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Identification of 4C Sources with Galaxies

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We suggest identification with galaxies for 59 radio sources from the 4C catalogue.

IN a previous paper (Jauncey and Hazard 1970) we suggested identifications with quasistellar objects for forty-nine 4C radio sources remote from the galactic plane. These identifications were based on an examination of the fields around 280 sources using the 4C right-ascension measurements (Pilkington and Scott 1965; Gower, Scott, and Wills 1967) with improved declinations (Hazard *et al.* 1969; Backer *et al.* 1970). In this paper we present the suggested identifications with galaxies for 59 sources. This work is part of a joint program with Sydney University to carry out optical identifications and to improve spectral information on 4C sources.

IDENTIFICATIONS

Table I lists the 4C number, the optical position, galaxy type, and estimated magnitudes of the suggested identifications. Finding charts for the 33 galaxies not previously suggested as identifications are given in Plate I. It is estimated that the positional errors of the quoted optical positions do not exceed 6″ except for those extended objects where it is difficult to define an optical centroid. The magnitudes were estimated from enlargements made from the Sky Survey Prints and may be in error by up to one magnitude. Where other accurate radio positions are available this is noted under comments: O refers to the measurements of Olsen (1967), B to positions measured with Bologna telescope (Grueff and Vigotti 1968; Colla *et al.* 1970), M to right ascensions from the Molonglo fan beam survey (Clarke *et al.* 1969), and P indicates that the source has been measured with the Parkes telescope (see references Table I). The symbols used to indicate the type of galaxy are

E—Elliptical galaxy
S—Spiral galaxy
N—Compact galaxy
g—galaxy of unspecified type
db—dumbell galaxy
pec—peculiar galaxy.

Attempts to identify radio sources with galaxies are complicated both by the clustering of galaxies and by real differences between the optical and radio positions. For a radio source in the direction of a compact cluster it is probable that the source is associated with the cluster but it is usually impossible to decide which cluster galaxy is the radio emitter. For this reason and because of our restriction to galaxies brighter than 18th mag we have excluded a number of probable identifications with very faint compact clusters.

Radio–Optical Displacements

A large fraction of radio galaxies have a double radio structure with angular component separations ranging from a few arc seconds to a few degrees, depending on the distance and spatial orientation, and where the components have unequal flux ratios they consequently often show significant radio–optical displacements. Where the angular structure is known there is usually little difficulty since the associated galaxy can usually be located from symmetry considerations; in any case radio and optical displacements are to be expected. However, for the majority of sources considered in the

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TABLE I. Optical positions and apparent magnitudes for the 59 suggested galaxy identifications.

