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FLARE STARS AND RAPID IRREGULAR VARIABLES IN THE SOUTHERN COALSACK

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SUMARIO

Una serie de placas ultravioleta de exposición múltiple ha revelado en el "Saco de Carbón" del sur que 140 estrellas muestran variaciones rápidas de intensidad en una escala de tiempo de 10 a 40 minutos. A pesar de que se observaron explosiones tipo ráfaga en la mayoría de estos objetos, a veces ocurre una rápida disminución de intensidad, lo cual sugiere variabilidad rápida irregular. Los objetos están entre U = 14 y 17 con amplitudes de 0.5 a 2 magnitudes. Cinco estrellas han mostrado actividad repetidamente. Estas variaciones ocurren frecuentemente: de 2 a 3 sucesos por hora por grado cuadrado en exposiciones múltiples de 10 minutos que llegan a la magnitud límite U = 17.

ABSTRACT

A series of multiple-exposure ultraviolet plates in the Southern Coalsack has revealed 140 stars showing rapid variations in brightness on a time scale of 10 to 40 minutes. Although flare-like outbursts were observed in the majority of these objects, a rapid diminution in brightness sometimes takes place more suggestive of rapid irregular variability. The objects are between U = 14 and 17 with estimated amplitudes of 0.5 to 2 magnitudes. Five stars have shown repeated activity. The detection rate is high, 2 to 3 events per hour per square degree for multiple 10 minute exposures reaching limiting magnitude U = 17.

I. Introduction

The technique of multiple-exposure photography utilized so successfully at the Tonantzintla Observatory for the detection of flare stars during the past two decades has been employed to investigate a region in the Southern Coalsack. The results of Haro and his colleagues, in collaboration with the Asiago and Byurakan Astrophysical Observatories, have demonstrated the importance of these objects in relation to the early evolutionary stages of clusters. The close association between flare stars and regions of emission nebulosity and obscuring gas and dust clouds such as, for example, in the Taurus Clouds, the Orion nebula, the Pleiades and NGC 2264, leads one to expect the detection of flare stars in other similar regions, especially in areas in which T Tauri stars have already been discovered. Westerlund (1960) and Hidajat (1962) have discovered several Hα emission objects in the vicinity of the Coalsack, but few appear to be late-type stars of the T Tauri-related class. However, Sanduleak (1968, 1969) has found 3 flare stars on objective-prism plates, showing temporary emission in the Balmer lines and the K line (CaII), with a detection rate of approximately 1 flare star per hour within an area of 50 square degrees. Sanduleak points out that these 3 stars appear on the edges of regions of heavy obscuration, and it is particularly interesting that Lindsay (1970) has found in 2 of these stars a featureless blue continuum extending into the ultraviolet although they present a late-type K-M spectrum in the near infra-red. This is characteristic of the T Tauri-related objects with their ultraviolet excesses and the veiling of their absorption-line features in the blue spectral region. The heavy obscuration in the Coalsack (photographic absorption 1 to 3 magnitudes) allows useful multiple-exposure plates in what would otherwise be a prohibitively dense stellar region in the galactic plane. These factors suggest that an intensive search for rapid variables which might form a T association at the distance of the Coalsack, about 174 pc according to Rodgers (1960), is worthwhile.

II. The Photographic Survey

The area selected for the present survey for rapid variables, centred at 12^h38^m, $-63°.1$ (1950), at galactic coordinates, $l^{II} = 301°.7$, $b^{II} = -0°.4$, covers 8.5 square degrees and contains part of the densest obscuration in the Coalsack to the east of α Crucis. The 32/36-inch Baker-Schmidt telescope of the Boyden Observatory was employed using 5 or 6 exposures taken on 103a-O plates in conjunction with a Schott UG 2 filter. Each exposure was of 10 minutes duration reaching an estimated limiting magnitude of U = 17. The area contains a UBV sequence by Rodgers (1960), and also the clusters, NGC 4609 and Hogg 15, studied photoelectrically by Feinstein and Marraco (1971). The photographic material consists of 33 plates with a total time coverage of 27.3 hours obtained by T. W. Rackham in February-March 1971.

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It was found most convenient to scan the Baker-Schmidt plates (scale 68″/mm) under a magnification of 40 times using the display panel of Sartorius iris-diaphragm photometer with a field diameter of 3 mins of arc. The X, Y-coordinates (±0.1 mm) of detected variables, together with the positions of 15 CPD stars, were determined, and reduced using standard astrometric procedures to equatorial coordinates (Equinox 1950) with an accuracy of $\Delta\alpha = \pm 1^s$, $\Delta\delta = \pm 0'.1$. Transfer from the discovery U plates to a red chart plate for the region (103a-E + Wratten 25A filter, exposure 90 mins) was achieved utilizing the re-converted coordinates at the Sartorius photometer. Identification was checked in a few doubtful cases when close companions existed directly against the discovery plate. Only in the case of single-image flares is there any serious doubt as to the identification, although it cannot be ruled out that in a few cases an extremely red star might have been mistaken for the variable.

A thorough examination of the 4 best plates has revealed over 200 stars suspected as exhibiting rapid changes of brightness on a time scale of 10 to 40 minutes. Although flare-like variation was detected in the majority of these objects, several stars showed instead a definite diminution in brightness in one of more of their multiple images indicating rapid irregular variability. The variation was always checked against all stars of similar brightness in the immediate neighbourhood. A repeated survey was employed in which one third of the initial list was omitted as being doubtful, and this procedure allowed a more homogeneous assessment of the material. The remaining 140 stars were assigned weights according to the scheme, definite variables (Wt = 3), suspected variables (Wt = 2), and stars with small amplitude or possible changes of image structure only and single images, possibly flares from below the plate limit (Wt = 1). See Table 1. Five stars (Nos. 65, 74, 75, 98 and 130) were independently detected to be varying on more than one plate. However, no attempt has yet been made to examine the whole plate collection for longer-term variations. None of the stars listed occur in the General Catalogue of Variable Stars or its Supplements. They coincide with neither the variables suspected by Westerlund (1960) nor the Hα emission objects of Hidajat (1962), and the flare stars of Sanduleak (1968) are outside the region surveyed. Red finding charts are provided for all except 35 stars, and the orientation as indicated by the reference numbers is south (top) and east (right) with each chart covering about 54′ × 63′. The detection rate is extremely high, about 2.5 stars per hour per square degree for variables of weight 3, being two orders of magnitude greater than that of flare stars in the Pleiades, the Orion aggregate and NGC 2264 (Haro 1968). The distributive properties of the variables are clearly complex and although apparently related to the stellar density across the region an interpretation is impossible without additional data much as might be derived from spectroscopic and multi-colour photometric investigations.

TABLE 1

Flare Stars and Rapid Irregular Variables in the Southern Coalsack

No.	*RA (1950)*	*Dec (1950)*	*U*	*ΔU*	*Wt.*	*Date*	*Remarks*
1	$12^h26^m44^s$	−63°34′.9	$15^m.5$	$-1^m.0$	3	1	
2	12 26 45	−63 36.8	16.0	−1.0	2	2	
3	12 27 39	−64 34.6	16.0	−1.0	3	1	
4	12 28 04	−62 29.2	16.5	−0.5	2	1	
5	12 28 13	−64 05.0	16.5	−0.5	3	3	
6	12 28 15	−63 06.1	14.5	−0.5	3	3	
7	12 28 28	−62 25.1	16.0	−0.5	2	1	
8	12 28 42	−62 39.4	15.5	−0.5	3	3	
9	12 28 47	−61 52.1	15.2	−0.5	3	3	
10	12 28 47	−63 45.9	14.5	−0.5	2	3	
11	12 28 52	−64 01.2	16.0	−1.0	3	3	
12	12 28 54	−63 47.2	15.5	−0.5	3	2	
13	12 28 55	−63 58.0	15.5	−0.5	1	3	Ident?
14	12 28 59	−63 33.5	16.5	−0.5	3	3	
15	12 29 01	−62 55.9	15.4	−0.5	3	1	
16	12 29 05	−62 15.3	15.2	−0.5	3	1	
17	12 29 09	−63 48.4	16.0	−1.0	3	2	
18	12 29 16	−62 47.6	15.3	−1.0	3	1	
19	12 29 30	−63 42.5	15.5	−1.0	3	1	
20	12 29 43	−62 57.1	15.1	−0.5	2	3	Ident?
21	12 29 55	−62 49.4	15.3	−1.0	3	1	Ident?

