of the cluster pair and clear of other clusters in the immediate neighbourhood. The measurements were made at least twice and were extended up to the background level b. For each cluster a diagram N/A vs. r was produced where N/A is the number of stars per unit area in the ring of radial distance, r, from the centre (Figs. 2, 3).

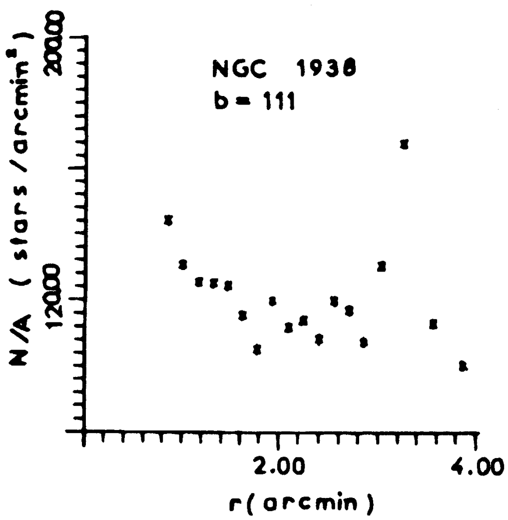

Fig. 2. Diagram N/A vs. r for the cluster NGC 1938.

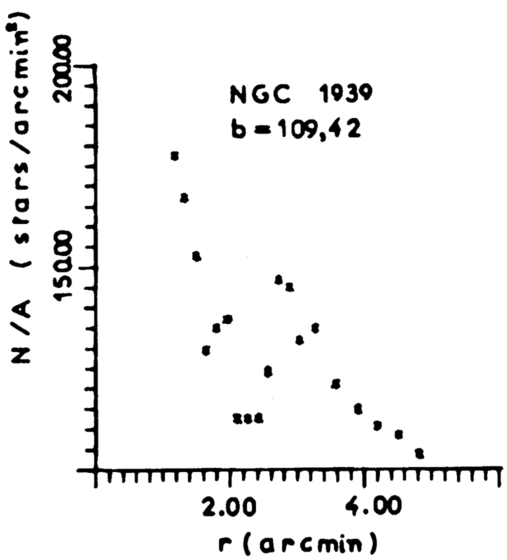

Fig. 3. Diagram N/A vs. r for the cluster NGC 1939.

The background level b for each cluster was defined from these diagrams when the N/A values were almost constant and then the ring densities

$$f_i = N_i/A_i - b$$

were found. The derived values of f are listed in Tabs. I and II. Usually, the determination of b is the main source of error in this kind of investigation. Especially for clusters like

Table I. Cluster NGC 1938 ($b = 111$).

Radius	Stars	$\log r$	$\log f$	M.e.
1–2	–	–	–	
2–3	49	−0.07	1.52	0.27
3–4	50	0.01	1.15	0.55
4–5	64	0.07	1.16	0.47
5–6	69	0.12	1.15	0.45
6–7	82	0.17	1.12	0.45
7–8	82	0.21	0.65	1.23
8–9	84	0.25	–	–
9–10	103	0.29	0.94	0.59
10–11	105	0.32	–	–
11–12	116	0.35	0.44	1.68
12–13	119	0.38	–	–
13–14	139	0.41	0.95	0.50
14–15	145	0.44	0.77	0.71
15–16	143	0.46	–	–
16–17	187	0.48	1.28	0.22
17–18	246	0.51	1.75	0.08
18–19	358	0.55	0.29	1.34
19–20	347	0.59	–	–

ours which are located at the dense regions of the bar, the background introduces a large error in the J plate which is crowded and dense. The error is given from the relation

$$\pm\frac{\sqrt{Ni}}{Ai}.$$

The first line of Tabs. I and II gives the name of the cluster and the adopted background density per arcmin^2. In column 1 the inner and outer radii are given in réseau units of each concentric ring. The total number of stars counted in that ring (cluster + field stars) are listed in column 2. Columns 3 and 4 give $\log r$ and $\log f$ (only if $\log f > 0$), where r is the "mean" radius in arcmin for all rings except the central circle and f is the stellar density per arcmin^2 of each ring. The "mean" radii "r", given in these tables, are defined as

