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OPTICAL POSITIONS FOR RADIO SOURCES IN THE 3C REVISED CATALOGUE

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ABSTRACT

The optical positions of seventy-three galaxies and four quasi-stellar sources identified with radio sources in the 3C revised catalogue are given with an accuracy of about 1″ in both coordinates.

The positions of objects in the field of fifty-four radio sources are also given so as to facilitate the eventual positive identifications of these radio objects.

Accurate optical positions for identified radio sources are needed for two purposes: (*a*) They are used as calibrators for radio position determinations. (*b*) When both the structure and the position of a radio source are well known, it is necessary to have a good optical position to determine if the radio and optical radiations occur in different regions of the source.

Griffin (1963) has measured the positions of optical objects in the field of forty-two radio sources, with an accuracy of about 0″.3–0″.5 in both coordinates. He measured these positions with reference to an average of ten catalogue stars, using, when available ($\delta < 30°$ and $\delta > 50°$), the *Yale Zone Catalogues* (Yale University Observatory 1939, 1959) which give the proper motion.

Since Griffin's study, the number of optical identifications has greatly increased—so much so that a more rapid but only slightly less accurate method of position determination was used in the present work.

The method of dependences (Schlesinger 1926) was used throughout, adopting the AGK_2 catalogue (Schorr and Kohlschütter 1952–1953) stars as the reference system for sources north of $\delta = -2°$ and the *Yale Zone Catalogues* for $\delta < -2°$.

The plates measured were 48-inch Schmidt 5 × 7-inch plates taken with a field flattener by A. Sandage for a two-color survey for ultraviolet excess objects near radio positions, by T. Matthews to determine the optical type of the identifications, and by several other observers, mainly G. Tammann and the present author, especially for this program.

The proper motions are not known for the AGK_2 stars, so they were not taken into account in the reduction. The observations for the AGK_2 catalogue were made between 1928 and 1932. The plates measured here were taken in 1964 and 1965, so the mean difference in epoch is 35 years. Some of the stars in the AGK_2 catalogue are also in the *Yale Zone Catalogues*, and we therefore know their proper motions. The dispersion (σ) of the distribution of the proper motions for 35 years for twenty stars listed in both cata-

logues that were used as reference in the program is 1".0. Three reference stars are used to measure one position, so the standard error in the position due to the proper motions is $\sigma = 1''.0/\sqrt{3} = 0''.6$.

As a check on the accuracy of the method, the positions of eighteen AGK_2 stars were measured by the method of dependences and compared with the catalogue values. The standard difference was found to be $\sigma = 1''.4$. But since the error on the catalogue position due to the proper motions alone is 1".0, the error in our measured position is also 1".0 in both coordinates.

The contribution to this error is 0".6 from the proper motions, 0".2 from the standard error in the AGK_2 positions, and probably the other 0".8 from the measurements.

There are three causes of error in the measurements themselves: (1) The error in the measurement of the coordinates X and Y of the stars is probably of the order of $\pm 5\ \mu$, which amounts to $\pm 0''.3$ on the scale of the 48-inch Schmidt plates. (2) If, during the measurements, the screws of the machine are not exactly parallel to the α- and δ-lines at the center of the plate, we get an error which depends on the angle of the tilt. (3) The plates were taken with a field flattener and the subsequent distortions are unknown.

Items 2 and 3 were not fully analyzed, but we know from the discussion above what the real standard error is, and that is what we are interested in.

Another way to check the accuracy is to compare the optical positions with the very accurate radio positions published by Wade, Clark, and Hogg (1965). There are eight sources in both lists for which the standard difference is 1".3 in right ascension and 1".1 in declination, but these differences are the combination of radio and optical errors, so they are upper limits to the standard errors of both optical and radio positions. There is no systematic difference. If the standard radio errors given by Wade *et al.* are good, we get for the optical errors 0".7 in right ascension and 0".4 in declination; but these values are very sensitive to the quoted radio errors and cannot therefore be trusted.

In conclusion, the standard errors on each position are probably of the order of 1".0 in both coordinates.

Table 1 gives optical positions for seventy-three radio galaxies contained in the 3C revised catalogue (Bennett 1962) which have been positively identified with optical objects either previously by several investigators or in the course of this investigation, or independently in a parallel study by Wyndham (1965). Finding charts for these objects are not given here as they are reproduced in Wyndham's compilation of all identifications known to him by November, 1965.

Table 2 gives optical positions for objects in the neighborhood of fifty-eight radio sources, but where, for the most part, positive identification has not yet been achieved. However, four objects in this table have been identified with quasi-stellar sources. They are: (*a*) 3C 351, which was identified by Lynds, Stockton, and Livingston (1965); (*b*) 3C 432 and 3C 454 which were confirmed by Schmidt (1965) from spectra and by Sandage (1965) from *UBV* photometry; and (*c*) 3C 454.3 confirmed by photoelectric photometry (Sandage 1965). The other objects in Table 2 are not generally considered to be identifications, but their positions may eventually be useful in locating the radio sources in the area. Among the sources are eight possible identifications with quasi-stellar sources that have not yet been checked spectroscopically or photoelectrically.

The fifth column in both Tables 1 and 2 gives the reference to a finding chart in the literature if such exists. Otherwise, finding charts are given in Figure 1 where the prints were made from the 48-inch Sky Survey charts. These charts show the radio galaxy 3C 318 from Table 1 and forty-three objects from Table 2.

I have not repeated here the optical positions already published for QSS's obtained in the early parts of this program (Bolton, Clarke, Sandage, and Véron 1965; Sandage, Véron, and Wyndham 1965; Véron 1965*a*, *b*). These comprise forty-one objects which should be added to a complete listing. In summary, there now exist accurate optical positions for 157 identified radio sources: 77 from Tables 1 and 2, 41 from the pre-

4. Wyndham, J. D. 1966, Ap. J. Suppl., in press.
5. Lynds, D. R., Stockton, A. N., and Livingston, W. C. 1965, Ap. J., in press.

