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OPTICAL IDENTIFICATIONS OF SELECTED 4C RADIO SOURCES

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Summary

The declinations of 64 4C sources have been measured with uncertainties of about $\pm 15''$ arc and a search for optical identifications of the sources is described.

1. *Introduction.* The positional uncertainties of most of the sources in the 4C catalogue (Pilkington & Scott 1965, Gower, Scott & Wills 1967) are too large to allow significant identifications to be made with galaxies fainter than about 18^{m}, although many identifications with brighter galaxies or with clusters of galaxies have been made (Caswell & Wills 1966, Pilkington 1964, Wills 1966a). Galaxies as faint as $m_{\mathrm{pg}} = 20$ can be recognized on the *Palomar Sky Survey* prints but in order to reduce the number of random coincidences to one half of the number of true identifications at this apparent magnitude, the declination uncertainties (which are typically $\pm 3'$ arc) must be reduced to about $\pm 20''$ arc if the 4C right ascensions (which are generally reliable to about $\pm 20''$ arc) are used. The present paper describes some observations in which the declinations of 64 4C sources were measured with uncertainties of about $\pm 15''$ arc and gives the results of a search for optical identifications of the sources.

2. *The observations.* A sample of 193 sources was initially selected, the sources being in the declination range 20° to 80°, further than 20° from the galactic equator and having 178 MHz flux densities $\geqslant 5 \times 10^{-26}$ w. m^{-2} Hz^{-1}, excluding sources listed in the *Revised 3C Catalogue* (Bennett 1962). The Cambridge three aerial interferometer (Ryle, Elsmore & Neville 1965) was used to observe sources at hour angles 18^{h} or 06^{h}, where the declination resolution is greatest. The typical observing time was 4 min at 1407 MHz, although a few sources were tracked for periods of up to 30 min near these points. More accurate results would have been obtained had the sources been tracked for longer periods but the method used allowed many sources to be observed in a comparatively short time. By comparing the phase of the interferometric signal with that calculated from the 4C position a more accurate declination was derived. Two simultaneous aerial spacings were used at each of two frequencies (408 and 1407 MHz) to provide four interferometer baselines. The observations were made at various times during 1966 June–August with typical aerial separations of about 2500 and 5000 feet which gave baselines of about 1100, 2200, 3750 and 7500 wavelengths; the phase collimation corrections were derived from observations of sources of known declination.

At the largest baseline a phase change of 360° corresponds to a declination shift of about $30''$ cosec δ for a source at declination δ and there is a lobe ambiguity which can usually be resolved by comparison with the phase differences observed at the other three baselines; if the results at the shortest baseline can be used the ambiguity is $3'\cdot5$ cosec δ and usually only one value is consistent with the 4C measurement. In general the 408 MHz observations were affected by confusion (there is, on average, at least one other 4C source in the aerial beam) and were used only to select the correct lobe at the larger baselines.

Many of the sources are resolved at the largest baseline and useful results can be obtained only for sources with angular diameters less than about $15''$ arc; this reduces the proportion of sources which are likely to be identified with galaxies since the radio source associated with a 20^{m} galaxy subtends this angle if its linear diameter is 100 kpc. In general the observations were analysed further only if the source was judged to be unresolved at the largest baseline and if the phase of the signal at this baseline was approximately constant during the passage of the source through the aerial beam. Of the 193 sources in the original sample, about 170 were observed; of these, 42 gave good agreement between the phase differences observed at all four baselines. Observations of a further 22 sources were analysed, although the positions of these sources are less reliable than those of the sources in the former group.

3. *Results.* The improved declinations of the 64 sources are listed in Table I, where the 4C right ascensions are included for reference. The uncertainties of the improved declinations are not given separately, but sources are assigned to two classes; for sources in class (i) the standard error in the declination is estimated to be about $\pm 5''$ cosec δ, while the errors for class (ii) sources are about 50% greater.

TABLE I

Class (i) sources

Radio source							Optical object			
								Position relative to radio position		*Notes*
4C	3C	R.A. (1950.0)			Dec. (1950.0)			R.A.	Dec.	
20.11	74	02	51	09.0	20	02.65				Partially obscured region; nothing visible near radio position.
34.09		02	58	34.2	35	00.60		0	0	NGC 1167
22.08	108	04	09	44.2	22	57.40		10″f	0	18^{m} star or galaxy.
77.06		06	38	07.6	78	00.05				Blue stellar object 50″p, 10″N; otherwise nothing visible.
44.15		06	59	16.2	44	35.60				Blue stellar object 55″S; otherwise nothing visible.
32.24		08	09	50.4	32	52.35				Nothing visible.
43.16	199	08	20	03.4	43	06.65		5″f	0	20^{m} galaxy.
34.30	211	08	54	34.9	34	15.80		30″p	15″N	Blue stellar object.
39.25		09	23	55.3	39	15.45		5″f	0	Very blue stellar object. $z=0\cdot698$ (Lynds *et al.* 1966).
31.35		10	17	48.7	31	53.35	(a)	35″p	5″N	18^{m} galaxy.
							(b)	10″p	10″S	20^{m} galaxy.