$$r = \sqrt{r_2^2 + r_1^2}\Big/2$$

(i.e. the radius r where the area of the ring r_1, r_2 is equally divided). The first radius in these tables was taken equal to the outer radius of the innermost circle. This is a good approximation since we cannot reach the central area and the "mean" value seems unrealistic. Column 5 shows the statistical mean error in $\log f$ which is given from the relation

$$\delta(\log fi) = \pm\sqrt{Ni}/2.303(Ni - bAi).$$

The cluster tidal radii were found from the diagrams ($\sqrt{f}$, $1/r$) as described by authors of Ref. [9], who assumed a density law of the form

$$f = f_0(1/r - 1/r_\mathrm{t})^2$$

for the outer parts of the clusters. The points of these diagrams should lie on a straight line, whose intersection on the $1/r$ axis is $1/r_\mathrm{t}$. This means that the surface density f of

Table II. Cluster NGC 1939 ($b = 109.42$).

Radius	Stars	$\log r$	$\log f$	M.e.
1–2	–	–	–	–
2–3	–	−0.07	–	–
3–4	–	0.01	–	–
4–5	92	0.07	1.83	0.13
5–6	101	0.12	1.81	0.13
6–7	92	0.17	1.70	0.15
7–8	108	0.21	1.42	0.29
8–9	118	0.25	1.51	0.22
9–10	106	0.29	1.53	0.20
10–11	115	0.32	0.98	1.42
11–12	124	0.35	0.97	1.37
12–13	144	0.38	0.99	1.33
13–14	182	0.41	1.32	0.31
14–15	193	0.44	1.64	0.13
15–16	190	0.46	1.62	0.13
16–17	198	0.48	1.46	0.19
17–18	384	0.51	1.50	0.17
18–19	399	0.55	1.26	0.23
19–20	424	0.59	1.08	0.45
20–21	442	0.62	0.88	1.82
21–22	453	–	–	–
22–23	419	–	–	–

the cluster actually drops to zero at the finite value r_t, i.e. tidal radii due to the tidal forces of the parent galaxy. Of course, due to the gravitational interaction points on the plot deviate from the straight line. With the least squares best fit method we calculated the r_t values for the two clusters using points that correspond to the outer parts of the clusters. We thus found r_t between 4.7 arcmin and 5.2 arcmin for our clusters. This means at least twice the observed separation of the two clusters.

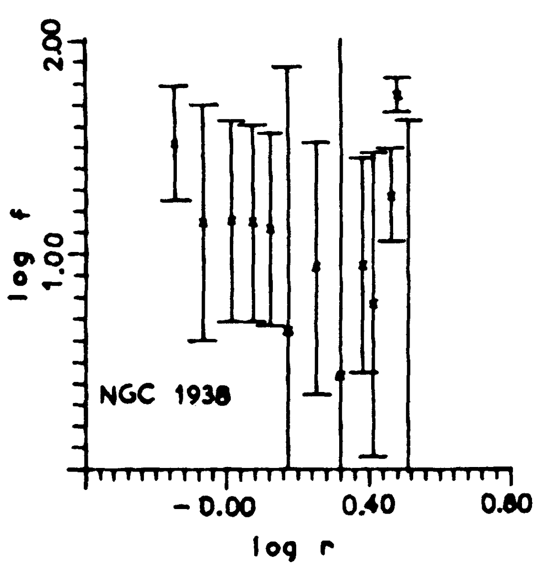

Fig. 4. Diagram $\log f$ vs. $\log r$ for the cluster NGC 1938.

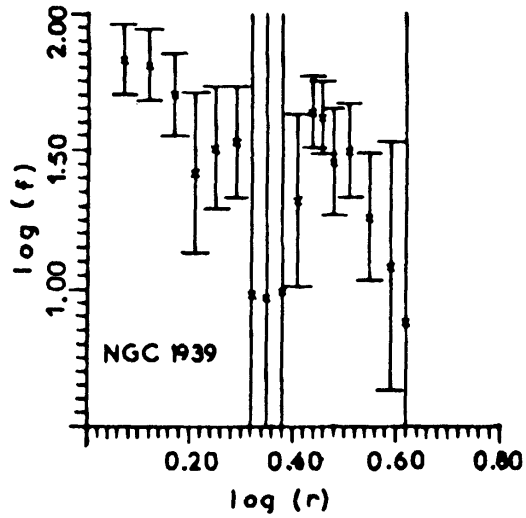

Fig. 5. Diagram log$f$ vs. log$r$ for the cluster NGC 1939.