TABLE 1 (continued)

No.	*RA (1950)*	*Dec (1950)*	*U*	*ΔU*	*Wt.*	*Date*	*Remarks*
22	12 30 04	−63 34.6	14.7	−0.5	2	2	
23	12 30 08	−63 32.0	>17	<−1.0	1	2	Single image
24	12 30 09	−64 06.6	16.5	−1.0	2	2	Overlap?
25	12 30 11	−63 48.9	15.0	−0.5	2	2	
26	12 30 28	−62 44.5	14.6	−0.5	3	1	
27	12 30 36	−64 26.1	15.0	−2.0	3	1	
28	12 30 38	−62 59.4	15.4	−0.5	2	2	Ident?
29	12 30 42	−62 14.3	14.6	−0.5	1	1	
30	12 30 51	−63 32.6	15.5	−0.5	3	1	
31	12 30 57	−63 39.4	15.5	−0.5	1	1	
32	12 31 01	−64 40.2	14.5	−0.5	2	3	
33	12 31 38	−63 51.4	14.1	−0.5	2	3	
34	12 31 47	−63 05.3	15.0	?	1	2	Image peculiar
35	12 31 49	−63 37.0	14.7	−0.5	2	2	
36	12 31 49	−64 17.2	16.5	−1.0	2	2	
37	12 31 51	−64 06.4	14.5	−0.5	2	2	Irreg. var.
38	12 31 59	−64 27.4	15.5	+0.5	3	2	Diminution
39	12 32 08	−62 14.1	14.9	−1.0	3	2	
40	12 32 17	−64 29.3	15.0	−0.5	2	1	
41	12 32 26	−62 22.7	14.6	−0.5	3	1	
42	12 32 33	−61 55.1	16.0	−1.0	3	3	
43	12 32 37	−62 26.8	14.5	−0.5	3	1	
44	12 32 43	−63 30.2	15.4	−0.5	2	1	
45	12 32 51	−62 52.1	15.4	−0.5	3	1	
46	12 33 05	−63 09.9	15.5	−0.5	3	1	
47	12 33 22	−62 29.6	16.5	−1.0	3	3	
48	12 33 27	−64 09.2	14.3	−0.5	3	3	
49	12 33 33	−62 16.8	15.3	−0.5	2	1	Decline 40 mins
50	12 33 33	−63 42.4	14.0	−1.0	3	3	
51	12 33 45	−64 33.8	14.5	+0.5	3	1	Diminution
52	12 34 05	−64 22.3	14.3	−0.5	3	1	
53	12 34 15	−63 50.0	15.0	−0.5	2	3	
54	12 34 23	−63 31.1	14.9	−0.5	2	3	
55	12 34 30	−64 01.1	15.0	−1.0	2	3	Overlap?
56	12 34 39	−64 13.1	14.3	+0.5	2	2	Diminution
57	12 34 58	−62 04.0	14.1	−0.5	2	3	
58	12 35 09	−64 24.5	16.5	−0.5	3	1	
59	12 35 10	−62 36.1	14.6	−0.5	2	3	
60	12 35 13	−63 37.2	15.0	−1.0	3	2	
61	12 35 17	−63 08.7	15.4	−0.5	3	1	
62	12 35 40	−63 15.1	15.2	−0.5	3	2	
63	12 35 41	−62 14.7	14.8	−0.5	3	1	
64	12 35 44	−62 19.4	14.8	−0.5	2	1	
65	12 35 48	−64 23.3	14.9	−0.5	2	1	
				+0.5	3	2	Diminution
66	12 35 51	−63 44.2	15.5	−1.0	3	2	
67	12 35 55	−64 34.3	16.5	−0.5	3	1	
68	12 35 56	−63 02.3	14.8	−0.5	3	1	
69	12 36 06	−62 23.8	14.8	−0.5	3	1	
70	12 36 06	−63 32.3	15.7	−0.5	2	3	
71	12 36 11	−64 34.9	14.7	−0.5	3	3	
72	12 36 22	−62 13.0	14.8	−1.0	3	1	
73	12 36 23	−63 16.4	15.4	−0.5	1	2	
74	12 36 26	−64 05.5	15.2	−1.0	3	1	
				−1.0	3	2	
75	12 36 32	−64 38.4	15.0	−1.0	3	1	
				−0.5	3	2	

TABLE 1 (continued)

No.	*RA (1950)*	*Dec (1950)*	*U*	*ΔU*	*Wt.*	*Date*	*Remarks*
76	12 36 35	−62 53.3	15.0	0.5	3	1	Diminution
77	12 36 55	−64 19.9	15.8	−0.5	3	1	
78	12 37 05	−63 37.0	14.7	−0.5	3	1	
79	12 37 16	−61 48.8	15.8	−0.5	3	3	
80	12 37 20	−63 39.9	15.5	−1.0	3	2	
81	12 37 29	−63 50.4	14.7	−1.0	3	2	
82	12 37 51	−64 19.9	15.2	−0.5	3	1	Double star
83	12 37 56	−63 11.2	16.5	−1.0	3	3	
84	12 38 14	−63 42.9	13.9	−0.5	2	2	
85	12 38 51	−62 43.7	14.8	−1.0	1	3	Overlap?
86	12 39 14	−63 11.7	14.0	−0.5	3	2	
87	12 39 15	−63 14.1	16.2	−1.0	2	3	Overlap?
88	12 39 56	−64 34.9	>17	<−1.0	1	1	Single image
89	12 40 03	−64 32.0	>17	<−1.0	1	1	Single image
90	12 40 06	−64 18.5	14.5	−0.5	3	1	
91	12 40 09	−63 15.0	15.1	−1.0	3	2	
92	12 40 14	−62 43.6	13.9	+0.5	2	2	Diminution
93	12 40 22	−63 09.2	15.2	−0.5	2	3	
94	12 40 32	−62 54.6	14.8	0.5	3	3	Diminution?
95	12 40 41	−63 53.5	15.8	−0.5	3	3	
96	12 40 44	−64 06.4	15.0	−0.5	3	1	
97	12 40 44	−64 31.5	15.0	−0.5	3	1	
98	12 41 06	−63 20.0	15.4	−1.0	3	2	
				−0.5	1	1	
99	12 41 19	−64 32.4	>17	<−1.0	1	1	Single image
100	12 41 32	−64 39.5	14.8	1.5	2	1	Diminution
101	12 41 33	−64 17.8	15.0	−1.0	3	2	
102	12 41 36	−64 33.8	14.9	−0.5	3	2	
103	12 41 38	−62 19.9	15.2	−0.5	2	2	
104	12 41 38	−64 24.2	15.0	0.5	2	1	Irregular?
105	12 41 42	−64 00.2	14.0	−0.5	3	2	
106	12 41 59	−63 10.1	15.0	−0.5	2	2	
107	12 42 01	−63 44.6	15.0	−1.0	3	2	
108	12 42 53	−63 44.0	15.5	−0.5	3	2	
109	12 43 02	−62 36.8	15.4	−0.5	3	3	
110	12 43 07	−62 42.7	15.8	−0.5	2	1	Ident?
111	12 43 42	−64 09.0	13.5	−0.5	3	3	
112	12 43 43	−64 30.4	14.3	−0.5	2	1	
113	12 43 58	−64 34.9	14.8	−0.5	1	1	Overlap?
114	12 44 13	−64 18.0	16.0	−0.5	3	1	
115	12 44 32	−63 09.6	16.0	−1.0	3	1	Red companion
116	12 44 33	−64 03.0	>17	<−2.5	1	1	Single image
117	12 44 52	−63 17.7	15.5	−0.5	3	1	
118	12 45 14	−63 16.5	16.0	+0.5	1	2	Diminution
119	12 45 33	−64 13.6	15.0	−0.5	3	2	
120	12 45 35	−62 43.5	14.8	+0.5	2	2	Diminution
121	12 45 43	−64 16.6	15.1	−0.5	2	1	
122	12 46 18	−62 20.9	15.6	−0.5	2	1	Irregular?
123	12 46 22	−61 53.2	>17	<−3.0	1	3	Single image
124	12 46 43	−63 30.2	15.0	−1.0	3	1	Slow rise
125	12 46 44	−62 21.6	14.2	+1.0	2	1	Diminution
126	12 46 44	−64 25.6	15.1	−0.5	3	2	
127	12 46 53	−62 49.4	15.0	−1.0	3	3	
128	12 46 55	−64 28.7	14.9	−1.0	3	2	Companion
129	12 47 10	−64 34.6	14.9	−0.5	2	2	Red companion
130	12 47 21	−64 06.8	14.3	−1.0	2	2	Red companion
				+0.5	3	1	Diminution