TABLE I (*continued*)

Radio source							Optical object			
								Position relative to radio position		*Notes*
4C	3C	R.A. (1950.0)			Dec. (1950.0)			R.A.	Dec.	
30.20	248	10	57	20.8	30	42.65		20″p	5″S	Star?
61.21		11	13	04.3	61	19.85				Nothing visible.
43.22		11	31	57.0	43	44.65				Nothing visible.
30.22	261	11	32	16.3	30	21.85		5″p	15″N	Blue stellar object $z = 0.614$ (Lynds *et al.* 1966).
49.22		11	50	48.0	49	47.85		0	10″S	Blue stellar object LB 2136 (Wills 1966b).
59.17		11	53	28.1	59	03.80	(a)	0	0	19^m galaxy.
							(b)	15″f	10″S	Blue 18^m galaxy.
31.40		12	19	23.9	31	47.60				Nothing visible.
39.37		12	32	39.3	39	41.40		0	0	19^m galaxy.
64.19	292	13	49	12.8	64	43.25				Nothing visible.
24.31		14	23	33.2	24	24.75				Nothing visible.
20.34	304	14	46	32.7	20	38.15		0	15″S	19^m galaxy.
69.17	307	14	53	06.5	69	39.70				Nothing visible.
75.05		15	00	35.6	75	33.70				Nothing visible.
60.19	311	15	02	57.8	60	12.60		5″f	5″N	Very blue stellar object.
48.39		15	46	45.6	48	44.15		30″p	5″N	19^m galaxy.
22.43	331	16	10	10.3	22	29.90		5″f	10″S	Star?
69.20		16	22	18.9	69	36.30				Nothing visible.
21.48		16	25	22.6	21	19.15	(a)	30″f	0	Blue stellar object.
							(b)	30″p	5″N	20^m galaxy.
26.49	342	16	34	36.3	26	53.95				Nothing visible.
75.06		16	50	20.5	75	51.60				Nothing visible.
38.43	350	17	03	22.7	38	44.80		25″p	5″N	Blue stellar object.
34.47		17	21	33.6	34	18.90		15″f	10″S	19^m galaxy.
47.46		17	23	35.3	47	08.55		5″f	0	20^m galaxy.
20.42	359	17	30	42.3	20	40.15	(a)	5″p	0	Star?
							(b)	0	10″N	20^m galaxy.
							(c)	5″p	0	19^m galaxy.
79.17		17	33	50.5	79	51.30		15″p	0	19^m galaxy.
24.42		17	35	34.6	24	02.60	(a)	15″p	5″S	19^m galaxy.
							(b)	0	45″N	Very blue stellar object close to 4C position.
59.28	363	17	47	29.6	59	44.50		5″p	10″S	19^m galaxy.
39.56		18	19	42.8	39	41.25		25″p	15″N	Slightly blue stellar object.
65.23	383	18	33	32.2	65	19.20		5″f	5″S	17^m galaxy with possibly blue stellar object just NW.
35.53		22	31	21.7	35	45.60		25″f	10″S	19^m galaxy.
27.52	463	23	25	28.9	26	59.40		0	10″S	Blue stellar object.
22.63	466	23	37	51.9	22	04.30				Nothing visible.
				Class (ii) sources						
77.04		04	22	14.5	77	01.6				Nothing visible.
58.18		09	13	14.7	58	51.5		30″p	0	19^m star or galaxy.
48.27	235	10	03	30.6	48	28.0		0	10″S	20^m object visible only on blue print.
59.11		10	04	14.2	59	19.4				Nothing visible.
27.21	240	10	15	00.7	27	47.5		10″f	5″N	Star?

TABLE I (*continued*)