The derived density profiles (log$f$, log$r$) are shown in Figs. 4, 5. The observed anomalies in these profiles indicate either an interaction between one another or a highly distorted background. The last case is considered improbable, since the study of a large number of single clusters [11, 14, 16, 17] has shown that the background is not so anomalous to account for the density profile deviations.

It is obvious that these profiles deviate from the isotropic King's model (Fig. 6) established by [9, 10]. However, we have assumed that each distorted profile could be approximated by a theoretical King profile in order to derive the dynamical parameters, like core radii and dynamical masses for comparison between each other as previously described. Using f_0 and r_c as free parameters the result is independent of the previous defined r_t.

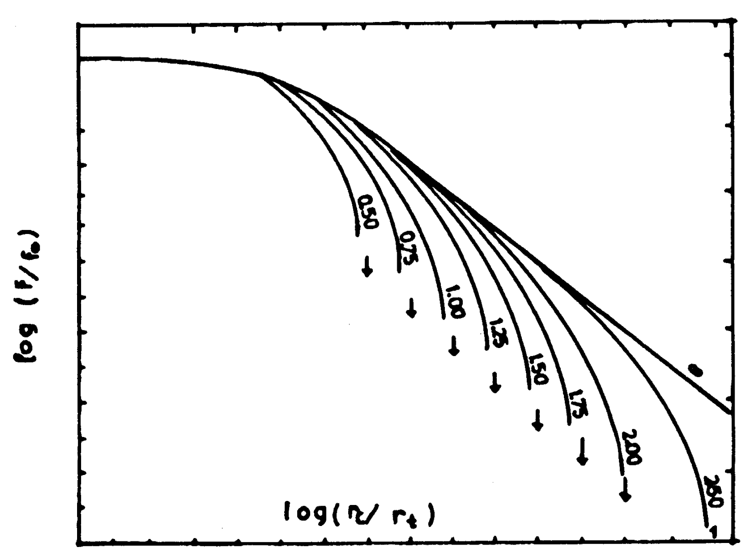

Fig. 6. King's theoretical model (1966).

The concentration parameters $\log(r_t/r_c)$ were found for the two clusters to be equal to 0.75–1.00 and 1.50–1.75. We have two values for each cluster for the reasons mentioned. We then calculated the core radii and found them to be between 0.07–0.17 arcmin and 0.47–0.84 arcmin for each cluster.

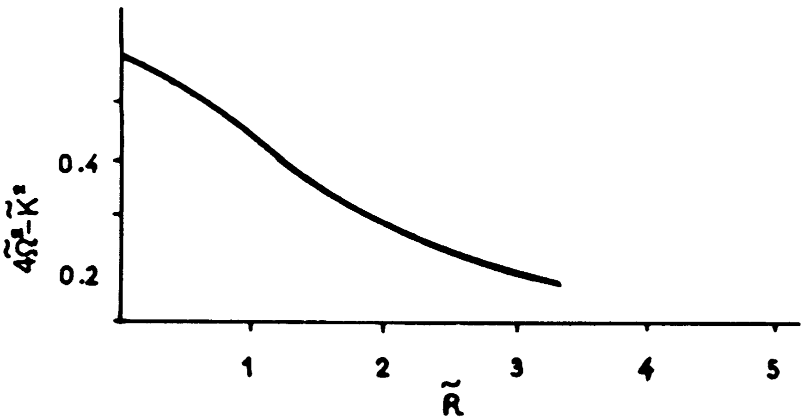

Fig. 7. The theoretical rotation curve of Freeman (1970). $\tilde{R}$ is the dimensionless radial distance from the rotation centre of LMC. $\tilde{\Omega}$ and k are the dimensionless angular velocity and epicyclic frequency at the cluster's location.