TABLE 1

OPTICAL POSITIONS OF 73 RADIO GALAXIES IN THE 3C REVISED SURVEY

Radio Sources	Ident.	α(1950.0)	δ(1950.0)	Finding Chart Ref.	Radio Sources	Ident.	α(1950.0)	δ(1950.0)	Finding Chart Ref.
3C 15		$00^h34^m30^s.52$	$-01°25'44''.3$	2	3C 285		$13^h19^m05^s.10$	$+42°50'57''.1$	4
17		00 35 46.79	−02 24 10.2	4	287.1		13 30 20.46	+02 16 09.0	4
18		00 38 15.01	+09 47 01.0	4	288		13 36 38.65	+39 06 22.8	4
28		00 53 08.94	+26 08 22.7	4	293		13 50 03.44	+31 41 32.2	3
29		00 55 01.41	−01 39 50.6	4	293.1		13 52 16.31	+16 29 33.8	4
31	NGC 383	01 04 39.18	+32 08 45.1	4	296	IC 5532	14 14 25.96	+11 02 15.1	4
35		01 09 05.04	+49 12 48.9	4	300		14 20 40.10	+19 49 12.4	4
63		02 18 21.90	−02 10 33.0	4	300.1		14 25 57.64	−01 10 48.3	4
67		02 21 18.05	+27 36 37.4	4	305		14 48 17.58	+63 28 36.4	4
75*		02 55 03.07	+05 49 36.2	1	313		15 08 32.66	+08 02 48.2	4
....		02 55 03.14	+05 49 20.6	...	314.1		15 10 11.35	+70 57 10.2	4
76.1		03 00 27.22	+16 14 36.6	4	318		15 17 50.74	+20 26 53.5	...
79		03 07 11.31	+16 54 37.4	4	319		15 22 43.90	+54 38 42.8	4
83.1	NGC 1265	03 14 57.00	+41 40 33.4	4	320		15 29 29.70	+35 43 48.5	4
88		03 25 18.25	+02 23 20.4	4	322		15 33 49.81	+55 46 36.1	4
89		03 31 43.37	−01 21 26.3	4	326		15 50 14.26	+20 14 26.7	4
109		04 10 54.82	+11 04 41.2	4	327.1		16 02 13.26	+01 26 13.4	4
132		04 53 42.44	+22 44 44.0	4	332		16 15 47.27	+32 29 45.0	4
135		05 11 33.78	+00 53 07.9	4	346		16 41 34.71	+17 21 19.7	4
153		06 05 44.75	+48 04 49.1	4	348*	Hercules A	16 48 39.98	+05 04 35.0	1
166		06 42 24.73	+21 25 02.8	4	349		16 58 04.87	+47 07 15.7	3
171		06 51 11.00	+54 12 48.0	4	357		17 26 27.41	+31 48 23.9	4
180		07 24 33.27	−01 58 24.4	4	379.1		18 25 55.93	+74 19 06.8	4
187		07 42 27.94	+02 07 44.6	4	381		18 32 24.43	+47 24 39.0	4
192		08 02 35.51	+24 18 28.2	4	382		18 33 12.11	+32 39 15.1	4
196.1		08 12 57.32	−02 59 13.9	4	390.3		18 45 37.80	+79 43 03.4	4
198		08 19 52.33	+06 06 47.0	4	401		19 39 38.82	+60 34 31.5	4
200		08 24 21.65	+29 28 41.2	4	403		19 49 44.57	+02 22 37.1	4
212		08 55 55.62	+14 21 24.2	4	403.1		19 49 55.20	−01 25 07.2	4
223		09 36 50.91	+36 07 34.9	4	424		20 45 44.40	+06 50 10.2	4
227		09 45 06.61	+07 39 17.1	4	430		21 17 02.66	+60 35 26.7	4
236		10 03 05.39	+35 08 48.5	4	436		21 41 57.94	+27 56 30.0	4
258		11 22 06.42	+19 35 58.8	4	449		22 29 07.71	+39 06 04.4	4
264	NGC 3862	11 42 29.64	+19 53 02.5	...	452		22 43 33.00	+39 25 25.6	4
265		11 42 53.40	+31 50 24.8	4	455		22 52 33.81	+12 57 14.3	3
272.1	NGC 4374	12 22 32.47	+13 09 54.8	...	456		23 09 56.65	+09 03 07.8	4
284		13 08 41.39	+27 44 03.1	4	459		23 14 02.30	+03 48 56.0	4

*The R.A. given by Griffin is affected by a copying error.

References to Tables I and II

1. Griffin, R. F. 1963, A.J., 68, 421.
2. Hazard, C. 1965, Quasistellar Sources and Gravitational Collapse, eds. Robinson, Schild, and Schücking (Chicago: University of Chicago Press) p. 135.
3. Wyndham, J. D. 1965, A.J., 70, 384.