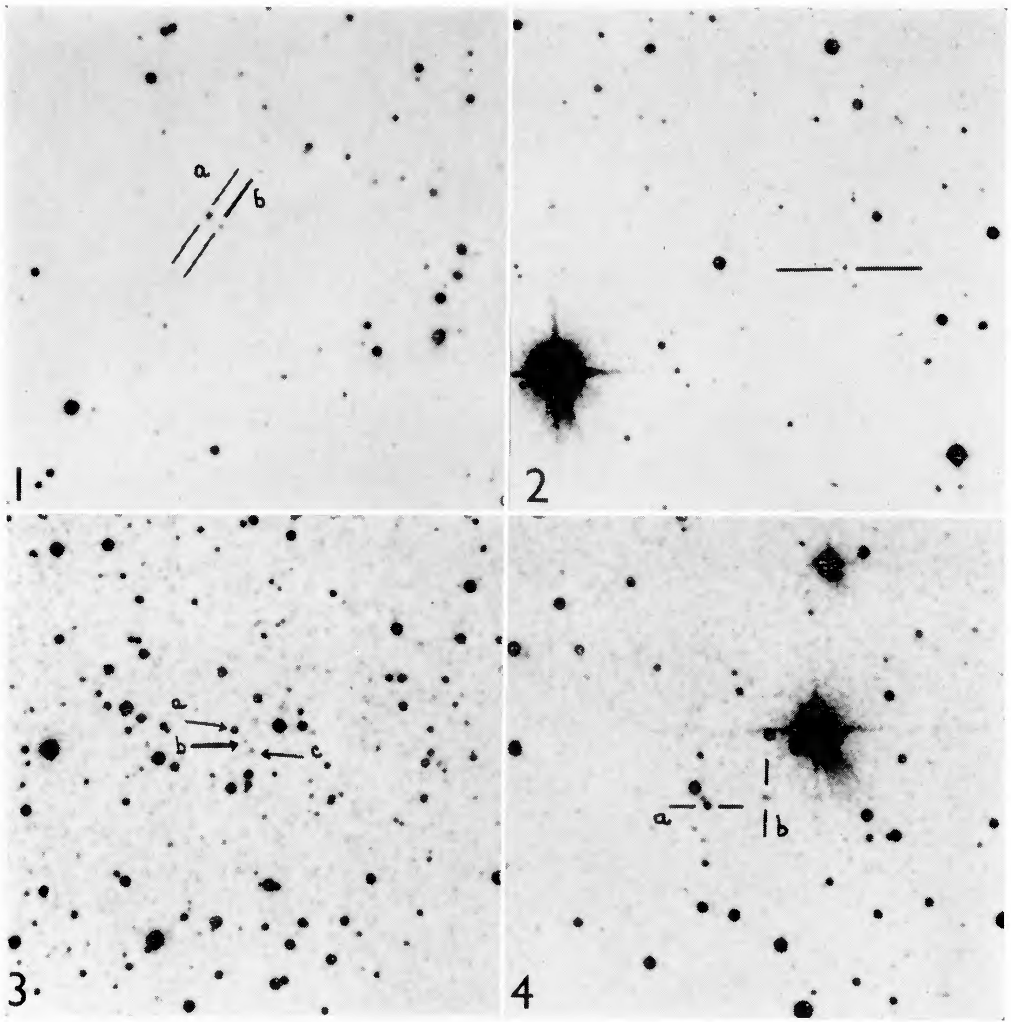
Radio source							Optical object			
								Position relative to radio position		*Notes*
4C	3C	R.A. (1950.0)			Dec. (1950.0)			R.A.	Dec.	
20.24		10	55	36.0	20	18.1	(a)	0	10″N	18^m galaxy.
							(b)	10″p	0	19^m galaxy or star.
59.16		11	38	05.5	59	29.0				Blue stellar object 55″S; otherwise nothing visible.
52.26		12	49	56.1	53	01.9				Nothing visible.
65.14	282	13	06	29.8	66	00.2		5″p	5″N	20^m galaxy.
72.20		15	20	56.4	72	34.4				Nothing visible.
30.29		15	47	13.8	30	56.4		30″p	10″S	Star?
44.27		16	02	35.6	44	31.5				Nothing visible.
33.39	329	16	08	11.3	33	06.5		0	15″S	Star?
21.47	333	16	15	05.9	21	14.9		30″p	0	Star?
37.50		16	46	18.1	37	57.7				18^m galaxy 1′f; otherwise nothing visible.
29.50		17	02	10.8	29	51.2		0	0	Very blue stellar object.
29.53		17	49	50.5	29	50.5		15″f	10″N	18^m galaxy.
48.43	367	17	59	33.7	48	32.7		20″p	10″S	20^m galaxy.
24.56		21	47	11.9	24	49.8				Nothing visible.
29.64		21	56	28.2	29	44.8		0	10″S	Blue stellar object.
26.62		22	27	14.7	26	04.8	(a)	10″f	20″N	18^m galaxy.
							(b)	10″f	0	Blue stellar object.
33.57		22	39	10.4	33	21.5		15″f	0	19^m galaxy.

Note.—The positions of the optical objects are given relative to the radio positions with uncertainties of about ±5″–10″ arc.