Since the clusters to be examined are located in the disk of LMC and the observational evidence by [8] shows that they are kinematically disk clusters, their masses ($M_{\rm cl}$) can be calculated from the derived tidal radii using the relation

$$M_{\rm cl} = \frac{1}{G} r_{\rm t}^3 (4\Omega^2 - k^2),$$

where G is the universal gravity constant, Ω and k are the angular velocity and epicyclic frequency at the cluster's position [4], defined by the exponential disk model [7] (Fig. 7).

The dynamical masses of the clusters thus calculated range from $4.4 \times 10^5 M_0$ to $5.4 \times 10^5 M_0$ which means very massive clusters.

It is shown that the uncertainty in the values of $(4\Omega^2 - k^2)$ introduces an error of 50% or more relative to the distance from the rotation centre [6]. It has to be emphasized that the 50% error introduced to the mass from this factor is not the only one considering the various assumptions of the adopted models, which make the derived masses uncertain by a factor of 2. The typical error, nevertheless, in the determination of the masses is of the order of a factor higher than 2 due to the distorted profiles.

The dynamical time and relaxation time for the half mass radius of the clusters were found to be according to [18], assuming a mean mass for individual stars of about $1.0 M_0$: 2.6×10^6–0.8×10^6 y and 1.6×10^8–0.6×10^8 y.

Table III. The observed dynamical parameters of the cluster.

Cluster	R.A.	Dec.	$r_{\rm t}$ [arcmin]	$\log(r_1/r_2)$	$r_{\rm c}$ [arcmin]	d [°]	$4\tilde{\Omega}^2 - \tilde{k}^2$	M/M_0 [$\times 10^5$]	r_h [arcmin]	r_h [pc]	t_{rh} [$\times 10^8$y]	t_d [$\times 10^6$y]
1	2	3	4	5	6Y	7	8	9	10	11	12	13
NGC 1938	$5^{\rm h}16.5^{\rm m}$	$-70°34'$	4.7	0.75–1.00	0.47–0.84	1.83	0.57	4.4	1.13	18.1	1.6	2.6
NGC 1939			5.2	1.5–1.75	0.09–0.17			5.4	0.57	9.1	0.6	0.8
Field NGC 1938 & NGC 1939	$5^{\rm h}19.3^{\rm m}$	$-70°07'$										

All the observed dynamical parameters derived here are listed in Table III. Columns 2, 3 list the coordinates of the clusters, column 4 lists the values of tidal radii in arcmin. Columns 5, 6 list the mean concentration parameters and the core radii in arcmin. In column 7 there is given the distance of the cluster from the rotation centre of the LMC and the corresponding value of the quantity $4\Omega^2 - k^2$ for the exponential disk from the theoretical rotation curve [7] is listed in column 8. Finally, the calculated values of the total mass of each cluster are given in column 9. The half mass radii are given in columns 10, 11 and the values of the crossing time meaning the relaxation time, are listed in columns 12 and 13, respectively.

4. Stellar content of the binary cluster

Spectral classification of stars in globular clusters and the distribution of the various spectral types give us information on their evolutionary history.

Comparing the two clusters distributions we tried to conclude for their binarity. In distant stellar systems like those of the Magellanic Clouds only the most luminous stars areobervable and the spectra of the blue yellow and red supergiants enable us to understand the evolution of massive stars. For this classification low (2440 A/mm at H_γ) and medium (830 A/mm at H_γ) dispersion objective prisms plates of the 1.2 m UK Schmidt telescope were used. All classified stars are brighter than $V = 17.5$ mag. The effectiveness of low and medium dispersion objective-prism plates from the 1.2 m UK Schmidt telescope has been well demonstrated by [15, 3] for the outer-innermost parts of the clusters respectively.

For each cluster a circular area was examined, defined by its tidal radius which was found by means of star count as we have already described. An assumed fiducial separation of the two clusters of each pair is marked by a solid line, vertical to the distance joining the centres of the clusters. The innermost part of the clusters, where images are crowded, was excluded as they exhibit a dark part smaller than 4% of the examined areas.