Source	Optical position						Type	m_{pg}	Optical–radio		Comments	References
	R.A.			Dec.					R.A.	Dec.		
4C	h	m	s	°	′	″			s	″		
34.1	00	11	07.2	34	24	48	db	18 17.5	−1.1	0	Separation ≈ 4″ EW.	
23.1	00	19	48.2	23	00	53	E	17	+0.5	+17	Compact group of ellipticals. Object marked partially obscured by star. Second galaxy 1^sf. 24″ N.	
26.3	00	55	40.8	26	35	45	E	13	−2.2	−21	P, O.	(1) (10)
25.3	01	00	06.5	25	35	28	E	17	−2.2	−50	P, O. Noted in (2).	(2) (10)
25.4	01	08	40.1	25	49	48	E	16.5	+1.3	+18	O. Probably in cluster.	(3) (10)
31.4	01	16	47.1	31	55	03	E	14	−0.2	−27	B. Brightest galaxy in cluster.	
31.7	01	58	01.4	31	33	00	E	18	−1.6	+96	B.	
29.5	01	58	43.4	29	19	12	E	16.5	−1.0	+24	O, B.	(10)
29.6	02	04	09.1	29	16	29	E	16.5	−2.8	+17	O, B. Compact—alternative identification is with member of cluster of faint galaxies north preceeding, possibly db 1′N.	(10)
33.5	02	46	55.6	33	20	36	g	18	+0.8	0	O, B. BSO 1′ p, 1′S.	(10)
35.6	02	58	44.1	35	38	40	E	13	−0.8	−8	O, Brightest member of compact group of six galaxies not all resolved on reproduction. Members of cluster Zw. 0257.8+35.42.	(10)
24.7	03	27	01.9	24	06	28	E	17.5	0	−8	P	(1)
25.12	03	34	31.3	25	35	29	g	18 (m_b)	−2.2	−37	Compact, almost stellar, blue galaxy.	
26.23 (a)	06	32	29.3	26	19	06	E	15	−1.8	+30	P. (2) identifies with elliptical.	(2)
(b)	06	32	28.9	26	18	26	S	16	−2.2	−10		
28.18	07	14	48.2	28	40	29	E	16	−0.8	+17	Blue objects close by.	
32.24	08	09	49.6	32	51	33	g	18	−0.8	−15	O, B.	(10)
24.18	08	37	01.4	24	14	03	pec	18	−0.9	+27	Unusual blue galaxy—BSO near radio position.	(7), (8)
31.32	08	44	54.4	31	58	09	E	15	−15	−9	O, B. NGC 2402.	(10)
06.32	08	45	57.1	06	06	00	E	17	−1.0	−24	P. Alternative identification is a fainter galaxy, 1^s6f, 27″N.	(4) (5)
24.19	09	07	29.8	24	31	28	E	18	+1.0	−8	P, O.	(3) (10)
22.33	12	04	00.5	22	32	28	E	13	0	−20	P, O.	(2) (10)
09.41	12	17	55.3	09	45	08	N	18	−0.2	+2	P, M. Possibly QSO—earlier identification was with galaxy 6^sf, 38″S.	(4) (5)
22.36	12	37	23.6	22	29	34	g	17	+1.3	+10	Galaxy noted in (2).	(2)
05.55	12	48	56.0	05	02	56	N	18	0	−34	P, M. (5) classified as QSO?	(5)
10.35	13	06	34.5	10	45	39	E	16	−1.6	+3	P, M. Galaxy and cluster noted in (6).	(6)
22.38	13	24	30.7	23	00	23	g	17.5	−1.1	−1	P, O. Very red compact.	(3) (10)
26.42	13	46	33.7	26	50	27	E	15	−1.7	+3	O, Member Zwicky compact M.D. cluster 1346.9+2655.	(10)
27.27	13	57	51.6	27	33	48	g	18	−0.2	+30	Object marked is closest galaxy in small cluster.	
07.36	14	27	30.9	07	29	19	E	17	0	−23	P.M. Cluster Member.	(5)
25.46	14	30	26.8	25	08	28	E	16.5	−1.5	−20	P, O.	(2) (10)
28.38	14	55	45.6	28	44	10	E	16.5	−0.7	−8	O.	(10)
06.35	15	08	27.5	05	55	59	E	14	+1.4	−7	P. IC1101. Adopted radio position differs significantly from position in (6).	(6)
23.41	15	11	30.4	23	49	55	g	17	+0.2	−17	P. Compact.	(3)
10.41 (a)	15	15	28.0	10	10	01	g	18	+1.2	−23	M. Compact cluster. Positions are given for (a) the brightest and (b) the closest galaxies.	
(b)	15	15	27.1	10	10	21	g	18.5	+0.3	−3		
28.39	15	21	21.4	28	47	55	E	15.5	−0.5	+7	O. Member Zwicky cluster 1521.0+2835.	(10)
23.42	15	51	35.0	23	57	14	E	16.5	+1.0	+38	P. Compact with blue stellar-like companion 15″f.	(2)
34.43	15	59	36.4	34	32	48	g	17.5	−0.8	+36	O. Blue galaxy with bright nucleus —alternative identification (b) 2^sf, 1 S.	(10)
24.36	16	02	49.0	24	03	57	E	14	−1.2	−27	P, O. Brightest member of cluster.	(2) (8) (10)
08.47	16	06	55.6	08	53	36	E pec	14.5	−4.9	−18	P, M. Large R. A. difference.	(6)
06.55	16	14	46.7	06	44	50	E	17.5	+1.1	−18	P, M. Cluster galaxy is noted in (6).	(6)
06.56	16	19	05.2	06	14	21	E	18	+0.8	−15	P, M. Brightest member of faint cluster.	(6)
02.42	16	43	10.6	02	17	02	E	16.5	−0.2	+14	M. Object marked is db or galaxy and star. Close elliptical Nf also possible identification.	