Key to finding charts

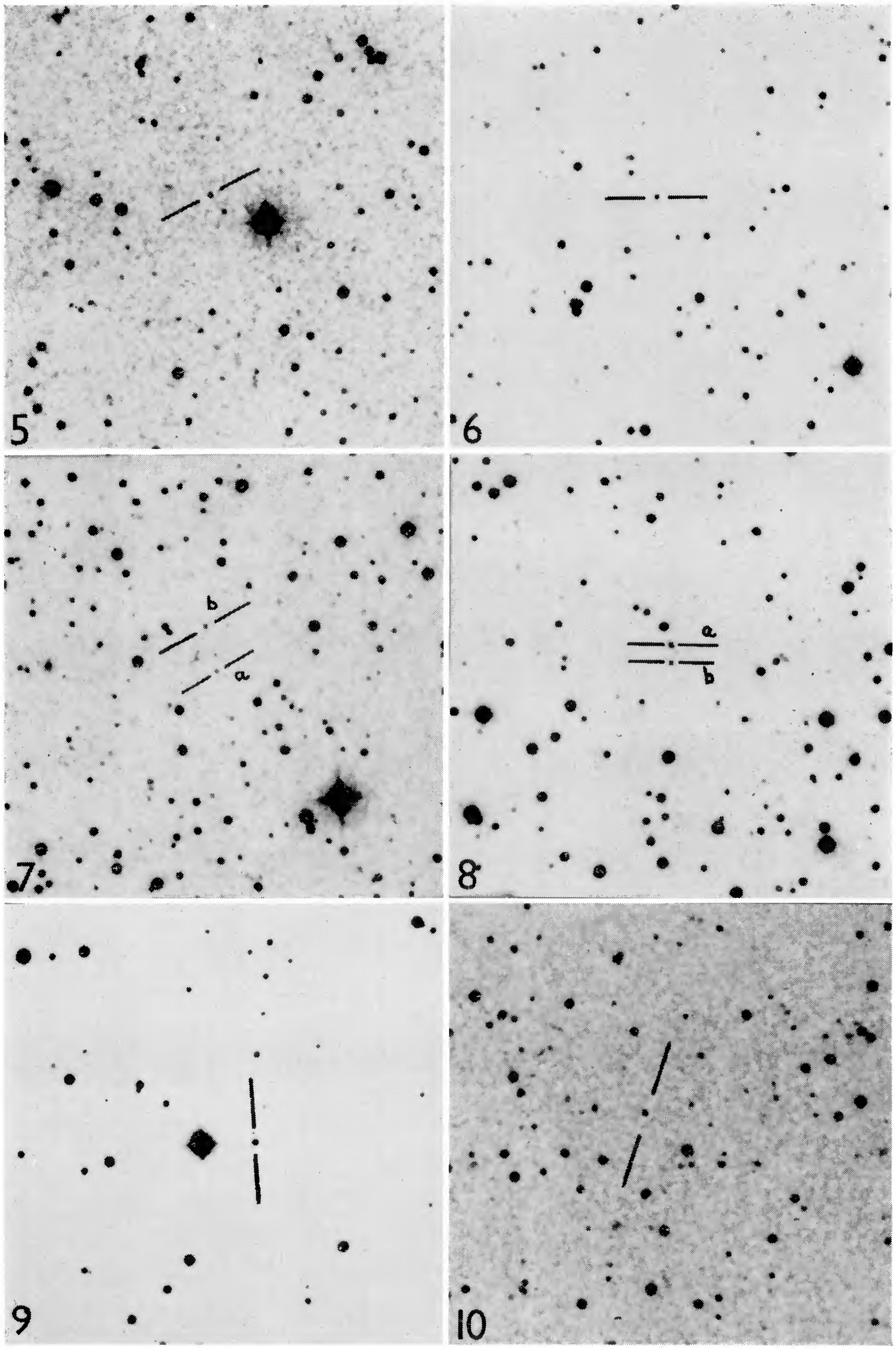
Number	Source	Number	Source	Number	Source
1	4C 20.24	13	4C 30.20	25	4C 48.27
2	20.34	14	30.22	26	48.39
3	20.42	15	31.35	27	48.43
4	21.48	16	33.57	28	49.22
5	22.08	17	34.09	29	58.18
6	22.43	18	34.30	30	59.17
7	24.42	19	34.47	31	60.19
8	26.62	20	35.53	32	65.14
9	27.52	21	38.43	33	65.23
10	29.50	22	39.25	34	79.17
11	29.53	23	39.37		
12	29.46	24	39.56		

Twenty-two of the sources were observed in the original 3C survey (Edge *et al.* 1959), although their flux densities are below the limit of the Revised 3C catalogue. They have also been observed by Pauliny-Toth, Wade & Heeschen (1966), whose declination measurements are accurate to about ±30″ arc. Comparison of their positions with those given in Table I shows that the distribution of the differences between the measured declinations is centred at zero, with a standard deviation of only ±25″ arc.