TABLE 1 (continued)

No.	*RA (1950*	*Dec (1950)*	*U*	*ΔU*	*Wt.*	*Date*	*Remarks*
131	12 47 31	−64 35.3	15.2	−0.5	3	1	
132	12 47 45	−64 06.6	14.8	−1.0	2	2	
133	12 47 55	−63 36.3	13.8	+0.5	3	1	Diminution
134	12 47 58	−64 17.5	15.0	−0.5	3	3	
135	12 48 58	−63 34.2	14.2	−1.0	2	2	
136	12 49 16	−63 30.3	15.0	−0.5	3	3	Red companion
137	12 49 26	−62 55.0	14.3	+1.5	1	2	Diminution
138	12 49 56	−63 31.6	15.8	−1.5	3	2	Red companion
139	12 50 49	−62 22.9	14.5	−0.5	2	2	Ident?
140	12 51 42	−63 21.8	14.8	−0.5	2	3	

Notes to Table 1

The dates of the plates (Column 7) are 1) 24 Feb 1971 22^h59^m U.T., 2) 27 Feb 1971 01^h09^m U.T. and 3) 7 Mar 1971 00^h35^m U.T. Positional ambiguity (up to 18 secs in RA) in the case of suspected flare stars with single images above plate limits may be resolved using the following information on image separations: 1) 2, 5, 3 and 7 secs., 2) 5, 3, 2 and 8 secs. and 3) 3, 3, 4 and 5 secs.