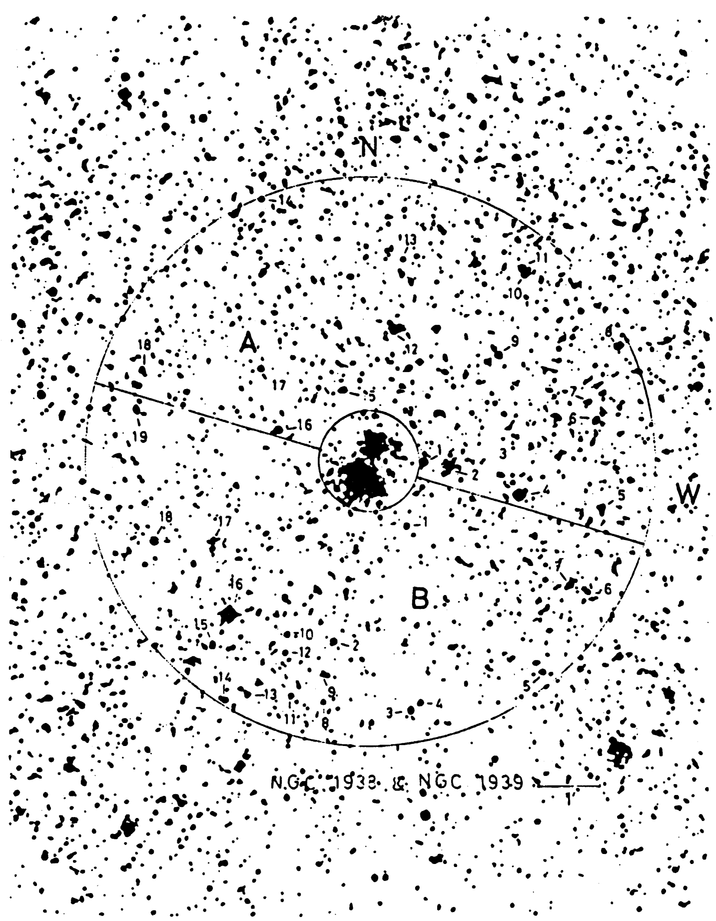

Fig. 8. Finding chart for the clusters NGC 1938 and NGC 1939.

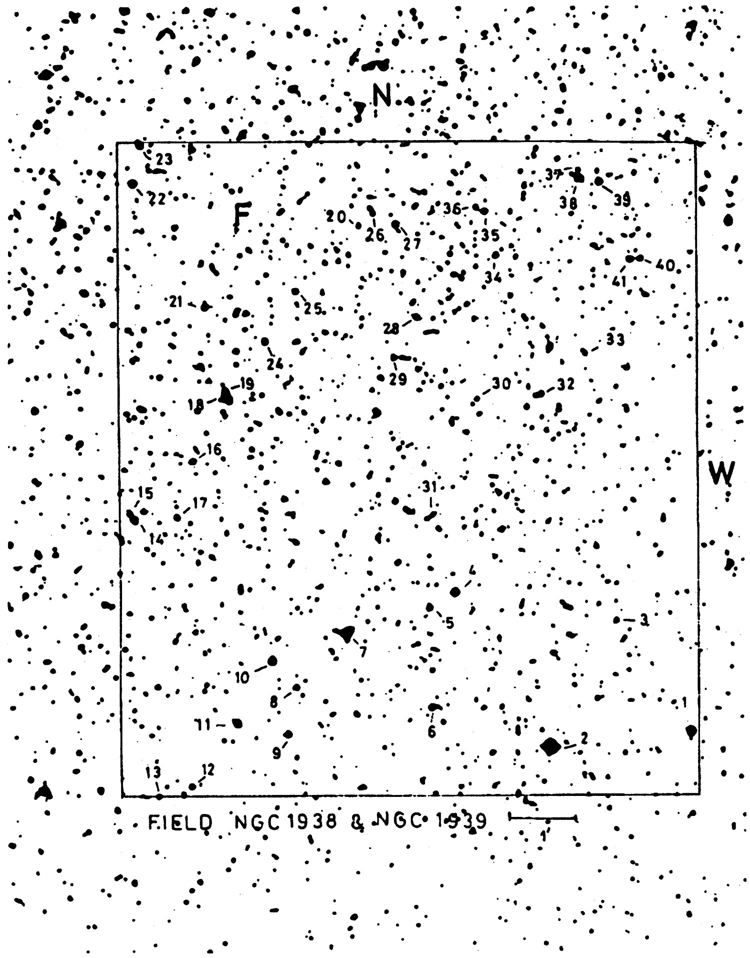

Fig. 9. Finding chart for the field of the clusters.