TABLE 2

OPTICAL POSITIONS IN THE FIELD OF 58 RADIO SOURCES

Radio Sources	Object Measured	α(1950.0)	δ(1950.0)	Finding Chart Ref.	Remarks	Radio Sources	Object Measured	α(1950.0)	δ(1950.0)	Finding Chart Ref.	Remarks
3C 13	a	00h31m37s.30	+39°08′10″.9	....	.....	3C 256	....	11h18m02s.73	+23°44′19″.8	4	.....
16	a	00 35 10.52	+13 03 57.7	....	.....	257	a	11 20 36.40	+05 46 28.0	....	.....
22	a	00 48 05.58	+50 55 45.5	....	.....	267	a	11 47 20.76	+13 04 16.0	....	.....
33.1	a	01 06 07.55	+72 54 50.9	....	.....	268.1	b	11 57 48.76	+73 17 56.0	....	.....
36	....	01 15 02.59	+45 20 31.3	4	QSS?		d	11 57 56.40	+73 17 37.2	....	.....
41	a	01 23 49.88	+32 56 47.7	....	.....	268.2	a	11 58 20.60	+31 50 29.8	....	.....
42	a	01 25 39.03	+28 48 01.8	....	.....	268.3	a	12 03 50.28	+64 30 59.0	....	.....
	c	01 25 44.33	+28 47 16.4	....	.....	280	a	12 54 42.46	+47 35 12.8	....	.....
46	b	01 32 31.39	+37 38 47.4	....	.....	288.1	....	13 40 30.29	+60 36 48.0	4	QSS?
54	b	01 52 29.98	+43 31 39.1	....	.....	289	....	13 43 28.80	+50 01 06.1	4	.....
55	a	01 54 20.03	+28 36 17.9	....	.....	294	a	14 04 33.24	+34 25 40.3	....	.....
65	a	02 20 37.40	+39 46 58.9	....	.....	303	a	14 41 22.94	+52 14 15.1	....	QSS?
68.2	a	02 31 18.93	+31 20 55.5	....	.....	305.1	a	14 48 06.37	+17 08 15.4	....	.....
107	...	04 09 50.20	−01 06 50.4	4	.....	309.1	a	14 58 58.74	+71 52 07.9	4	QSS?
169.1	a	06 47 33.53	+45 11 59.9	....	.....	318.1	a	15 19 26.17	+07 49 58.8	....	.....
175	....	07 10 15.44	+11 51 24.5	4	.....	323	....	15 49 49.60	+60 25 06.2	4	.....
190	a	07 58 38.61	+14 23 17.3	....	.....	323.1	a	15 45 32.29	+21 01 42.1	....	QSS?
	c	07 58 43.33	+14 23 04.3	....	.....	325	a	15 49 18.03	+62 50 01.8	....	.....
205	a	08 35 10.50	+58 04 31.2	....	.....	330	a	16 09 11.35	+66 03 27.5	....	.....
217	a	09 05 58.03	+38 04 36.3	....	.....	340	a	16 27 30.32	+23 26 45.8	....	.....
	b	09 06 19.05	+37 57 26.6	....	.....	341	a	16 25 59.09	+27 48 34.5	....	QSS?
	c	09 06 04.40	+38 11 47.6	....	.....		b	16 25 56.54	+27 47 55.0	....	.....
	d	09 06 11.51	+37 59 32.3	....	.....	343	a	16 34 13.24	+62 51 09.9	....	.....
	f	09 05 45.43	+38 00 58.5	....	.....	343.1	a	16 37 55.30	+62 41 13.7	....	.....
220.1	a	09 26 10.99	+79 19 47.7	....	.....	351	....	17 04 03.58	+60 48 29.9	5	QSS
	b	09 26 36.79	+79 20 17.5	....	.....	356	....	17 23 06.96	+50 59 59.9	4	.....
220.2	....	09 27 30.00	+36 14 37.9	4	.....	368	b	18 02 44.55	+11 01 18.2	....	.....
225	a	09 39 29.39	+14 00 23.4	....	.....	427.1	....	21 04 51.92	+76 21 27.6	4	QSS?
	b	09 39 30.08	+14 00 11.9	....	.....	432	....	21 20 25.64	+16 51 46.0	4	QSS
230	c	09 49 23.31	+00 12 24.4	....	.....	435	....	21 26 37.78	+07 19 46.6	4	QSS?
	d	09 49 24.89	+00 12 39.8	....	.....	437	a	21 45 01.05	+15 06 09.7	....	.....
238	a	10 08 19.37	+06 39 08.4	....	.....	438	a	21 53 47.85	+37 45 55.0	....	.....
244.1	a	10 30 16.35	+58 30 19.0	....	.....	441	a	22 03 49.64	+29 14 52.1	....	.....
	b	10 30 21.04	+58 30 32.9	....	.....	454	....	22 49 07.86	+18 32 46.6	4	QSS
249	a	10 59 29.12	−01 01 09.1	....	.....	454.3	....	22 51 29.61	+15 52 53.6	....	QSS
	b	10 59 28.78	−01 00 19.3	....	.....						