TABLE I (*continued*)

Source	Optical position R.A.			Dec.			Type	m_{pg}	Optical–radio R.A.	Dec.	Comments	References
4C	h	m	s	°	′	″			s	″		
02.43	16	46	00.8	02	47	22	db	17	−1.8	+10	M. Possible faint QSO 0.′2 f, 0.′2 S.	
30.31	16	58	49.0	30	12	38	E	16	−1.9	+14	O, B.4C R.A. lobeshifted. Olsen source at original R.A. partially obscured by foreground star.	
34.45	17	07	49.2	34	29	40	E	16.5	−1.6	−8	O. Cluster member.	(10)
28.43	17	11	29.0	28	16	04	g	16.5	+0.8	−32	O. Compact—several faint galaxies in region.	(10)
24.41	17	19	57.9	24	16	48	E	17	−1.6	−78	P, O, BSO (b), 1′Nf. Also possible identification.	(2)(10)
23.46	17	50	31.9	23	40	42	E	17.5	−0.4	−42	Cluster member.	
06.63	17	56	58.5	06	17	16	pec	13.5	−6.3	+58	P, NGC 6509. Large R.A. difference. (6) suggests BSO close to radio position as possible identification.	(6)
22.59	21	42	32.3	22	36	30	g	18	−1.8	+30	P, O.	(3)(10)
06.71	21	58	27.9	06	54	23	g	18.5	+0.2	−7	P. Very red compact.	(6)
26.62	22	27	16.0	26	05	07	E	18	+1.3	−5	P. Blue galaxy 20″S.	(1)
24.60	22	40	22.7	24	43	48	E	16.5	+0.7	−24	P.	(2)
27.48	22	42	41.3	27	27	05	db	18.5	−0.2	−7	O.	(10)
36.47	22	44	12.6	36	40	39	E	16.5	+0.2	+3	O.	(10)
01.74	23	13	43.6	01	12	37	g	18	−0.1	+19	P. Brightest member of faint cluster.	(5)
30.44	23	30	36.2	30	38	44	E	18	+1.0	−10	B. Very red. Second galaxy 1.s8f, 20″S	
20.57	23	33	59.3	20	52	15	E	15	−0.6	+15	O. Member Zwicky cluster 2332.8+2027, IC5338?	(9)(10)
20.58	23	49	46.9	20	54	38	db	18	−1.2	+20	South-preceding object is N galaxy or QSO.	

References to Table I

(1) Merkelijn (1968).
(2) Merkelijn, Shimmins, and Bolton (1968).
(3) Shimmins and Day (1968).
(4) Clarke, Bolton, and Shimmins (1966).
(5) Merkelijn (1969).
(6) Wills and Bolton (1969).
(7) Hazard, Gulkis, and Sulton (1968).
(8) Burbidge (1970).
(9) Caswell and Wills (1967).
(10) Olsen (1970).

present paper no such structural information is available. We have attempted to minimize the problem by considering only radio sources with an angular extent of no more than a few minutes of arc, but large radio–optical displacements are still possible if any of the sources are complex with the majority of the flux arising in one component. Then, not only may the radio source be displaced by several minutes of arc from the optical object, but its angular size may be apparently much smaller than the displacement. The source 4C24.18 appears to be of this type. It was originally suggested as possibly associated with the galaxy listed in Table I from occultation observations (Hazard, Gulkis, and Sutton 1968), an identification since confirmed (Burbidge 1970). The occultation observations show that the radio source lies 40″ from the galaxy and yet is only some 3″ in extent. No corresponding source can be detected on the opposite side of the galaxy and must be at least 10 times less intense. Similar sources associated with brighter galaxies and exhibiting larger angular displacements are clearly possible.

Given that significant radio–optical displacements occur, but that accurate radio structure is not available, a possible identification procedure would consider all galaxies within several arc minutes of the source position and estimate their likelihood of being associated with the source from the known surface density of galaxies within given ranges of apparent magnitude. Such a procedure would ensure that the majority of radio galaxies in a given list would be detected but at the expense of including a large number of spurious identifications. We have not attempted this type of analysis but in general have suggested identifications only where a galaxy brighter than 18th mag was found within about ±30″ in right ascension and ±40″ in declination. From results presented elsewhere it is estimated that such identifications should be reasonably reliable with at most 30% representing chance coincidence (Hazard, Jauncey, and Backer 1970). However, since large radio–optical displacements are to be expected for the brighter galaxies and since these are easily observed without a special search outside the error region, we have tentatively associated a few sources with bright galaxies outside the error region where no obvious identifications lay close to the radio position. The most notable examples are 4C08.47 and 4C06.63, both of which are possibly associated with bright peculiar galaxies of $14^{m}_{.}5$ and $13^{m}_{.}5$ respectively. The object associated with 4C08.47 is of particular interest being markedly blue and showing evidence of activity in the nucleus similar to M82.