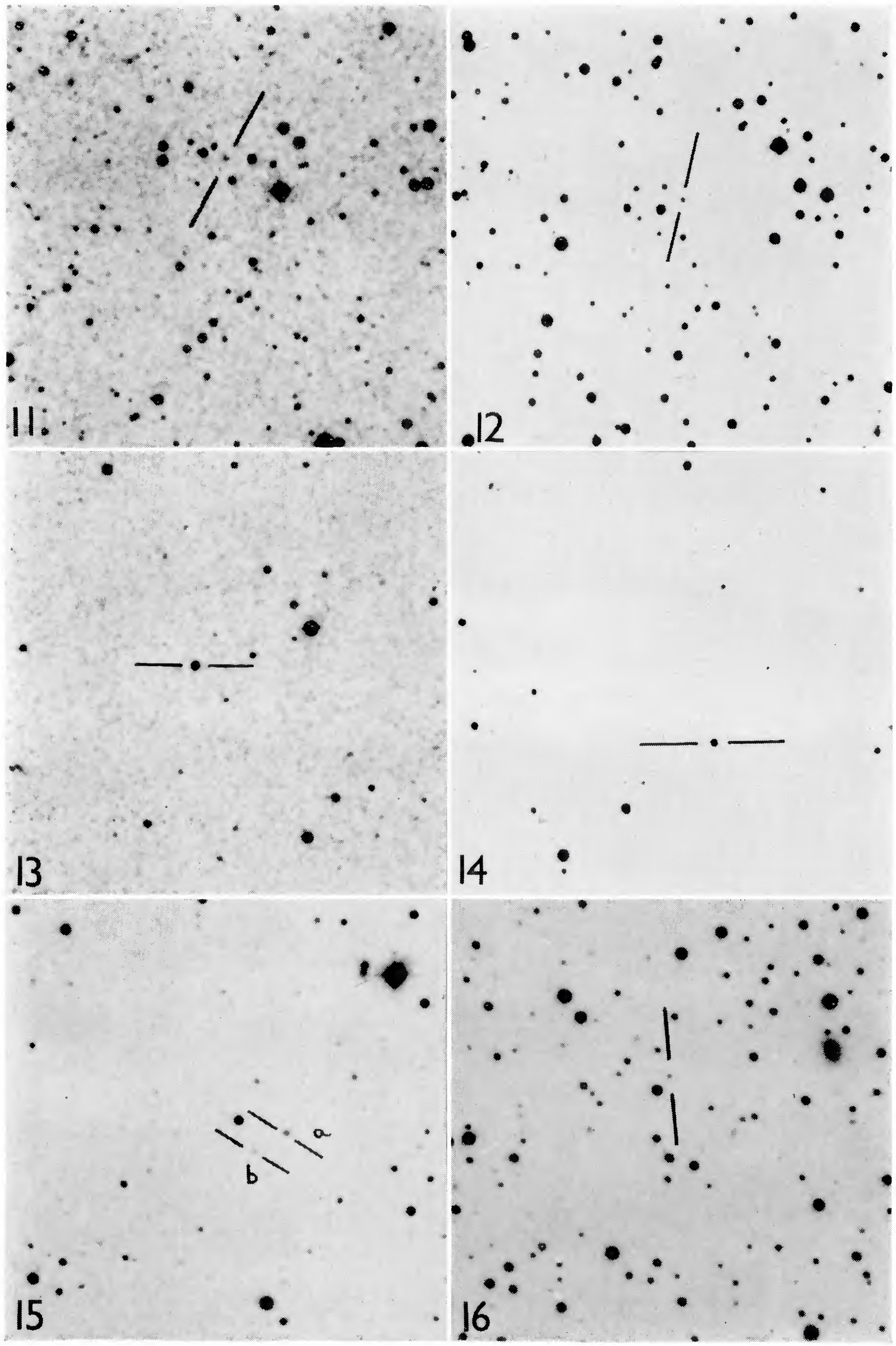


The fields of the radio sources. North is at the top, east to the left. The prints measure 8′ arc square (copyright 1957, National Geographic Society—Palomar Observatory Sky Survey). In general the red print is shown, but the blue print is shown where a quasi-stellar source is the suggested identification.