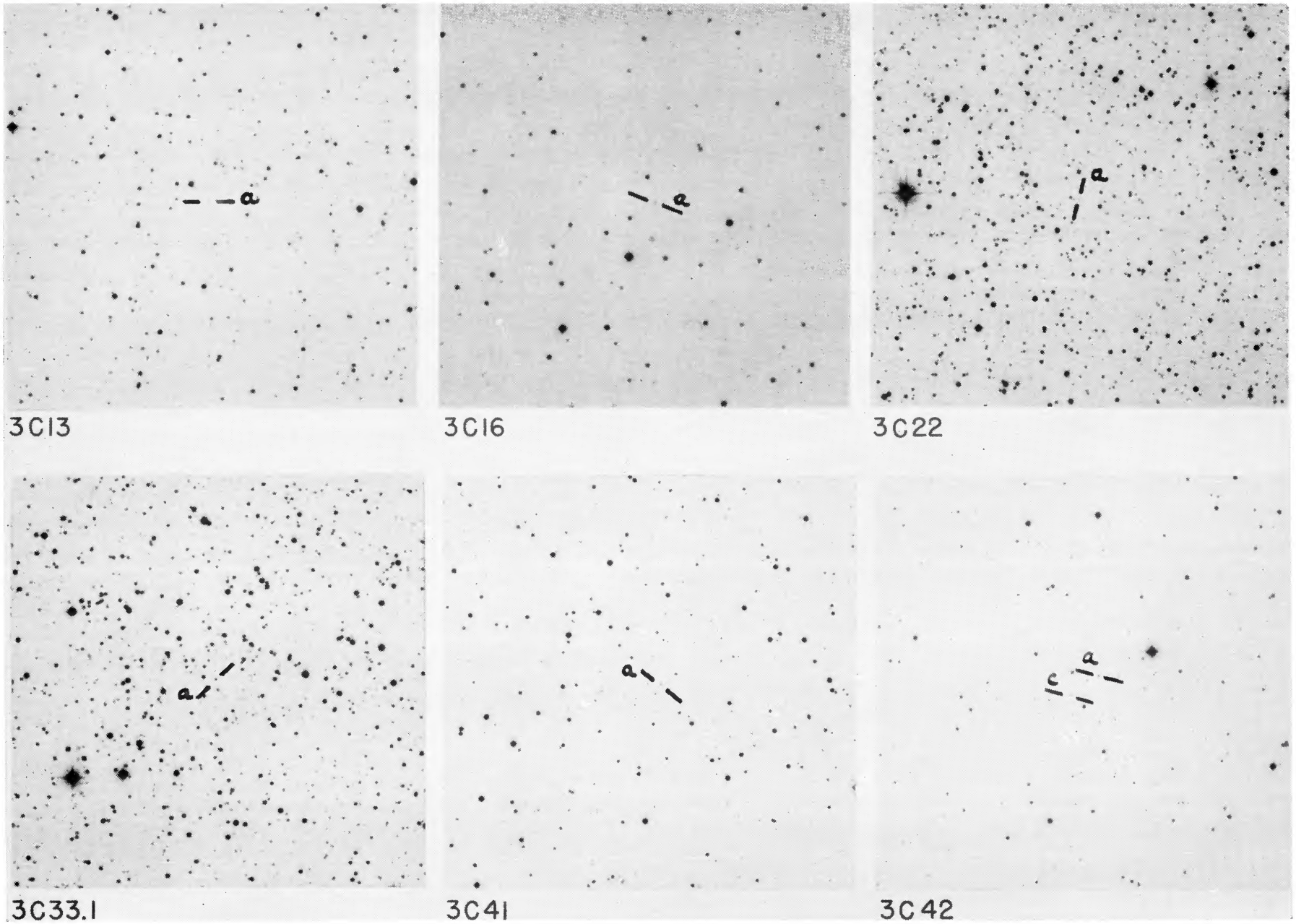
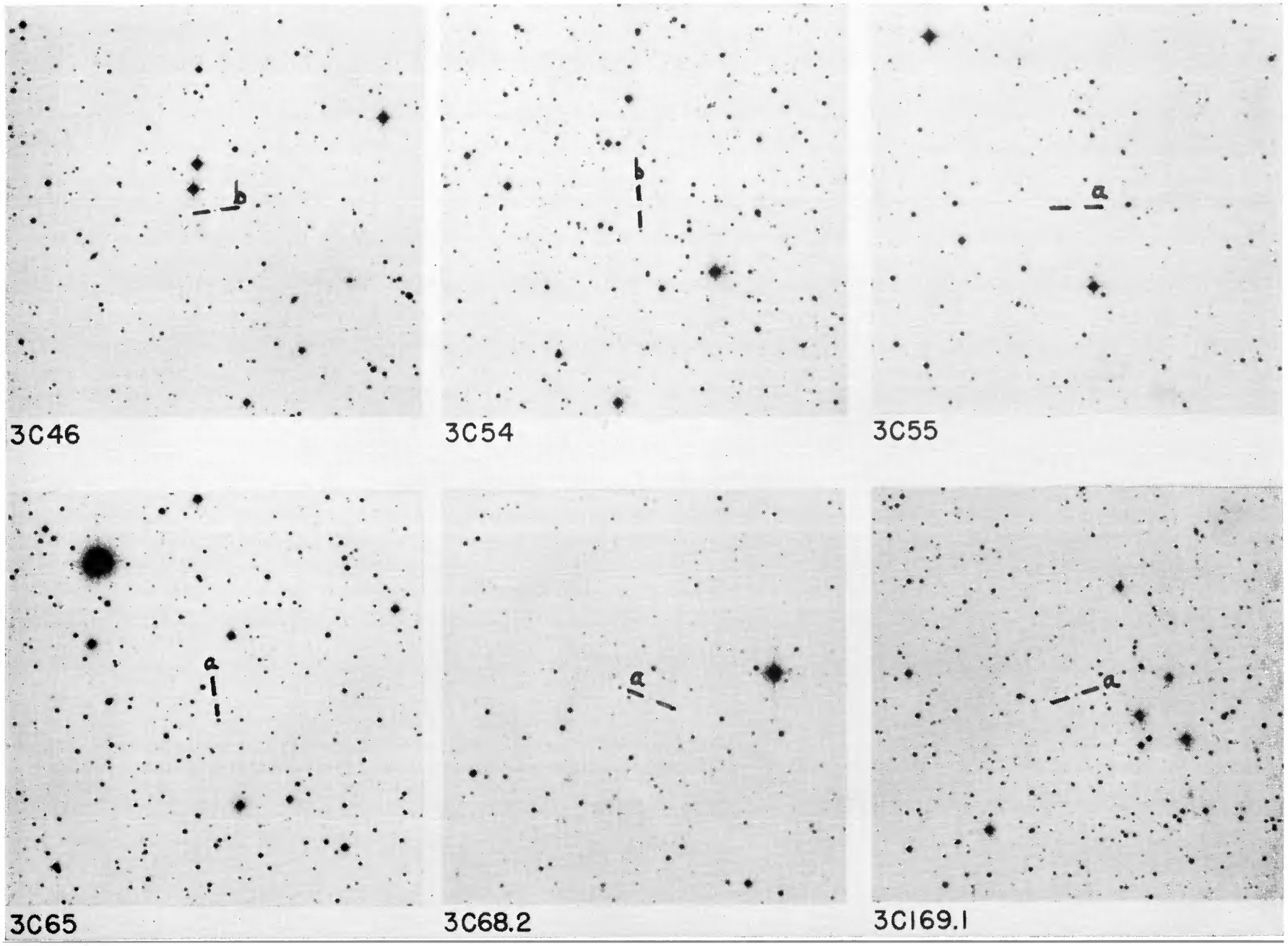


FIG. 1*a*.—Identification charts for 1 object in Table 1 and 43 objects in Table 2, reproduced from the 48-inch Schmidt Sky Survey charts