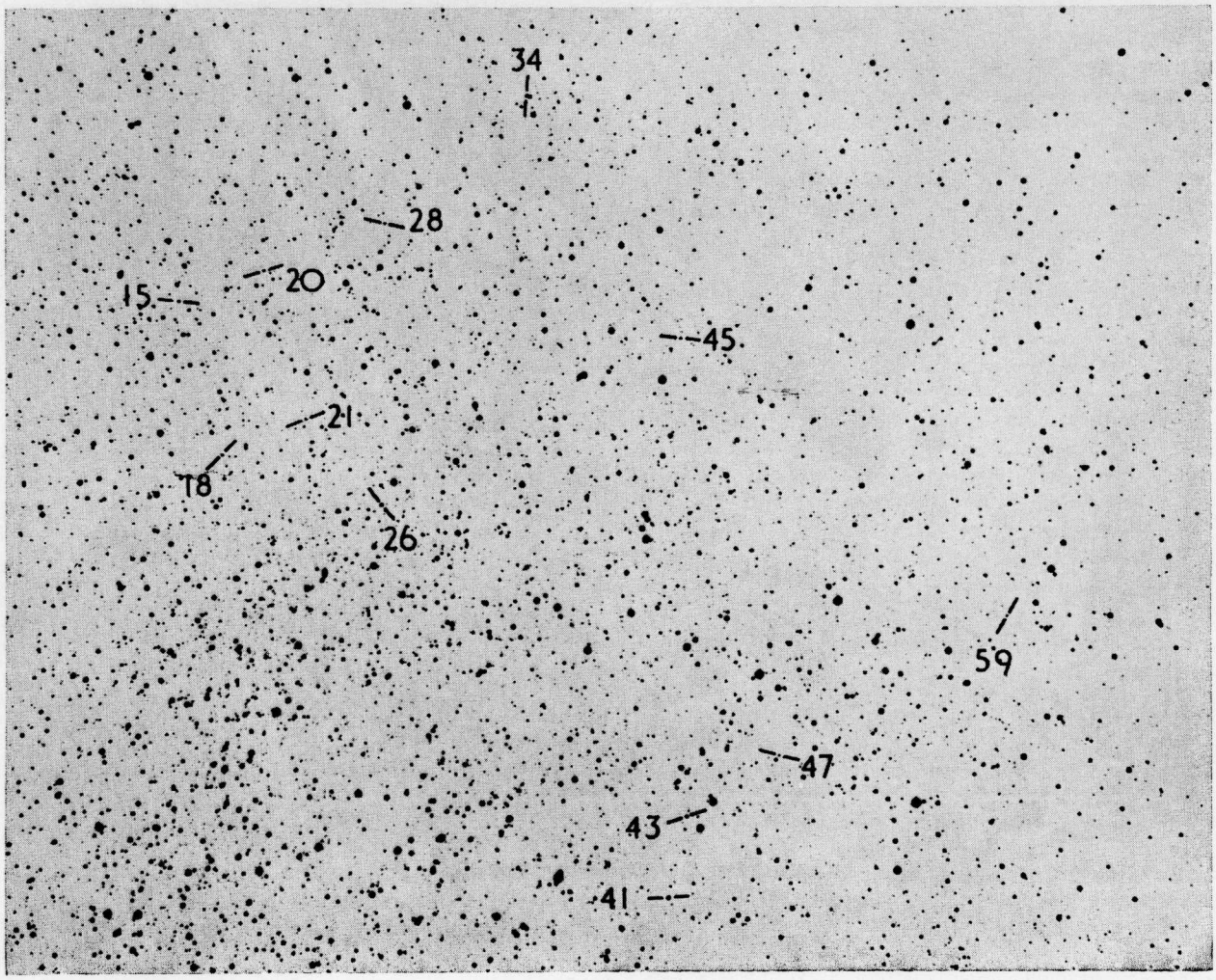

Fig. 1. *Identification charts.*

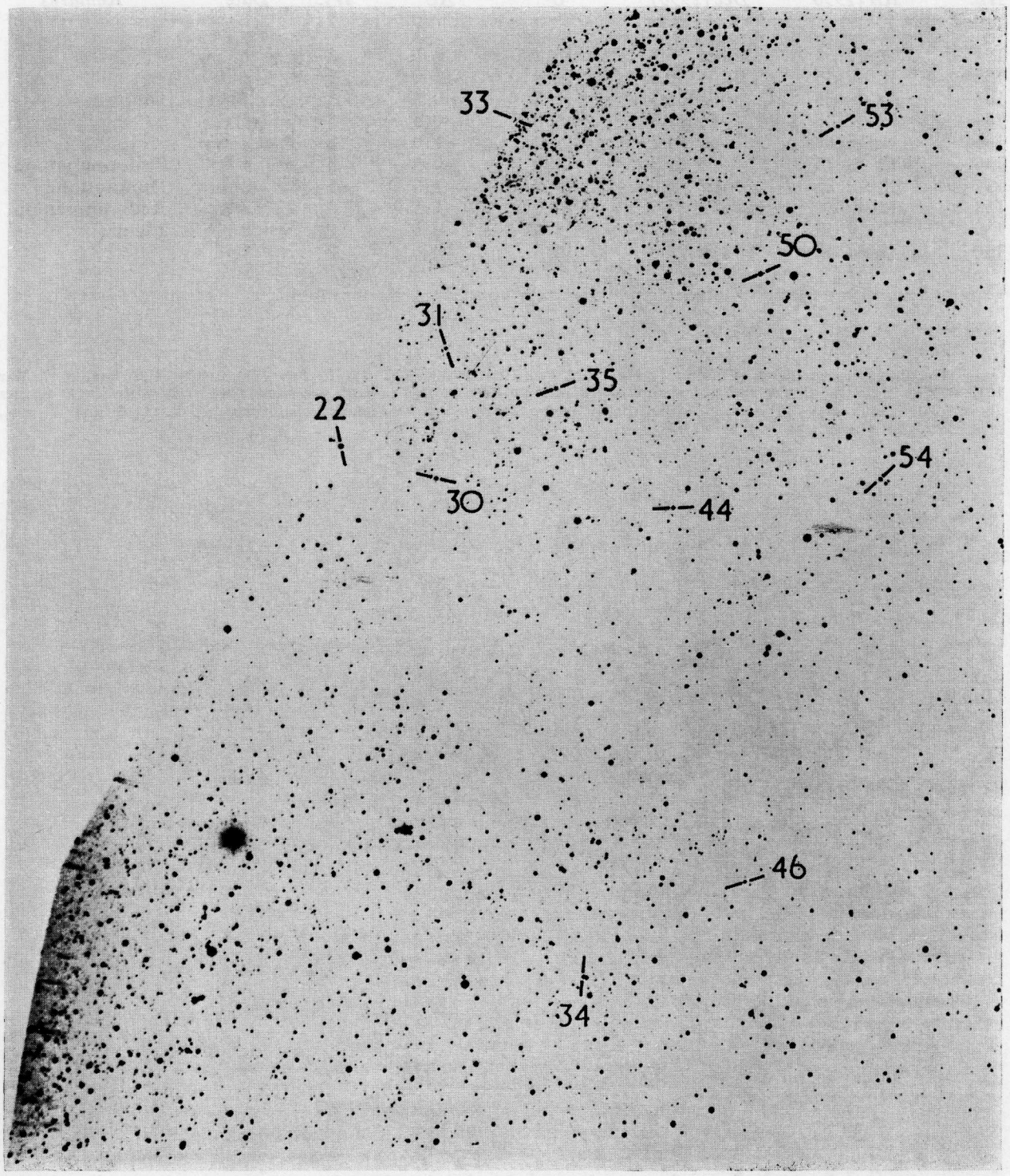

Fig. 2. *Identification charts.*

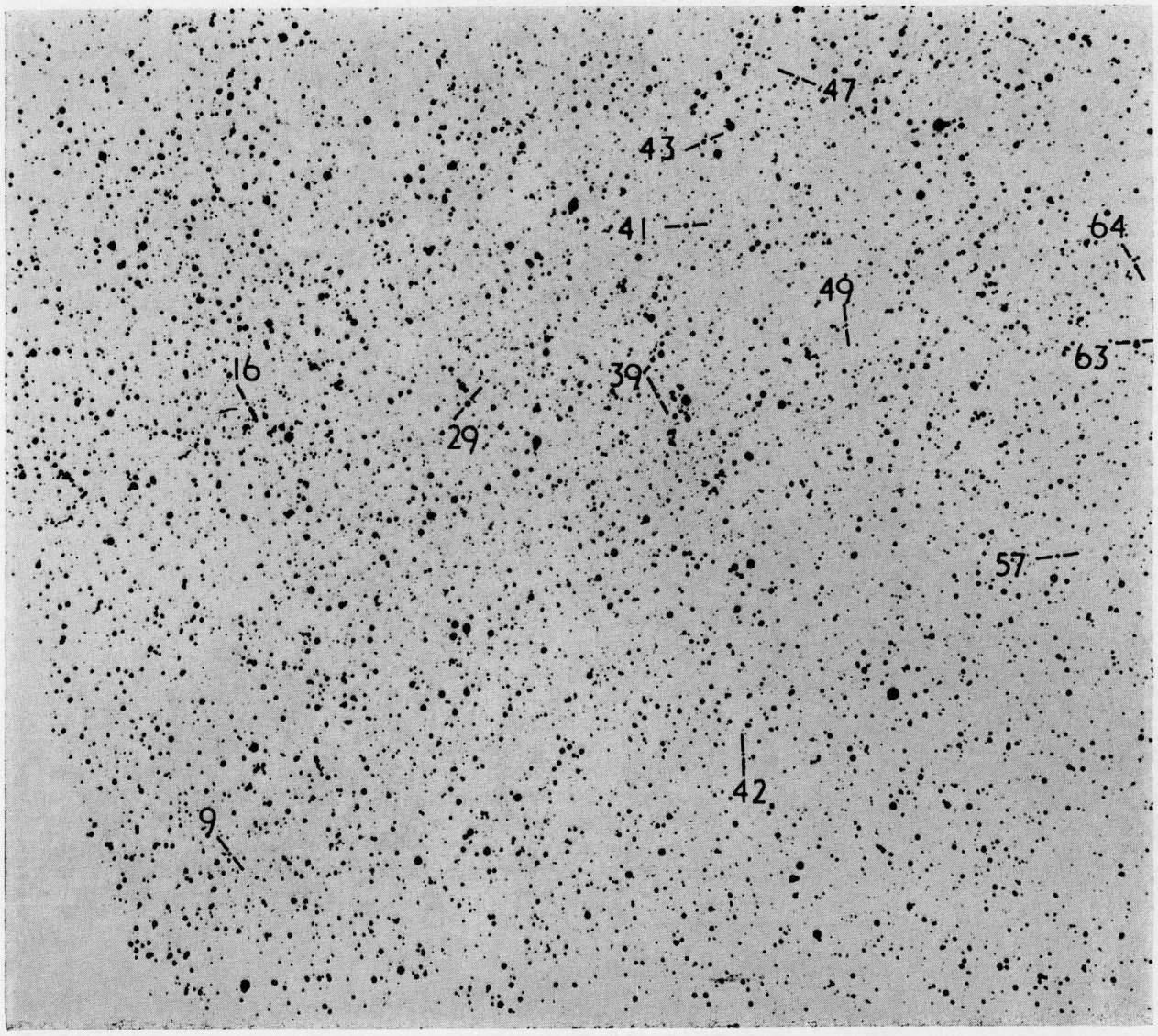

Fig. 3. *Identification charts.*

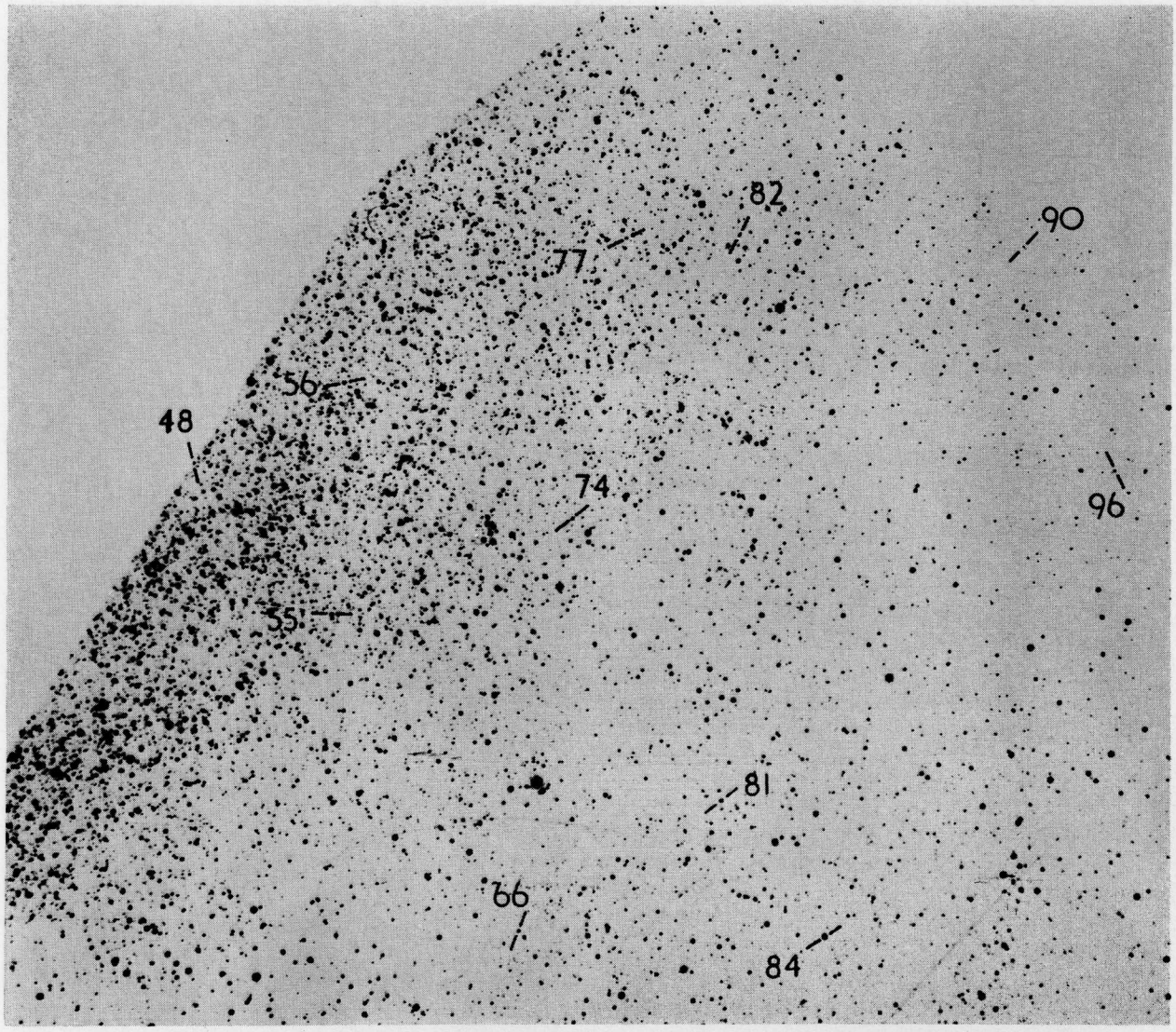

Fig. 4. *Identification charts.*

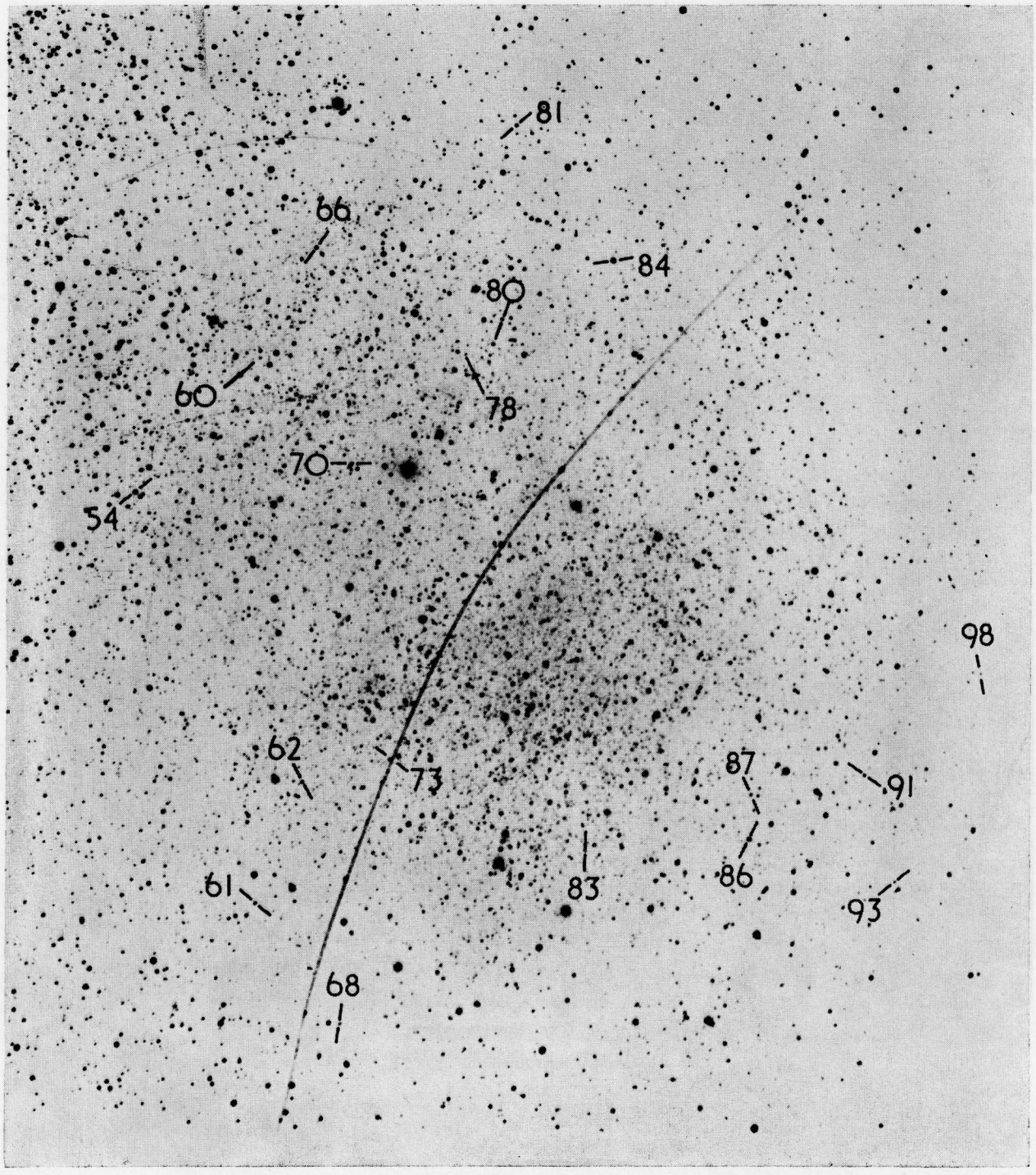

Fig. 5. *Identification charts.*

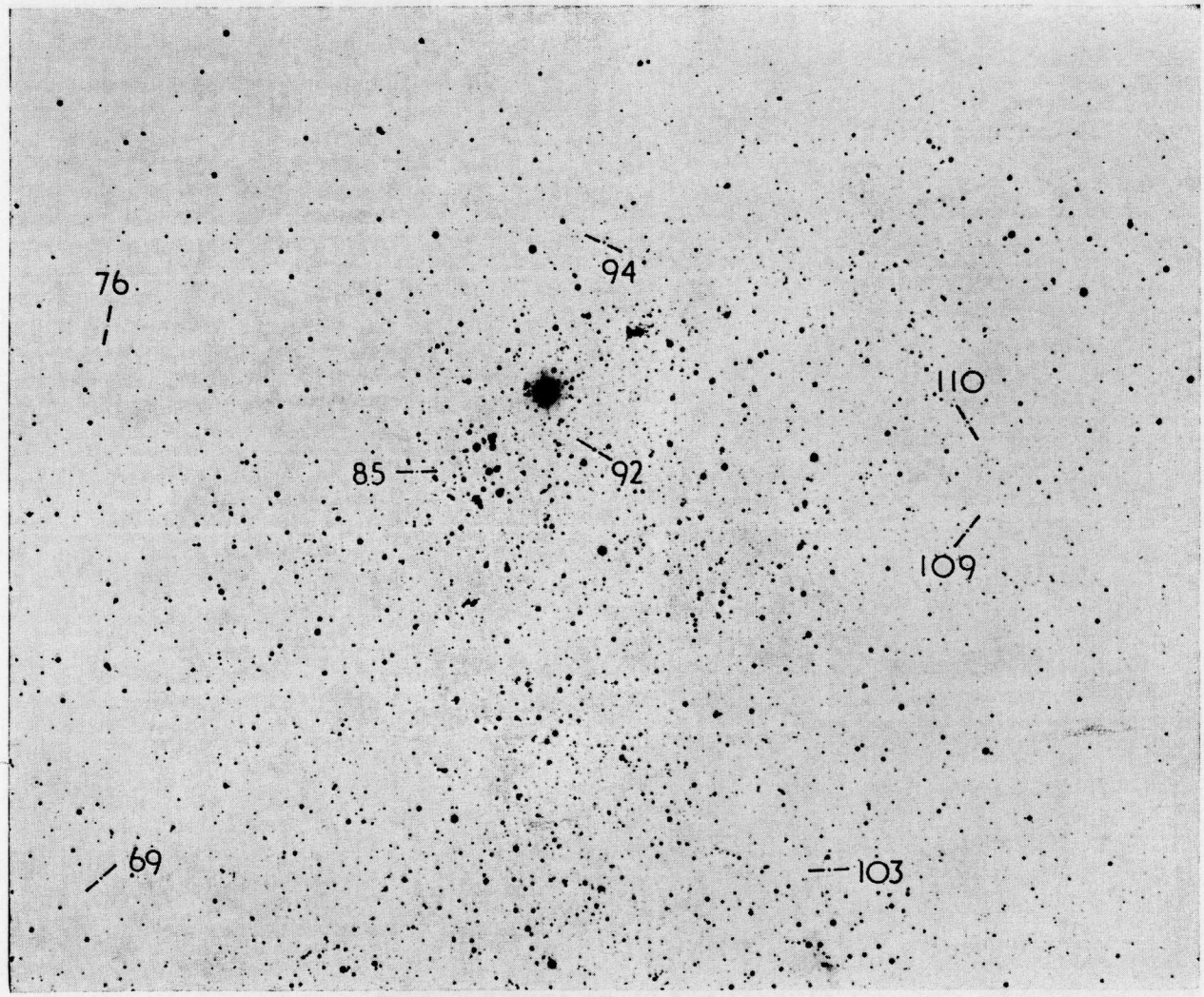

Fig. 6. *Identification charts.*

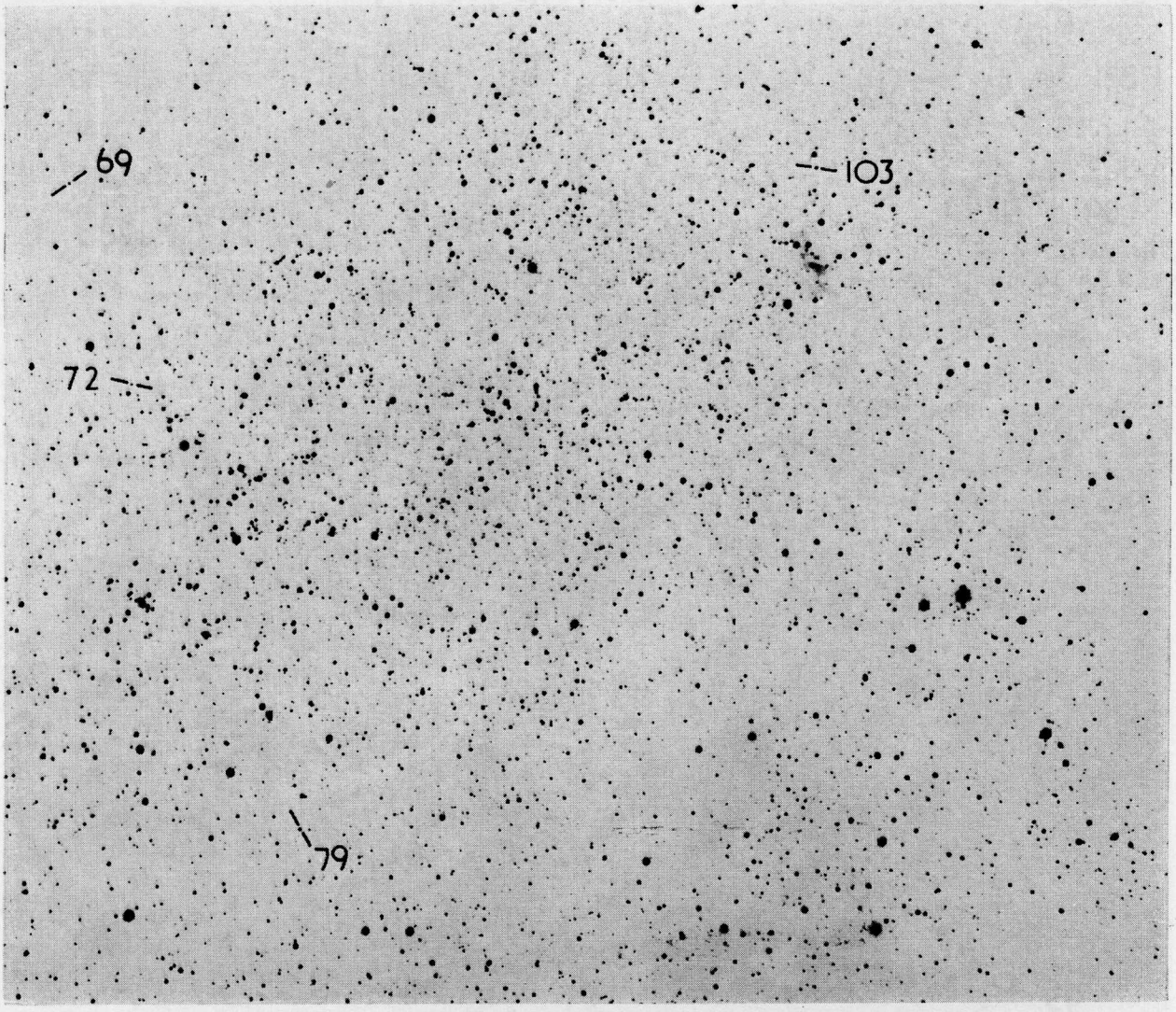

Fig. 7. *Identification charts.*

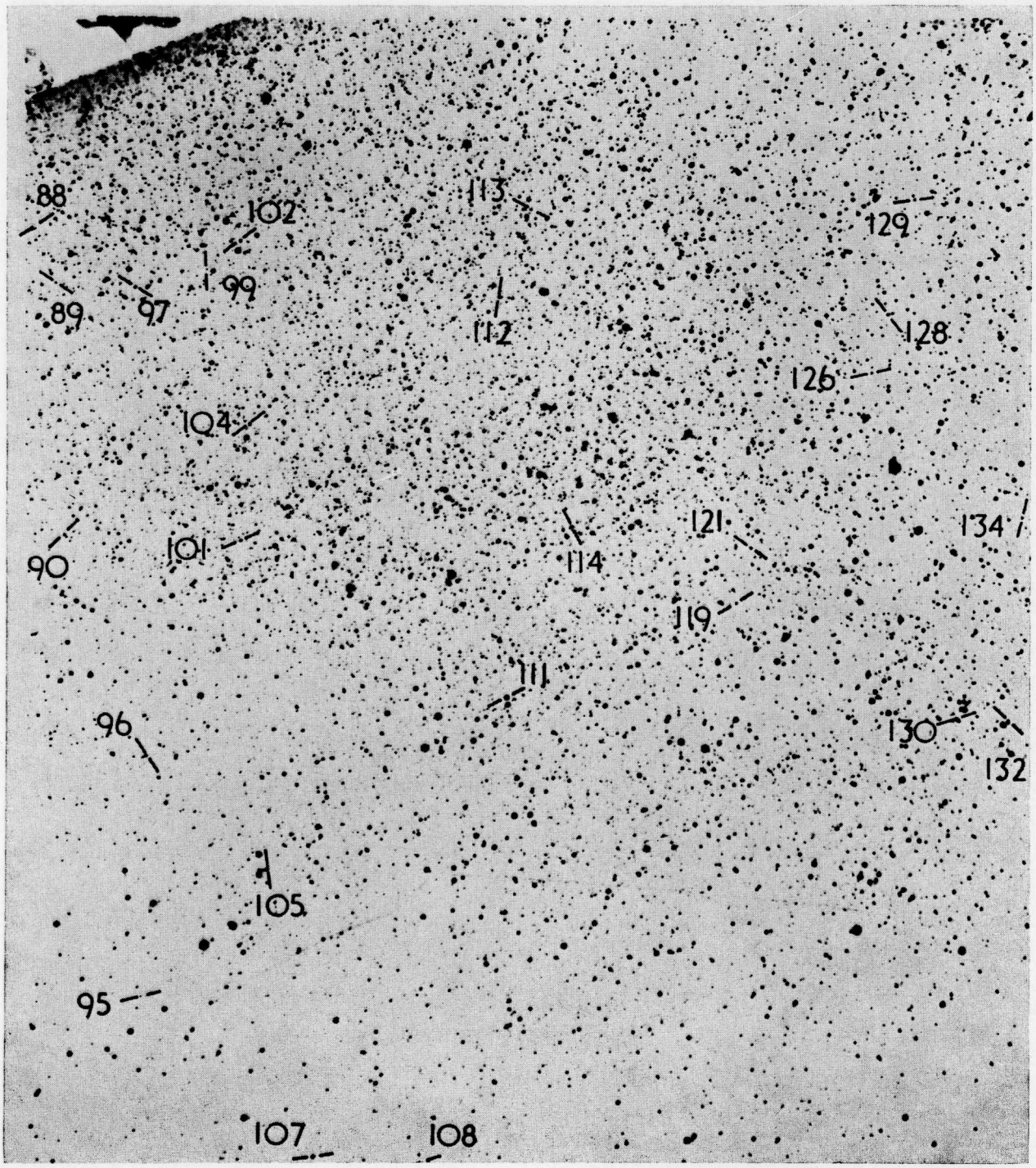

Fig. 8. *Identification charts.*

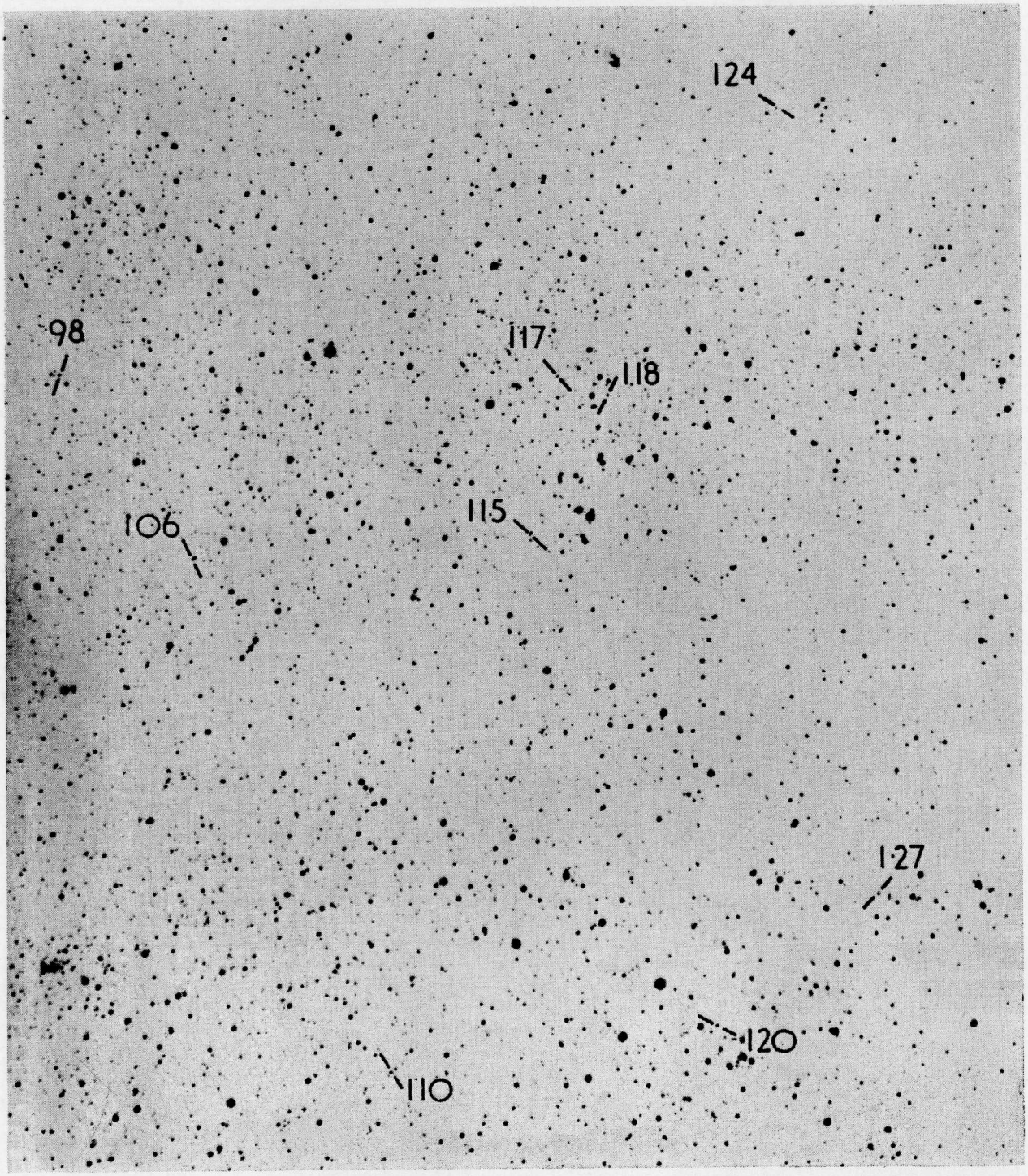