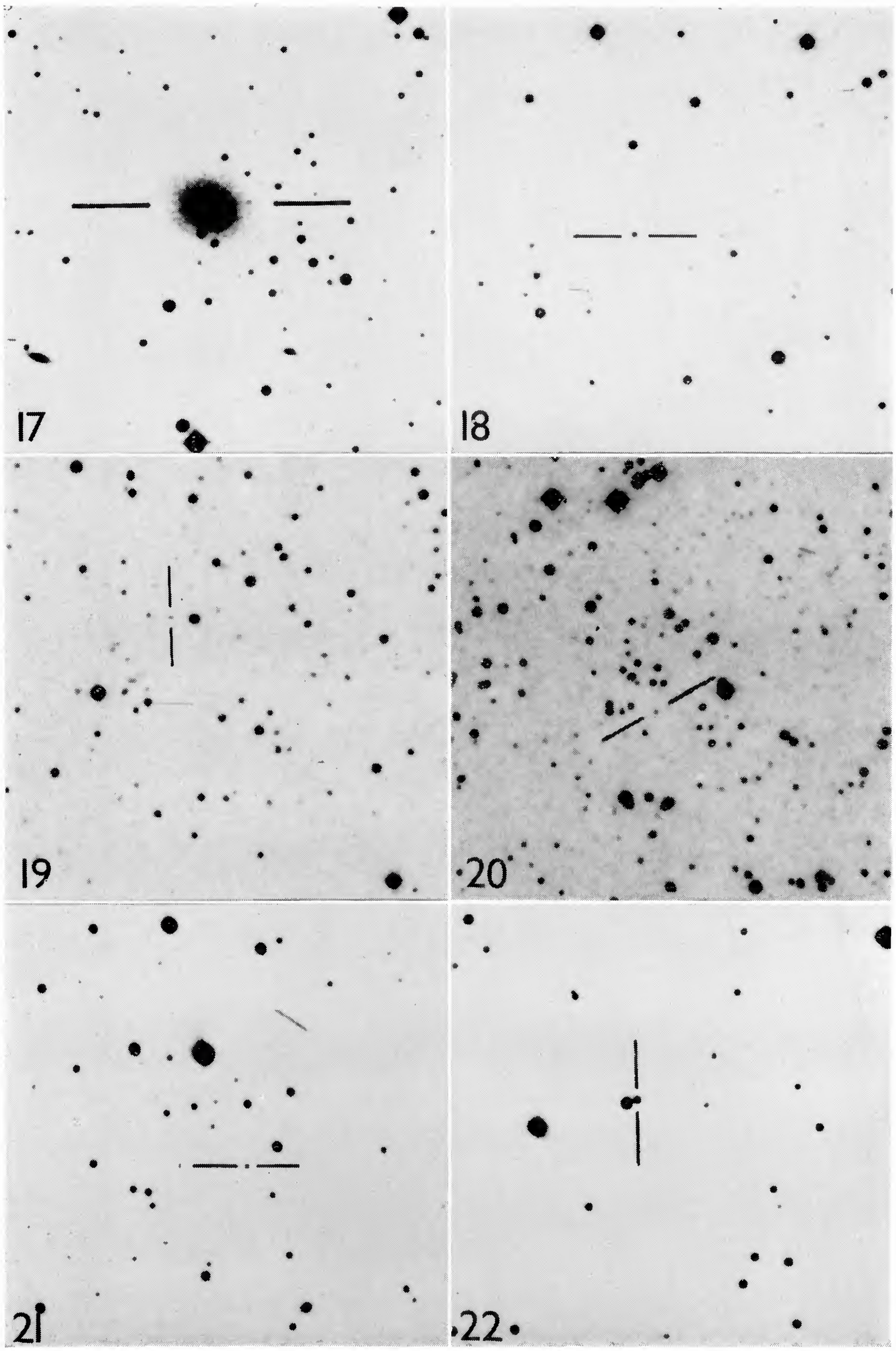
D. Wills. Optical identifications of selected sources



