THE ASTRONOMICAL JOURNAL VOLUME 84, NUMBER 6 JUNE 1979

IDENTIFICATION OF RADIO SOURCES IN THE SOUTH POLAR CAP

C. ANGUITA, L. E. CAMPUSANO, C. TORRES, and M. PEDREROS[a)]
Observatorio Astronómico Cerro Calán, Departamento de Astronomía, Universidad de Chile, Santiago, Chile
Received 14 February 1979

ABSTRACT

Optical search areas centered on the radio position of 108 radio sources of the Parkes 2700-MHz survey (fourth part) have been examined for optical counterparts using two-color plates and the ESO quick blue survey film-copies. Twenty-one new identifications are proposed, of which 12 are QSO candidates and 9 are galaxies, while the search areas of five radio sources appear blank to the limit of the ESO film copies. Ten of the QSO candidates were selected for their ultraviolet excess and the remaining two purely on the basis of positional agreement. With this work the program of optical identification in the region south of declination −75° has been completed as to provide a sufficient number of potential position calibrators well distributed in right ascension. Finally, this program has also shown that no substantial obscuration can be attributed with certainty to this whole area of the sky.

I. INTRODUCTION

This paper presents further results of a systematic search of optical counterparts for radio sources of the Parkes 2700-MHz survey (fourth part) (Shimmins and Bolton 1972), which covers the declination zone from −75° to −90°.

First results of this program were published by Anguita and Pedreros (1977), hereafter referred to as paper I.

Savage, Bolton, and Wright (1976) have shown that the radio position of radio sources south of declination −45° can be considerably improved if a sufficient number of position calibrators is available in the region and if a more sophisticated model is used to represent the pointing corrections for the Parkes 64-m radiotelescope. In this search we have used new radio positions recomputed by Bolton (1978) with data from new calibrators that have been identified since this survey was published. According to Bolton (1978), the probable errors of the new positions for the rather strong sources are smaller by a factor of 2 or more than the previous ones. For this reason we have included candidates based on positional agreement for sources stronger than $S_{2700} = 0.45$ Jy, which were not considered in paper I.

The radio source fields numbered 108 and are distributed from $\alpha = 11^h30^m$–0^h to $\alpha = 3^h$; in addition we explored a plate almost in the south pole containing ten sources. We present here 21 new candidates for optical counterparts of radio sources. With the results of paper I, which covered sources between 0^h and 10^h30^m, the present total number of optical identifications in the Parkes 2700-MHz survey (fourth part) is 55 out of the 454 radio sources, of which 28 are QSO candidates or spectroscopically confirmed QSO and 27 are galaxies. This identification work has therefore produced a sufficient number of potential position calibrators well distributed in right ascension and covering the southern polar cap. Continuation of the identification work in this zone of the sky would be justified mostly for statistical purposes.

II. OBSERVATIONS AND IDENTIFICATIONS

The plate material for this work was obtained with the 70/100-cm Maksutov telescope located at Cerro El Roble Astronomical Station of the Universidad de Chile. Each plate covers a field of 5° × 5°, with a scale of 99 arcsec/mm.

Double exposures were made on Kodak 103a-O emulsions; the first one with a 2-mm Schott GG 385 filter, hereafter referred to as "blue image," and the second one with a 2-mm filter, similar to Schott UG2, hereafter "ultraviolet image." The exposures were made on the same night and with a small displacement of their centers. The limiting magnitude, in the blue, is estimated to be 18.5.

The surveyed fields are specified in Table I, numbered as a continuation of those covered in paper I. It includes the plate number, the coordinates of the center, the number of radio sources contained in each field, and the date of observation. The location of all the fields, with respect to the south celestial pole, is given in Fig. 1.

The search of optical counterparts was done within a square area of ± 2 rms errors of the radio source positions. The position of the radio sources on the two-color plates and the selection of ultraviolet excess objects ($U - B \lesssim -0.5$) with stellar appearance in their vicinity was done in the manner described in paper I. Any of such UV-excess objects that were found to lie in the search area are here suggested as QSO candidates. For those radiosources with no associated UV-excess object we explored the ESO(B) film copies, using the finding

[a)] On leave of absence. Present address: Astronomy Department, University of Toronto, Toronto, Ontario, Canada M5S 1A7

 0004-6256/79/060718-07$00.90

TABLE I. Centers of the survey plates.