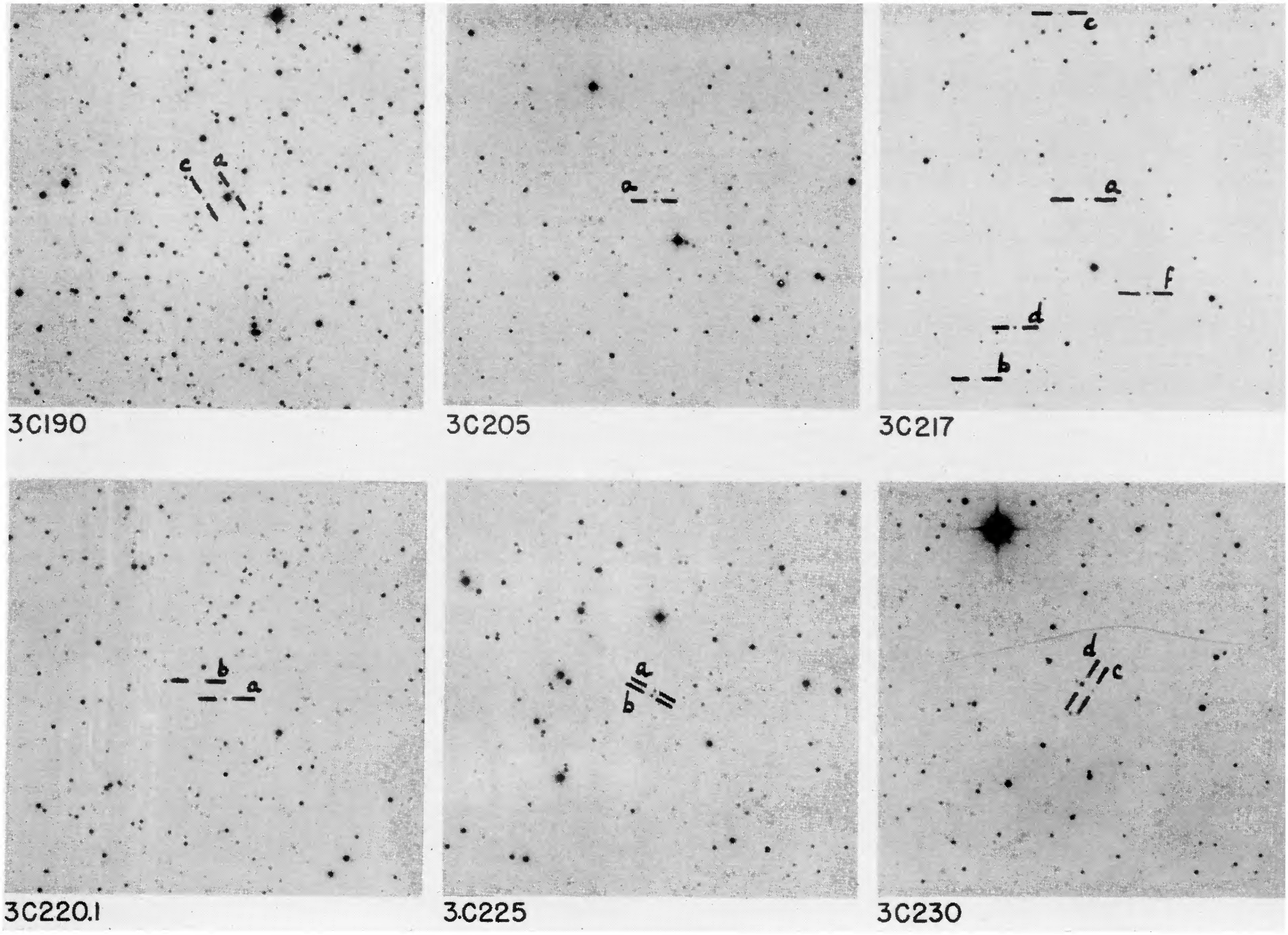
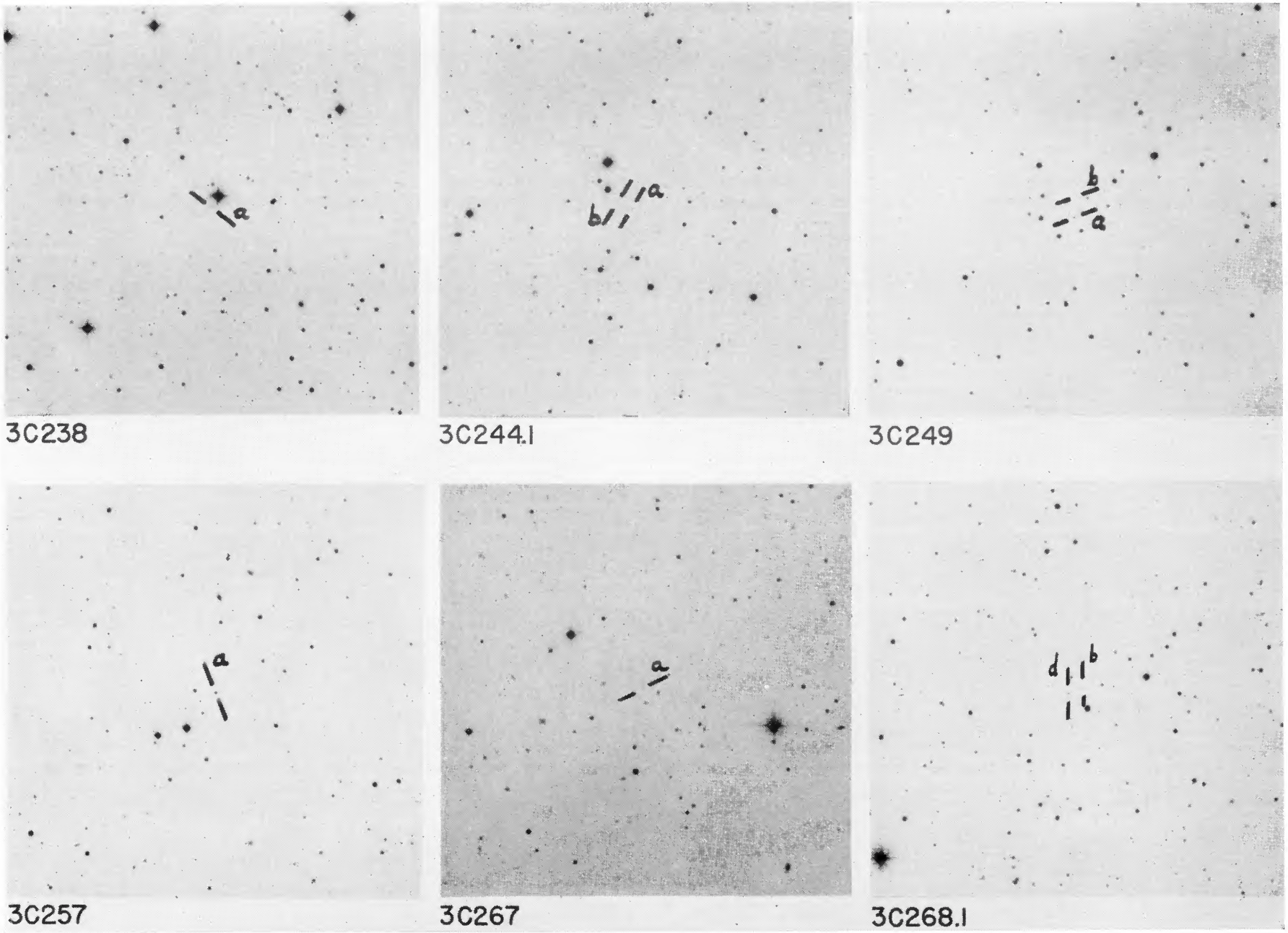