Comparison with Olsen Identifications and Discussion

There are 24 of the sources in Table I that are common to Olsen's (1970) search for 4C identifications, excluding 30.31 where we are apparently observing different sources. There is complete agreement on 16 of these sources. For two others, 4C22.38 and 4C28.39, Olsen (1967) notes extended structure at 1417 MHz. For 4C22.38 the optical position lies between the low frequency and high frequency right ascensions and the source is extended east–west. 4C28.39 is noted as being extended north–south and our optical position is 49″ north of Olsen's declination. Thus, the suggested galaxies are probably correct. The remaining six sources (4C33.05, 32.24, 24.19, 34.43, 28.43, and 27.48) are mostly faint, ≈18th mag and near the edge of or just outside Olsen's search area. However, because of the comparatively large radio–optical displacements already encountered, these objects must still be considered possible identifications.

A comparison of the 4C and Olsen right ascensions for these 24 sources shows that for nine the quoted values differ by $\leq 0^{s}_{.}5$, nine by between $0^{s}_{.}5$ and $1^{s}_{.}5$, and another six by between $1^{s}_{.}5$ and $5^{s}_{.}2$. In an earlier paper presenting some suggested BSO identifications (Jauncey and Hazard 1970) there were 27 sources common to Olsen's (1967) accurate-positions list. The quoted 4C and Olsen right ascensions differ by $\leq 0^{s}_{.}5$ for 18 of these and there are no differences greater than $1^{s}_{.}5$. It thus appears that the positional discrepancies between the 4C and Olsen measurements are significantly larger for sources associated with radio galaxies than for sources associated with QSO's. This is presumably a result of the much larger angular extent of the radio galaxies and the differing frequencies and resolutions of the two sets of interferometer measurements.

Although radio–optical displacements are a less serious problem for quasistellar objects than for radio galaxies, nevertheless such displacements should be taken into account in any identification program. The source MSH 14-1 *21*, with a redshift $z \approx 1$, provides a good example. It has two components of unequal flux density separated by 40 arc sec and symmetrically placed on either side of the optical object (Hazard and Sutton 1971). The position of the source as measured by a beam of a few arc minutes in width would differ by about 10″ from the position of the optical object. For a component separation roughly proportional to redshift (Hazard 1967; Miley 1971) significant radio–optical displacements may exist for smaller redshift objects. Large radio–optical displacements are also to be expected for QSO's similar to 3C273 with separated components of differing spectral indices. It follows that if agreement to a few arc seconds between the radio and optical positions is demanded, when the radio structure is unknown, there may be a discrimination against the larger angular size and hence smaller redshift objects.