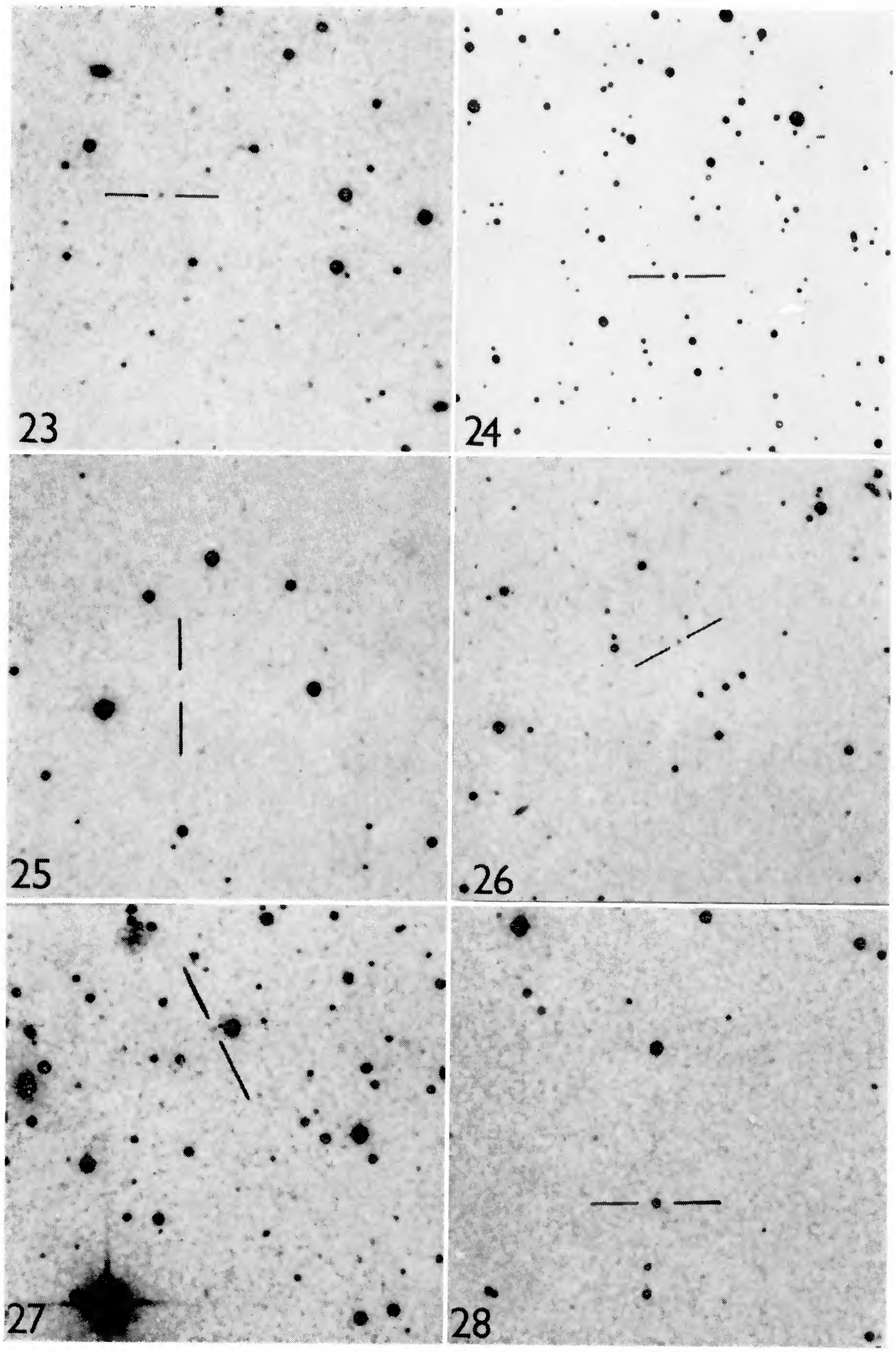
D. Wills. Optical identifications of selected sources



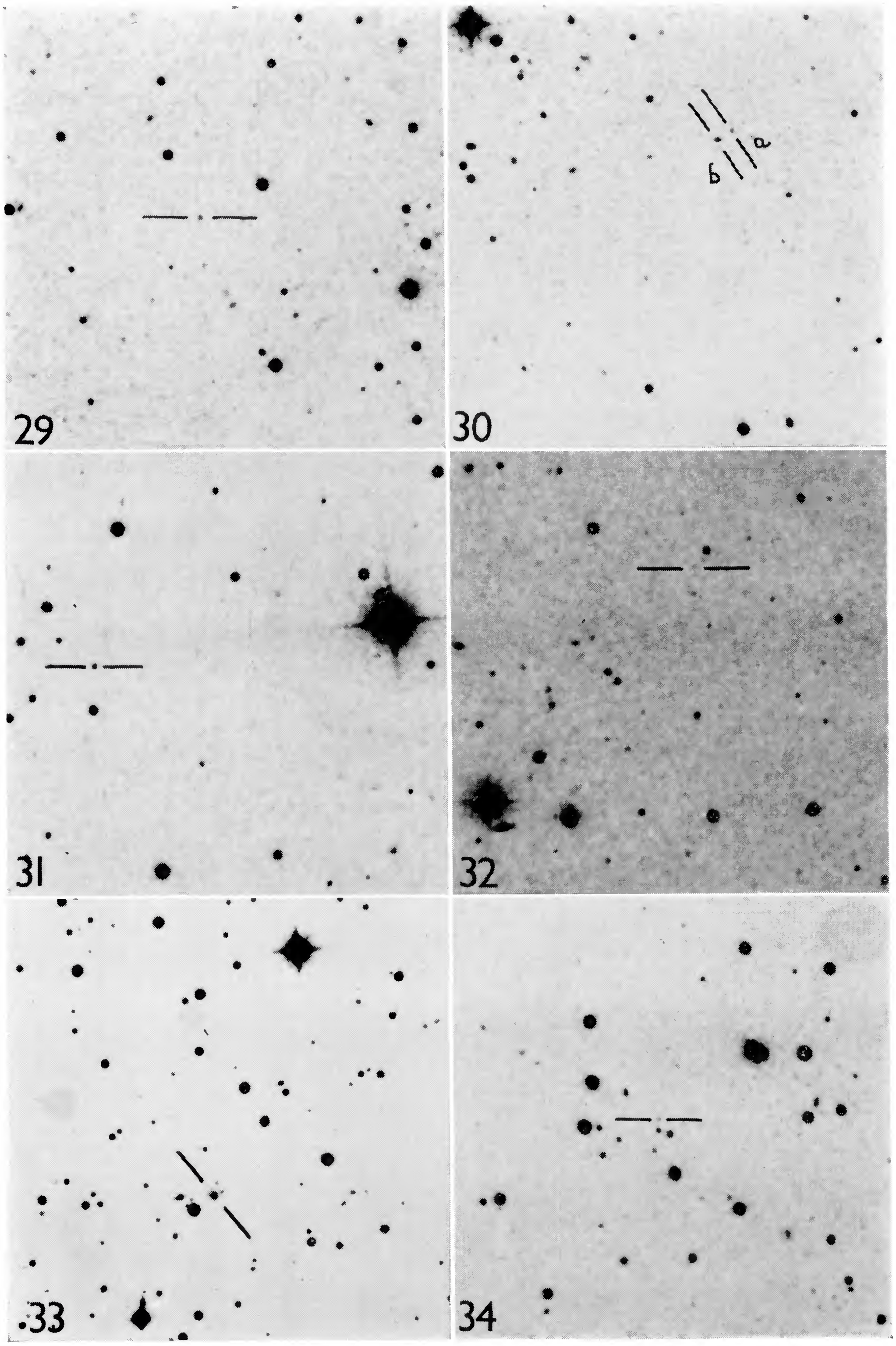
D. Wills. Optical identifications of selected sources