Field	Plate number	Center (1950) α	δ	Number of sources	UT date of two-color plates
8	3487	02^h14^m	−76°36′	8	23 Oct. 1977
9	3549	11 56	−87 56	10	28 Mar. 1977
10	3546	12 37	−80 00	10	27 Mar. 1977
11	3547	13 27	−75 59	11	27 Mar. 1977
12	3550	14 24	−75 58	9	28 Mar. 1977
13	3475	18 42	−77 57	18	21 Aug. 1977
14	3473	20 24	−80 29	11	20 Aug. 1977
15	3481	21 20	−76 59	23	22 Aug. 1977
16	3486	23 16	−79 46	13	23 Oct. 1977

charts already obtained from the two-color plates. If a galaxy was present in the search area we suggest this one as the optical counterpart. When no galaxy was detected, but instead there was a single object of stellar appearance, we suggest this object as the optical counterpart on the basis of positional agreement for those radio sources with $S_{2700} > 0.45$ Jy. In the case where no optical object satisfied the 2 rms errors criteria, above the limit of the ESO(B) film copies, we considered the optical field corresponding to the radio source as a blank field.

The rms errors of the radio positions used in this work are not those given in the Parkes 2700-MHz survey (fourth part), but have been derived from the information on the total errors of the new radio positions of the rather strong sources as given by Bolton (1978) and from the behavior of the error due to noise as a function of flux density given in the original survey.

III. RESULTS AND DISCUSSION

The suggested optical counterparts of radio sources are listed in Table II. Column 1 gives the designation of the radio source from the Parkes 2700-MHz survey (fourth part). Columns 2 and 3 contain the measured positions of the optical candidates. These positions were obtained by the plate constants method. The accuracy is estimated to be about 1 arcsec. Column 4 gives their blue magnitudes estimated by comparison with the sequences I and II near the southern cluster NGC 3532 (Butler 1977). The magnitudes of all the optical candidates were obtained from the ESO(B) film copies, but in addition magnitudes were estimated from the "blue image" of the UV-excess objects which are the ones listed in column 4. These magnitudes may be in error by as much as 1 mag for the candidates of stellar appearance,

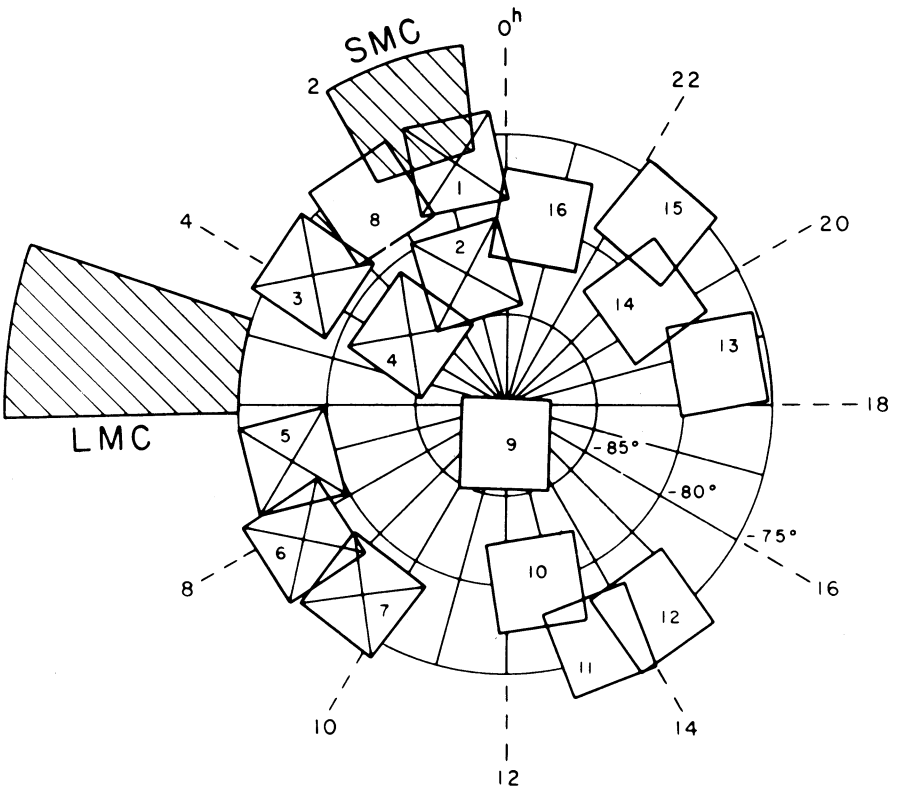

FIG. 1. The 16 plate fields of the Maksutov telescope defining the search completed with this work. The fields 1–7 correspond to those included in paper I.

TABLE II. Identifications and optical positions.