Fig. 9. *Identification charts.*

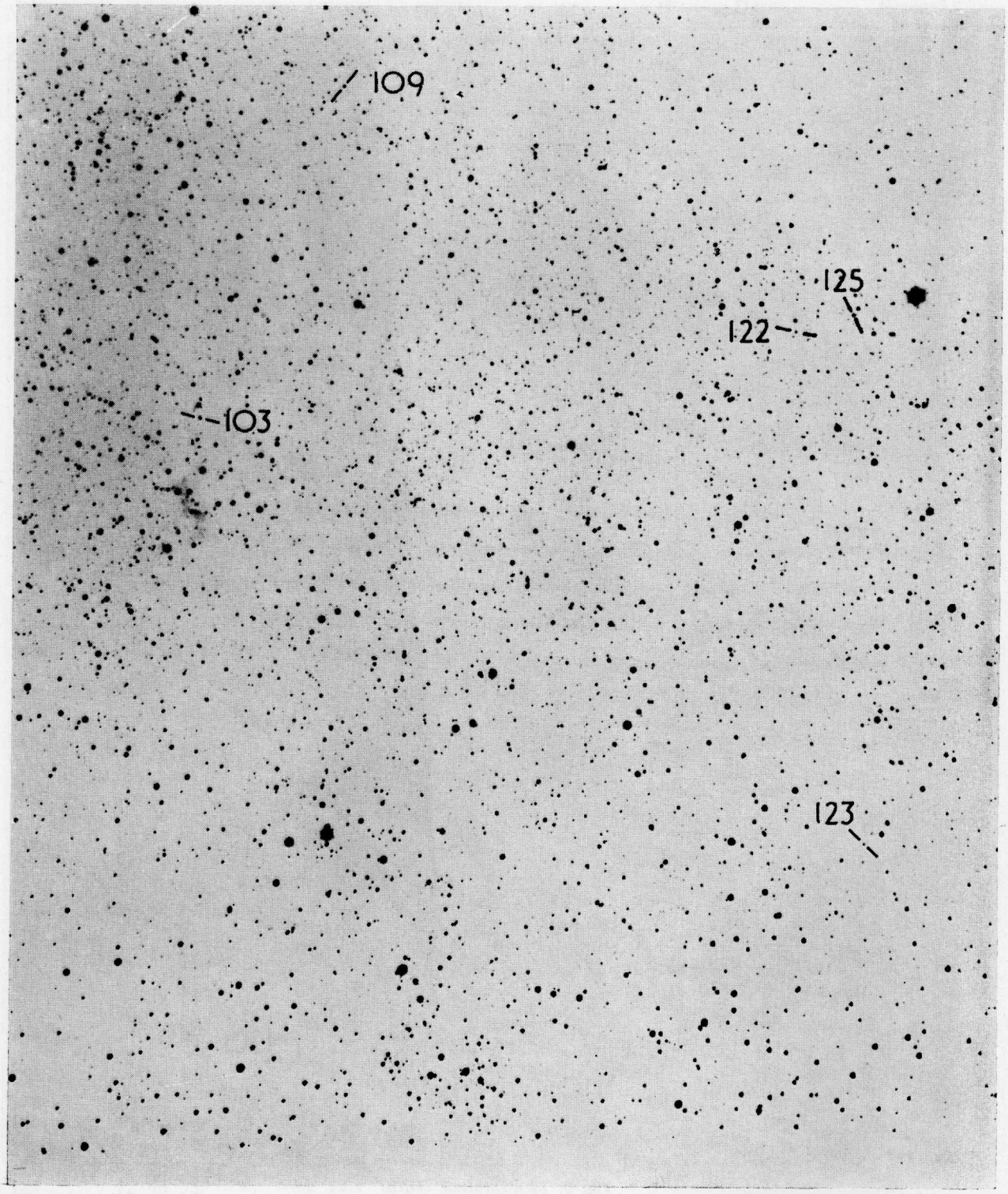

Fig. 10. *Identification charts.*

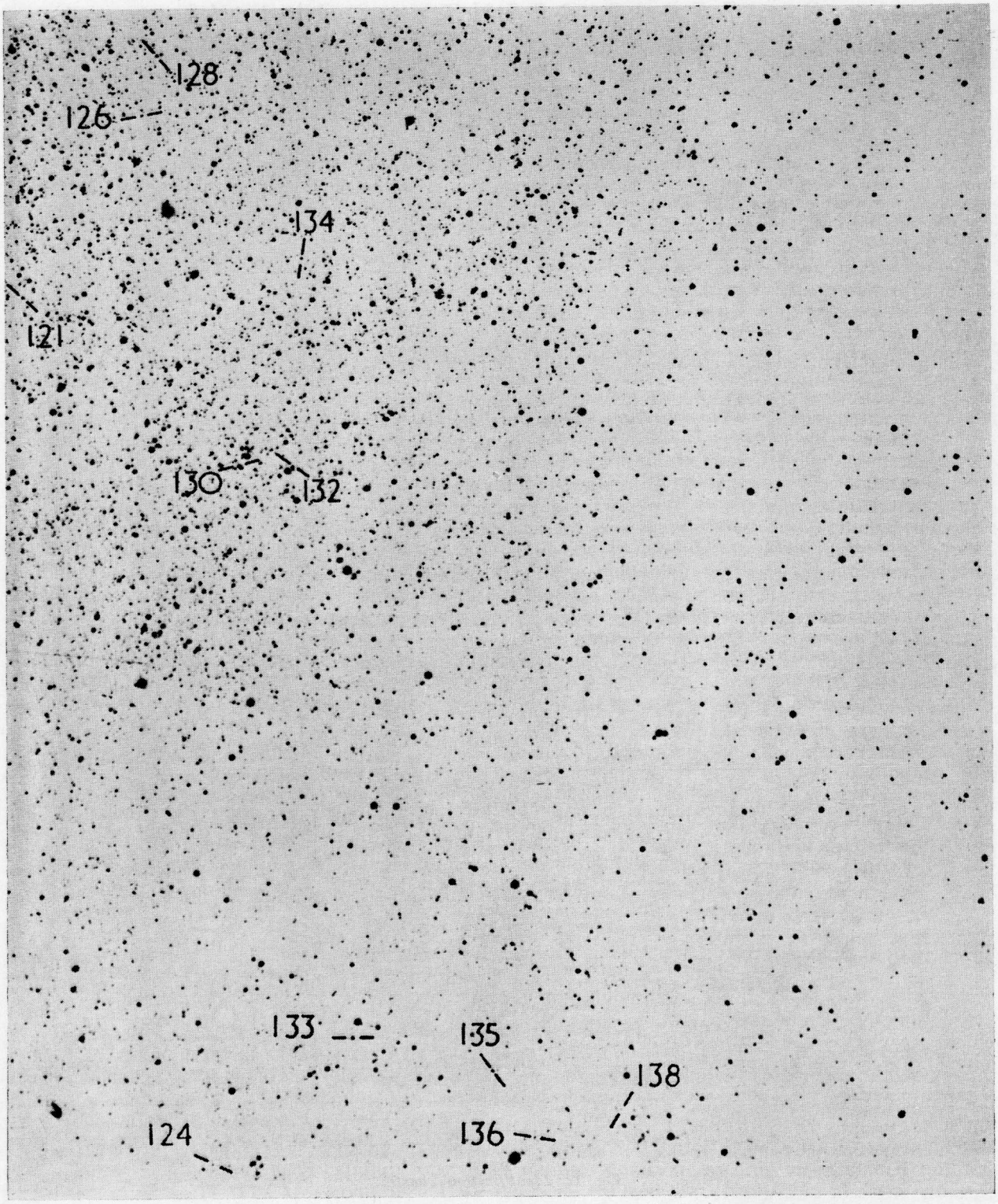

Fig. 11. *Identification charts.*

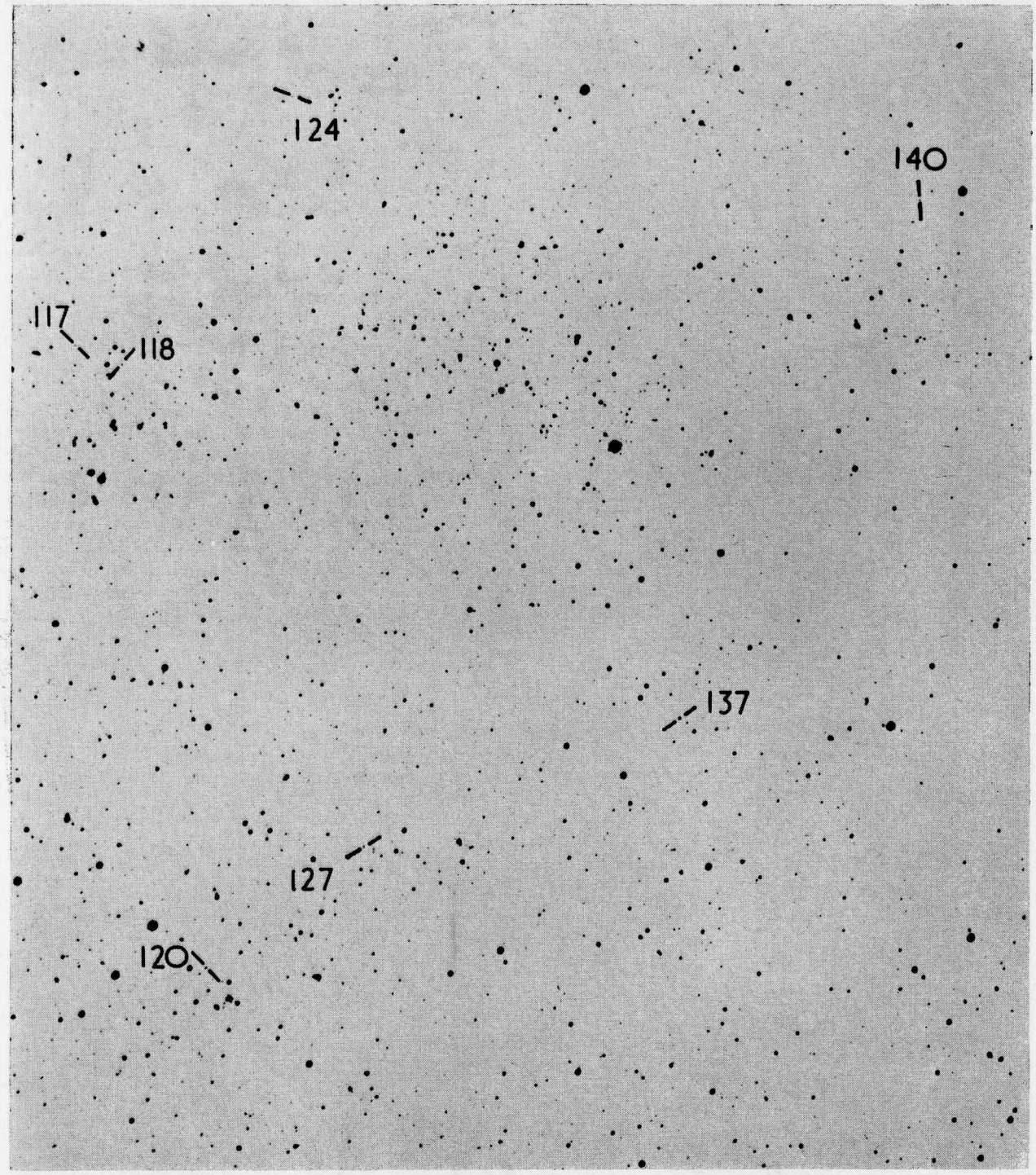

Fig. 12. *Identification charts.*

During the survey the photometric measurement of stars with U magnitudes given by Feinstein and Marraco (1971) revealed several inconsistencies. For example, in NGC 4609 star No. 46 (U = 13.61) is equal in brightness to No. 16 (U = 13.16) and in Hogg 15 star H 16 (U = 14.05) is about one magnitude fainter than H 15 (U = 14.24); also H 14 (U = 