FIG. 1c



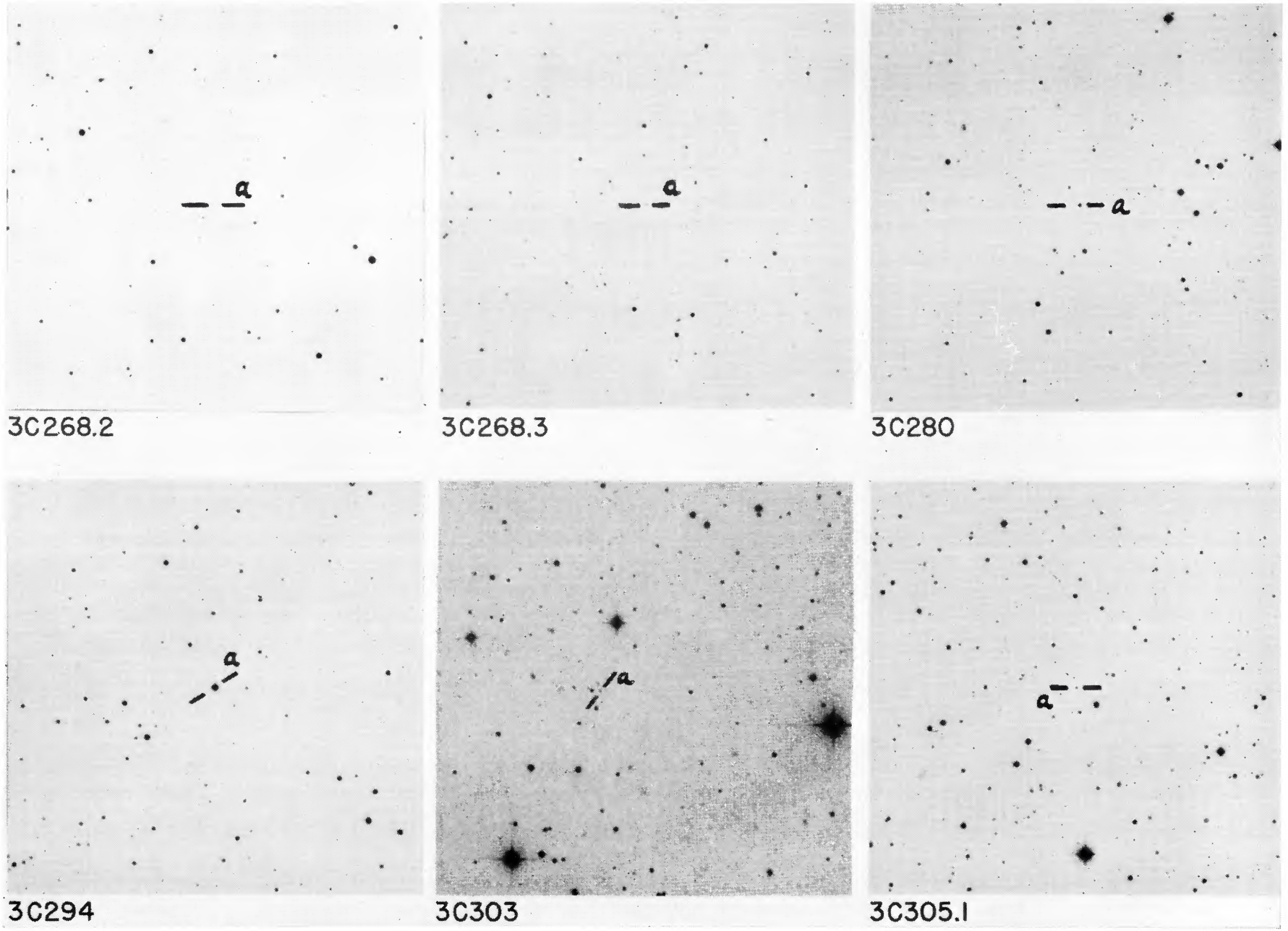
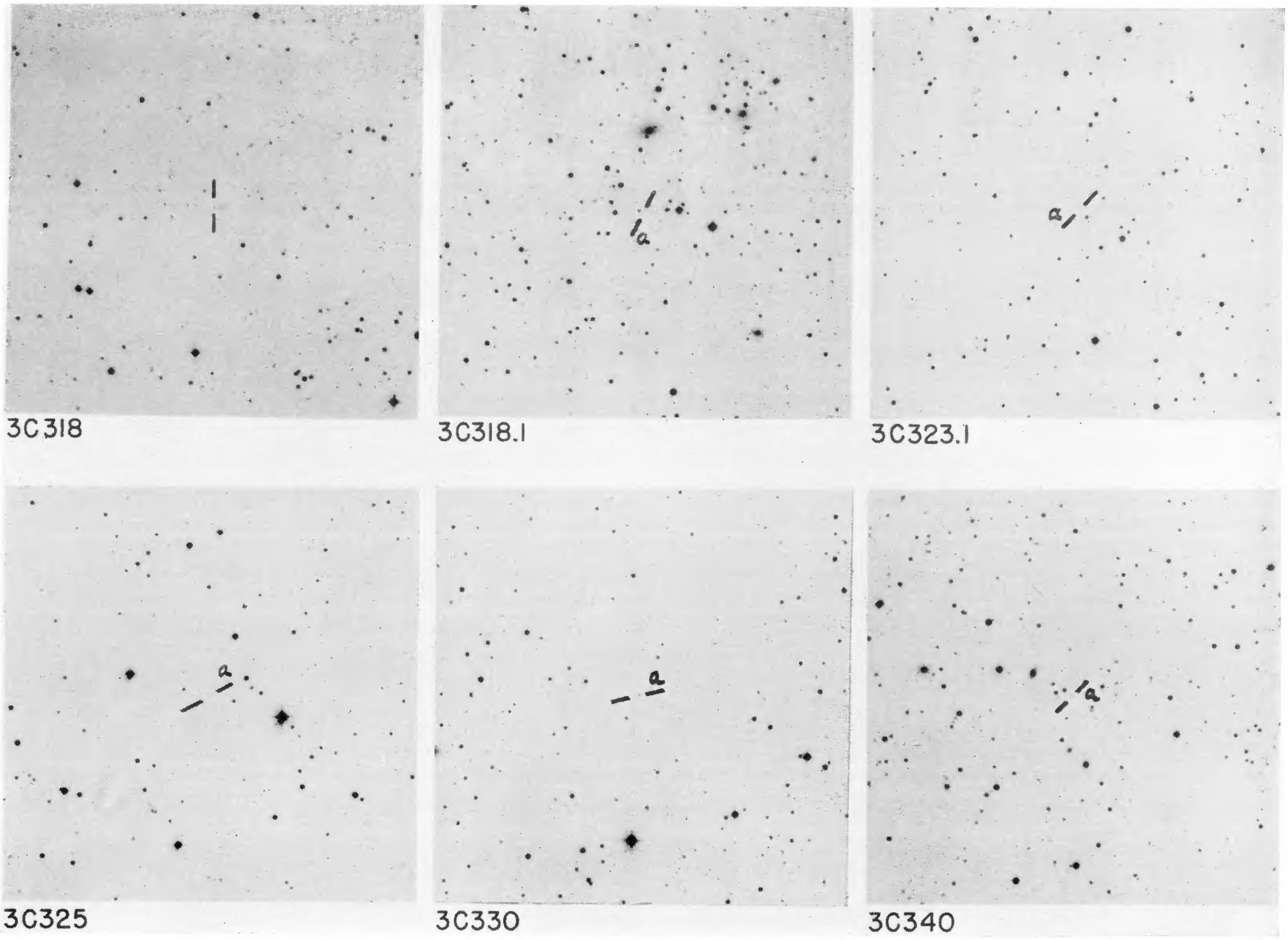