PKS	(1950) α	δ	m	Type	Optical-radio $\Delta\alpha\cos\delta$ (arcsec)	$\Delta\delta$ (arcsec)	Radio rms errors (arcsec)	S_{2700}	Field	Previous identifications	Notes
0144-763	$01^h44^m20^s.2$	−76°21′05″	19.0	G	−12	18	21	0.12	8		
0202-76	02 02 00.6	−76 34 27	18.0	UVs	1	2	7	1.37	8	Ekers (1970)	1
0247-77	02 47 27.9	−77 17 19	19.0	G	13	−5	16	0.20	8		
1240-788	12 40 37.9	−78 50 56	19.0	G	−39	−27	19	0.16	10		
1304-748	13 04 57.0	−74 54 08	>19.5	UVw	26	−15	15	0.25	11		2
1337-875	13 37 21.5	−87 35 39	17.0	Q?	−5	7	9	0.49	9		
1445-74	14 45 37.2	−74 57 29	>18.5	UVw	−20	−10	8	0.57	12		
1814-76	18 14 10.9	−76 36 16	14.0	G	1	−5	10	0.39	13		3
1820-774	18 20 42.5	−77 29 06	18.5	UVw	−6	−29	16	0.21	13		
1826-782	18 26 12.8	−78 12 34	19.5	UVm	14	20	17	0.18	13		
1833-77	18 33 14.7	−77 12 09	13.0	G	−4	−6	8	0.57	13	Savage, Bolton, and Wright (1977)	4
1833-759	18 33 59.6	−75 58 38	19.0	G	9	31	14	0.27	13		5
1839-772	18 39 20.4	−77 14 56	19.	G	4	−18	17	0.16	13		
1842-767	18 42 41.6	−76 45 52	>18.5	UVm	1	1	15	0.24	13		6
1847-79	18 47 54.7	−79 36 28	18.	G	1	−2	10	0.40	13	Savage, Bolton, and Wright (1977)	
1903-80	19 03 56.8	−80 15 01	19.	Q?	4	−1	7	1.54	13		7
2109-811	21 09 15.9	−81 06 09	20.	G	11	8	8	0.65	14		8
2128-75	21 28 29.4	−75 03 18	19.	G	20	7	15	0.22	15		
2130-752	21 30 55.1	−75 15 38	19.	UVw	3	20	21	0.13	15		
2139-753	21 39 39.1	−75 21 37	17.	G	5	30	17	0.16	15		9
2141-760	21 41 19.3	−76 02 42	18.5	UVw	25	4	16	0.21	15		
2141-784	21 41 31.3	−78 26 18	>19.	UVw	−3	−10	11	0.33	15		
2142-75	21 42 13.0	−75 50 08	18.5	UVm	3	−8	7	1.38	15	Savage, Bolton, and Wright (1977)	10
2142-76	21 42 45.5	−76 35 26	19.	UVw	2	−15	10	0.45	15		
2302-783	23 03 00.3	−78 24 06	16.5	UVw	40	−29	22	0.06	16		11

Notes on individual objects

(1) 0202-76. Spectroscopically confirmed as a QSO with $Z = 0.389$ (Jauncey *et al.* 1978).
(2) 1304-748. The blue magnitude, estimated on the ESO film copy was at least two magnitudes brighter. This variability, if real, would further support this object as a QSO candidate.
(3) 1814-76. Elliptical galaxy.
(4) 1833-77. Another galaxy at 60 arcsec from the radio position.
(5) 1833-759. Possibly in cluster. At least another four galaxies in the vicinity of the search area.
(6) 1842-767. The blue magnitude was estimated from the ESO film copy.
(7) 1903-80. Spectroscopically confirmed as a QSO with $Z \sim 0.5$ (Bolton, 1978).
(8) 2109-811. Three galaxies within the optical search area of the radio position. Optical position and magnitude given for the brightest one.
(9) 2139-753. Possibly two galaxies with a very slight angular separation. Optical position and magnitude given for the whole object.
(10) 2142-75. The blue magnitude estimated on the ESO film copy was two magnitudes brighter. Possibly variable. Spectroscopically confirmed as a QSO with $Z = 1.139$ (Jauncey *et al.* 1978).
(11) 2302-783. Redshift of 0.127 by Campusano and Pedreros (1979).

or more for the galaxies. Column 5 indicates the type of optical counterpart: UV for ultraviolet excess stellar object, followed by an s, m, or w to indicate strong, medium, or weak cases; G for galaxies; and Q? for stellar-like object with positional coincidence with a source. Columns 6 and 7 give the differences, optical minus radio position, in seconds of arc. Column 8 gives the rms error of the radio position, according to an approximate curve derived by us. Column 9 lists the flux densities in janskys at 2700 MHz that appear in the radio survey. Column 10 gives the number of the Maksutov field to which the object belongs. Column 11 shows references to previous identifications, if any. Column 12 indicates remarks on individual objects.

TABLE III. Blank fields.

PKS	Radio rms errors (arcsec)	Field
0157-78	9	8
1255-773[a]	21	11
1854-800	17	13
2059-78	8	14
2123-756	17	15

[a] In a zone with very low density of optical objects.