14.00) is equal to No. 12 (U = 14.40). There is no evidence for a colour dependence to account for these inconsistencies which indicates that considerable care must be exercised in the use of individual standard stars. Since the number of photoelectric standards fainter than U = 14.5 is small and the Coalsack variables lie between U = 14 and 17 at quiescent light only estimates of amplitudes and normal brightness could be obtained. Amplitudes of variation detected in the survey are in the range 0.5 to 2 magnitude, with an uncertainty of $\pm 0^m5$ in the normal U magnitude.

An earlier survey for flare stars in the Coalsack north of α Crucis (Andrews, unpublished) utilizing multiple exposures on IIa-O plates without filter revealed no rapid variables during 6.7 hours coverage with the same instrument. However, that survey in a relatively transparent region near NGC 4349, centred at 12^h18^m, $-61°.1$ (1950), $l^{II} = 299°.2$, $b^{II} = +1°.4$, suffered severely from overlapping stellar images. The narrower passband and shorter effective wavelength employed in the present survey may be partly responsible for the large number of detected variables since flares radiate more strongly towards the ultraviolet.

III. Conclusions

The results indicate that the region of the Southern Coalsack is exceptionally rich in rapid variable stars of a type possibly related to the flare stars in young stellar aggregates. There are 75 stars within 8.5 square degrees classified as definite variables. Both the high rate of detection and the fact that 5 stars showed repeated activity within only 3.5 hours coverage suggests that the photometric properties should be further investigated. However, without spectroscopic and multi-colour photometric data it is unclear whether these stars form a homogeneous group such as a T association.

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