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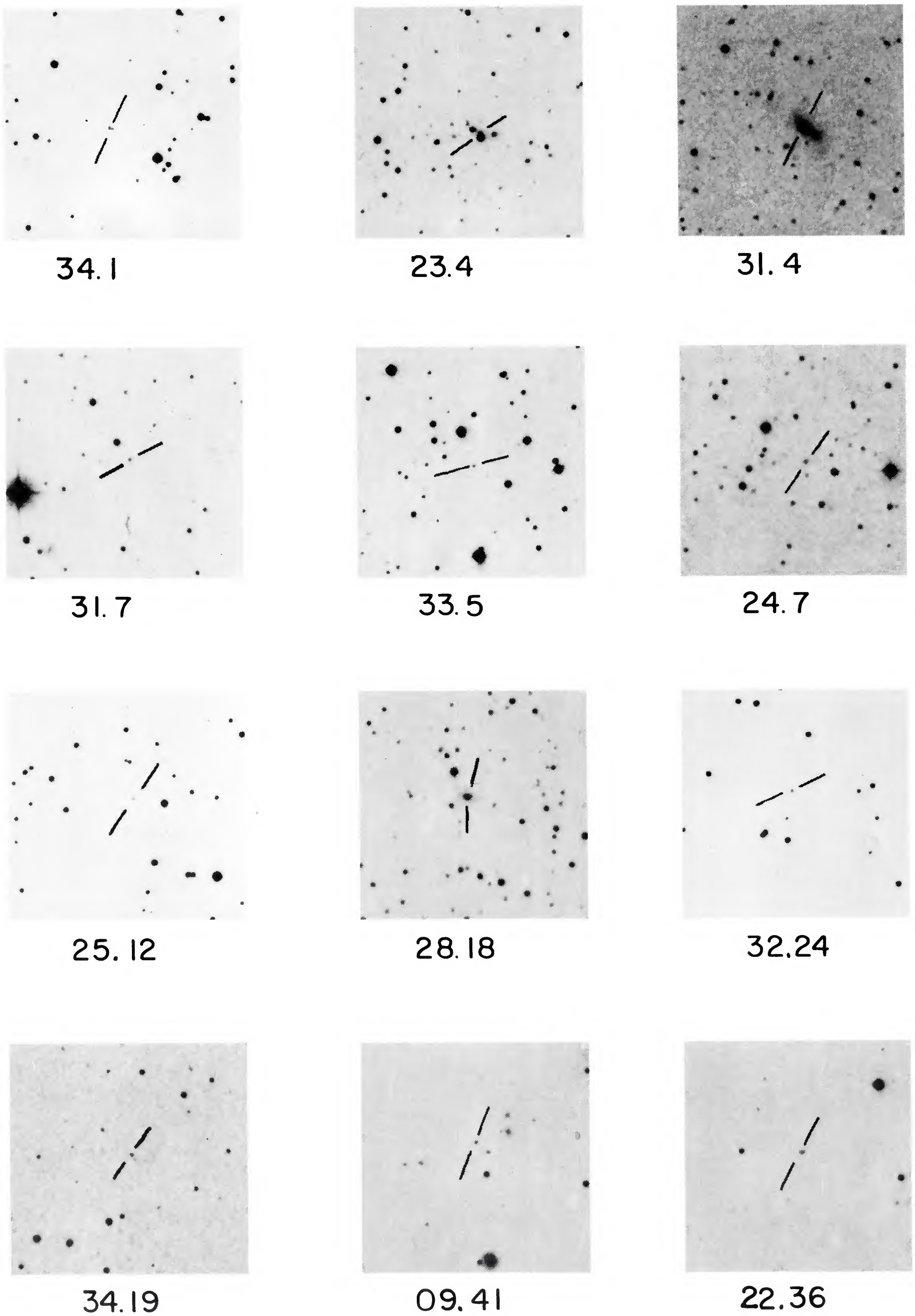
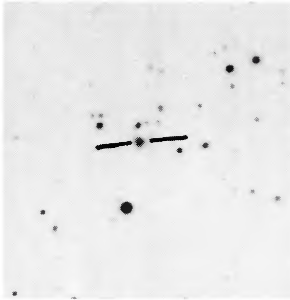


(a)