D. Wills Optical identifications of selected sources



D. Wills. Optical identifications of selected sources



D. Wills. *Optical identifications of selected sources*

4. *Optical identifications of the sources.* The fields of the sources were examined on the *Sky Survey* prints, using transparent overlays to locate the radio positions with reference to nearby bright stars (Wills & Parker 1966); the search was limited mainly to an area $\pm 30''$ arc in right ascension by $\pm 20''$ arc in declination around each source. Notes on the fields are given in Table I and finding charts for most of the objects mentioned are given in the Plates 5–10. The charts, which are enlargements of regions of the *Sky Survey* prints, measure $8'$ arc square, with north at the top and east to the left.

Because of the angular resolution effect the data are not homogeneous. About half of the suggested identifications are quasi-stellar sources, which in general have small angular diameters. Some of the sources are near red stellar objects which are probably stars, although some of them could be quasi-stellar sources similar to 3C 2 (Sandage, Veron & Wyndham 1965). The identification of 4C 34·09 with NGC 1167 has already been suggested (Caswell & Wills 1966); the present results show that the source is not resolved at a baseline of 7500 wavelengths, indicating the presence of structure on an angular scale of $15''$ arc or less, which is much smaller than the optical extent of this 14^{m} galaxy.

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References

Bennett, A. S., 1962. *Mem. R. astr. Soc.*, **68,** 163.
Caswell, J. L. & Wills, D., 1967. *Mon. Not. R. astr. Soc.*, **135,** 231.
Edge, D. O., Shakeshaft, J. R., McAdam, W. B., Baldwin, J. E. & Archer, S., 1959. *Mem. R. astr. Soc.*, **68,** 37.
Gower, J. F. R., Scott, P. F. & Wills, D., 1967. *Mem. R. astr. Soc.*, **71,** 49.
Lynds, C. R., Hill, S. J., Heere, K. & Stockton, A. N., 1966. *Astrophys. J.*, **144,** 1244.
Pauliny-Toth, I. I. K., Wade, C. M. & Heeschen, D. S., 1966. *Astrophys. J. Suppl. Ser.*, Vol. 13, No. 116.
Pilkington, J. D. H., 1964. *Mon. Not. R. astr. Soc.*, **128,** 103.
Pilkington, J. D. H. & Scott, P. F., 1965. *Mem. R. astr. Soc.*, **69,** 183.
Ryle, M., Elsmore, B. & Neville, A. C., 1965. *Nature, Lond.*, **207,** 1024.
Sandage, A. R., Veron, P. & Wyndham, J. D., 1965. *Astrophys. J.*, **142,** 1307.
Wills, D., 1966a. *Observatory*, **86,** 140.
Wills, D., 1966b. *Observatory*, **86,** 245.
Wills, D. & Parker, E. A., 1966. *Mon. Not. R. astr. Soc.*, **131,** 503.