For these clusters, stars of a neighbouring field were classified on the same plate, adopting the same classification criteria used for the clusters of stars. The coordinates of the field are listed in Tab. II. The finding charts for the clusters and the corresponding field are illustrated in Figs. 8 and 9. Using the criteria of classification we mentioned above, we came to Tab. IV for clusters' stars and the field stars. The derived distributions of spectral types of the stars are in Fig. 10. It is found that their stars are too faint for our limit of detection so the poor statistics did not allow for comparison among the two cluster-members of each pair.

However, the bright limit of their stars implies ages $> 6 \times 10^8$ y for both clusters according to the criteria of [13].

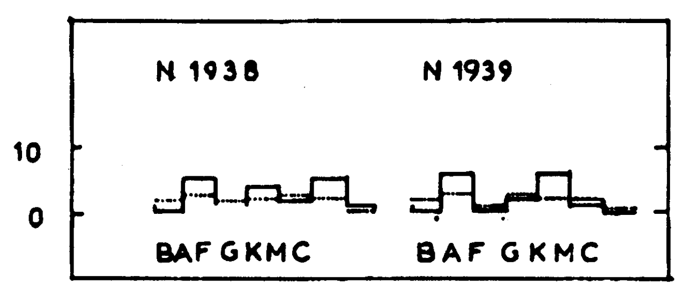

Fig. 10. Distributions of spectral types of the stars of the clusters NGC 1938 and NGC 1939.

Table IV. Coordinates of the cluster fields.

Cluster N1938		Cluster N1939		Field N1938 and N1939			
No.	Sp	No.	Sp	No.	Sp	No.	Sp
A1	G	B1	A	F1	K	F22	G
A2	–	B2	K	F2	F	F23	A
A3	A	B3	A	F3	B	F24	F
A4	F	B4	A	F4	A	F25	F
A5	K	B5	A	F5	K	F26	B
A6	M	B6	–	F6	K	F27	M
A7	–	B7	A	F7	G	F28	M
A8	G	B8	–	F8	M	F29	A
A9	M	B9	–	F9	–	F30	B
A10	M	B10	G	F10	G	F31	B
A11	K	B11	K	F11	G	F32	M
A12	A	B12	–	F12	M	F33	A
A13	G	B13	–	F13	A	F34	K
A14	–	B14	K	F14	A	F35	M
A15	A	B15	–	F16	A	F36	–
A16	A	B16	G	F18	G	F37	–
A17	C	B17	K	F20	A	F38	–
A18	M	B18	K	F21	K	F39	K
		B19	M			F40	B

5. Conclusions — discussions

The close pair of clusters NGC 1938 and NGC 1939 examined here from the point of view of their dynamical behaviour and their stellar content have shown the following:

1. Their radial density profiles exhibit distortion giving evidence of gravitational interaction between the clusters of the pair.

2. The spectral classification of their stars indicates for both clusters ages $> 6 \times 10^8$ y while the poor statistics did not allow for comparison between them.

Such massive clusters are expected to be relaxed in a time $> 5 \times 10^9$ y by two-body relaxation mechanism.

According to an evolutionary scenario of [19] it is probable that clusters with total masses of about $10^5 M_0$ and $N \approx 10^4$ stars form in binaries and in a few 10^7 y they merge to become one stable globular cluster.

The derived dynamical parameters, the observed profiles, and their evolutionary ages support the argument that these clusters are binaries and dynamically old systems which had time to relax by stellar encounters. From the density profile of cluster NGC 1938 (Fig. 2) which provides a width of $\Delta(N/A) \approx 10$ stars/arcmin^2 which is a very small value, we can assume that this cluster is up to be merged with the other one.

Summarizing, it has been found that the two clusters examined have been found dynamically old with distorted radial density profiles suggesting mutual interaction and each cluster of the pair has similar ages embedded in the same environment.

The above observed data support the suggestion of common origin and rise the question whether these star clusters formed as binaries from the fragments of a giant molecular cloud.

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