PLATE I (a)–(c) (Hazard and Jauncey, p. 621). Finding charts for the 33 previously unpublished identifications. The scale is approximately 10 arc sec per mm. North-east is the top left-hand corner of each chart.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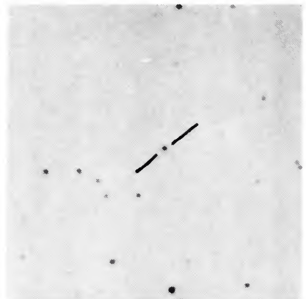
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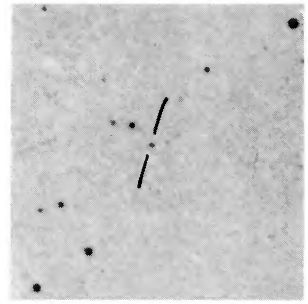
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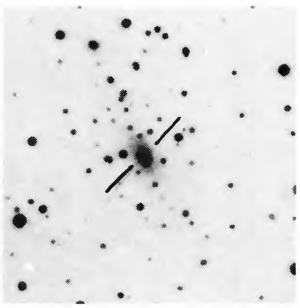
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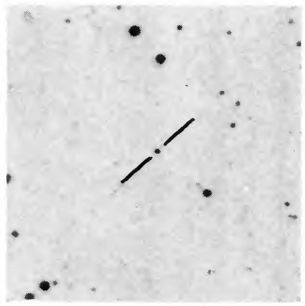
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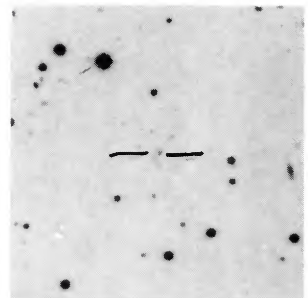
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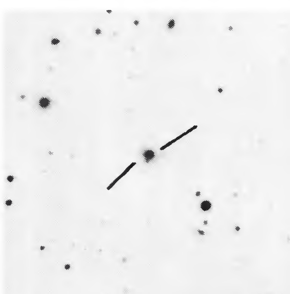
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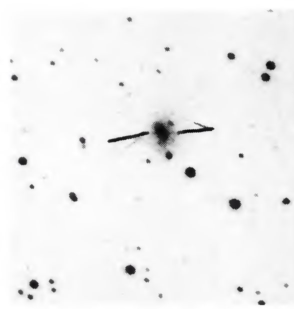
34.43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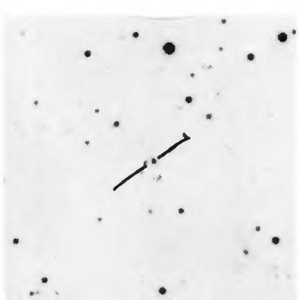
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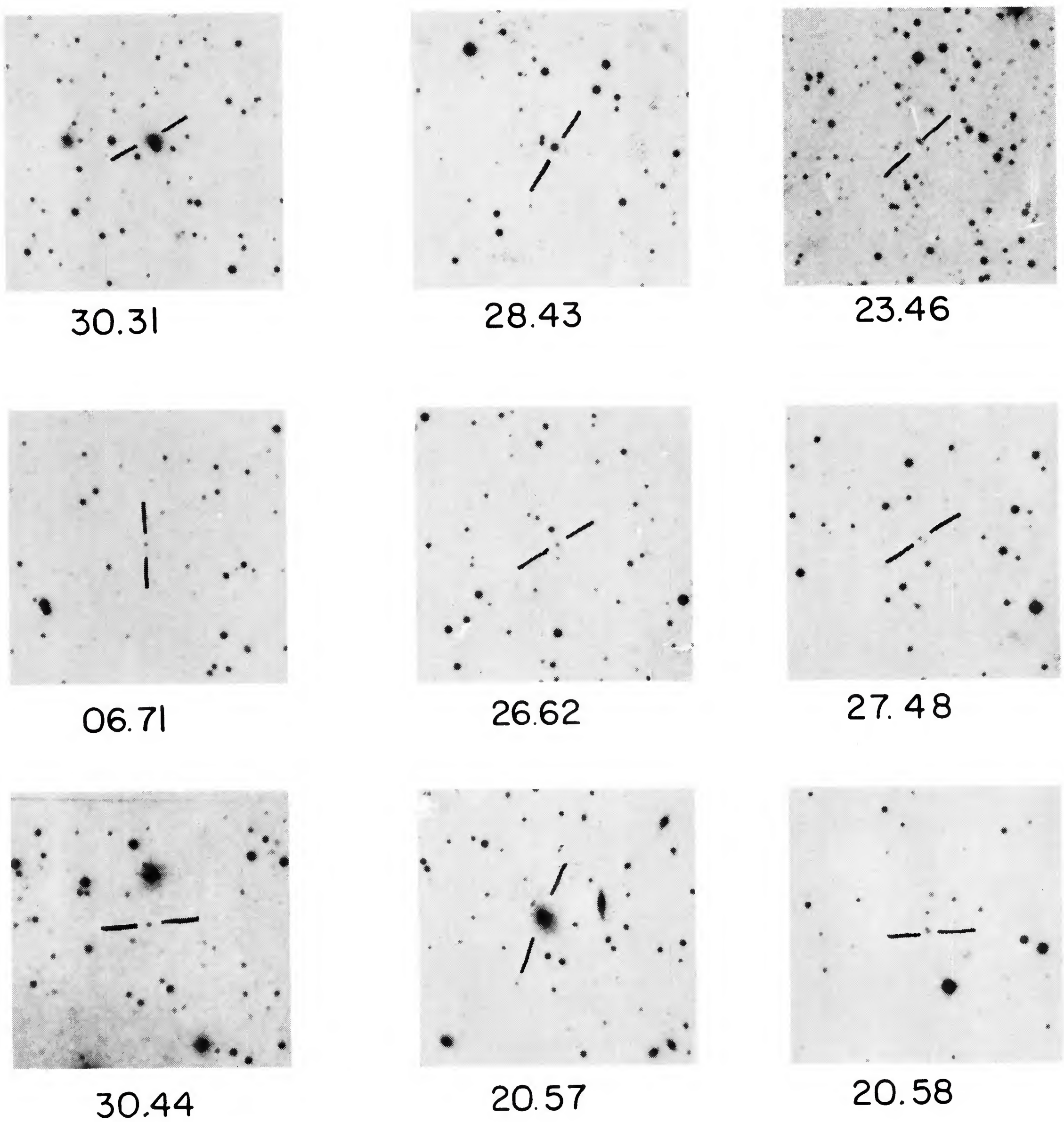
02.42


02.43

(b)

PLATE I (*continued*)



(c)

Plate I (*continued*)