FIG. 1e

1966ApJ...144..861V



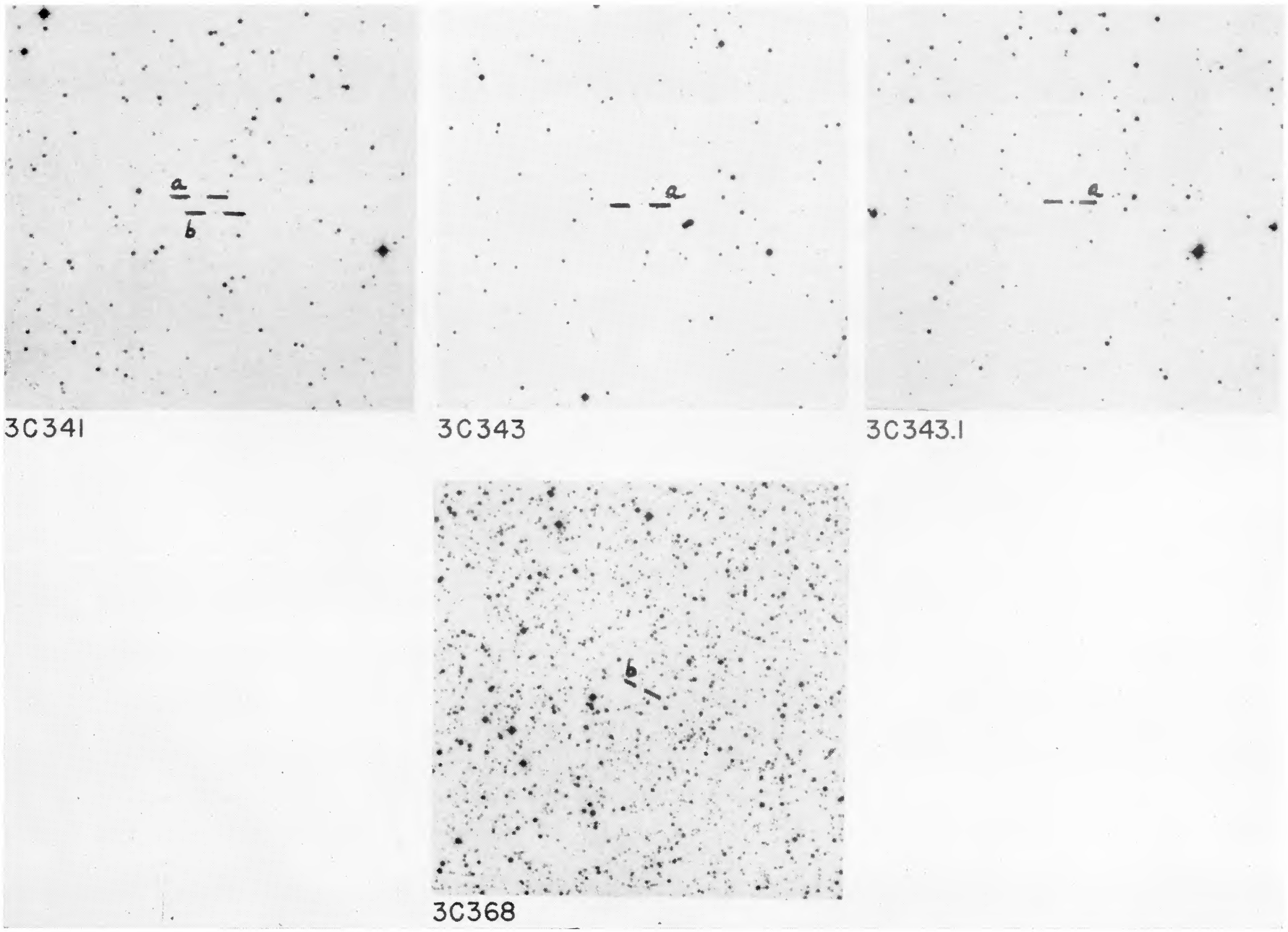
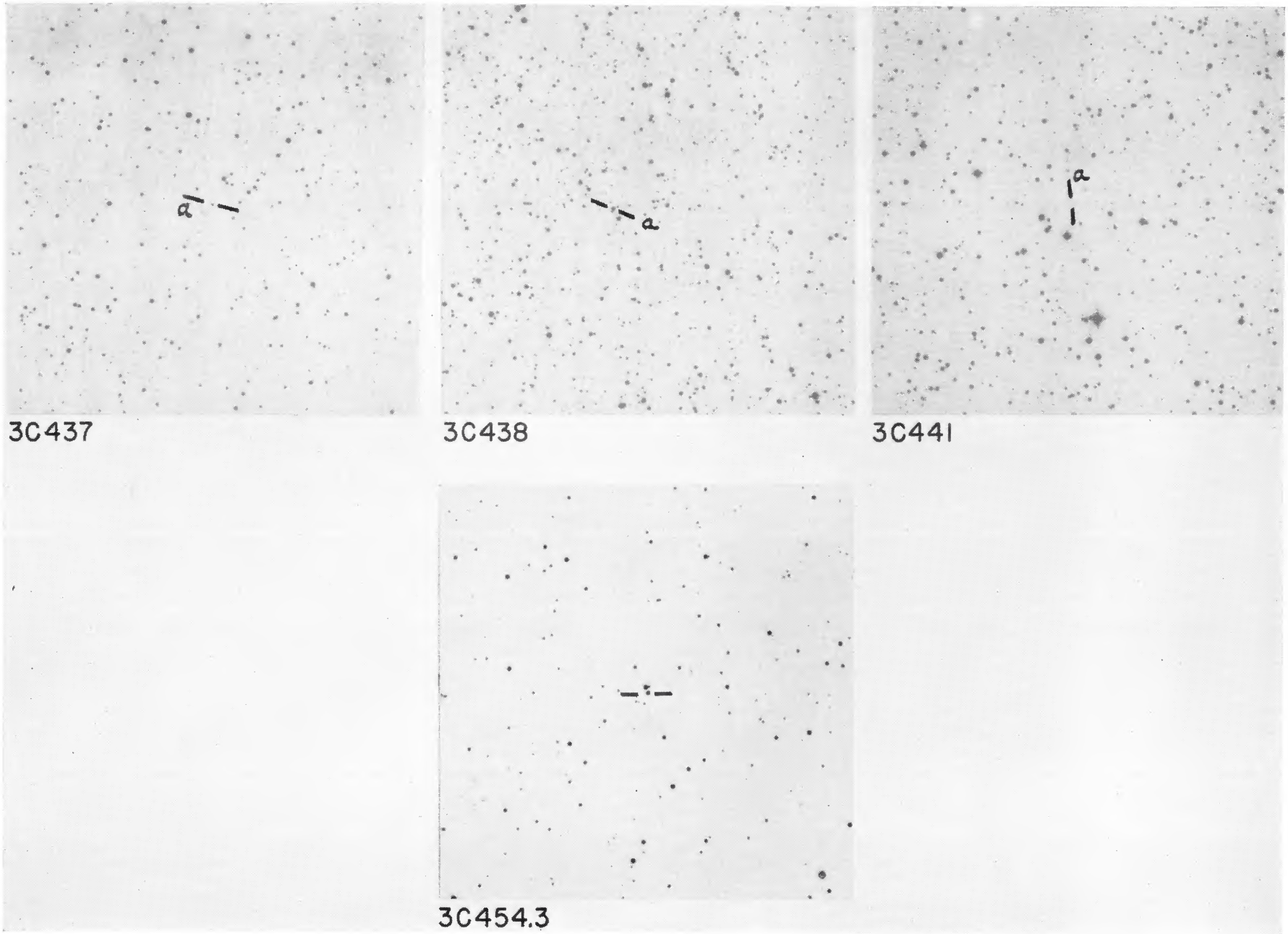


FIG. 1a



viously published QSS positions in the current program, and 39 from the initial work on this problem by Griffin.

These, together with the data of Table 2, comprise the material from which the absolute errors of the radio catalogues and/or physical displacements of the radio and optical objects can eventually be discussed.

It is a great pleasure to thank A. Sandage, who suggested the problem and who has helped by discussions throughout the year, and to A. Sandage, T. Matthews, G. Tammann, and the other observers who have placed at my disposal their available plate material or who have taken some plates specially for this program.

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