The blank fields are listed in Table III. It is worth mentioning that in one of them, PKS 1255 − 773, the absence of objects is probably due to the strong obscuration present in its vicinity.

Figures 2(a)–2(c) show the finding charts of all the objects included in Tables II and III, except for PKS 0202 − 76, PKS 1833 − 77, PKS 1847 − 79, and PKS 2142 − 75, whose finding charts have been already published. Figure 2 also includes the finding chart for PKS 1903 − 80, which has been independently identified by Bolton (1978), because it is not yet available in the literature. Charts are given in the blue, and have been taken from Maksutov plates or ESO(B) films.

In the areas defined by ± 2 rms errors from the radio positions of the 108 sources searched in this work, we find

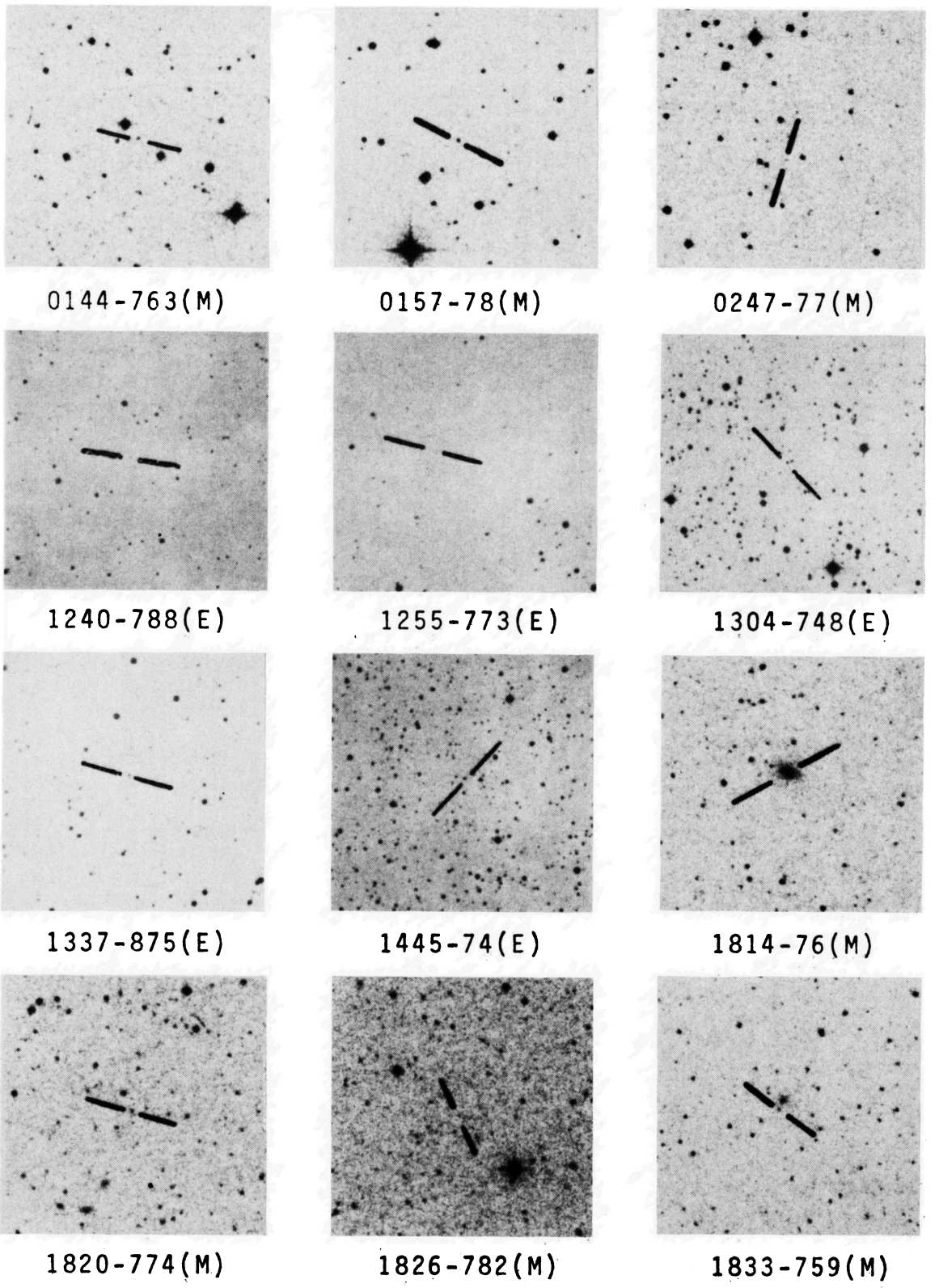

FIG. 2

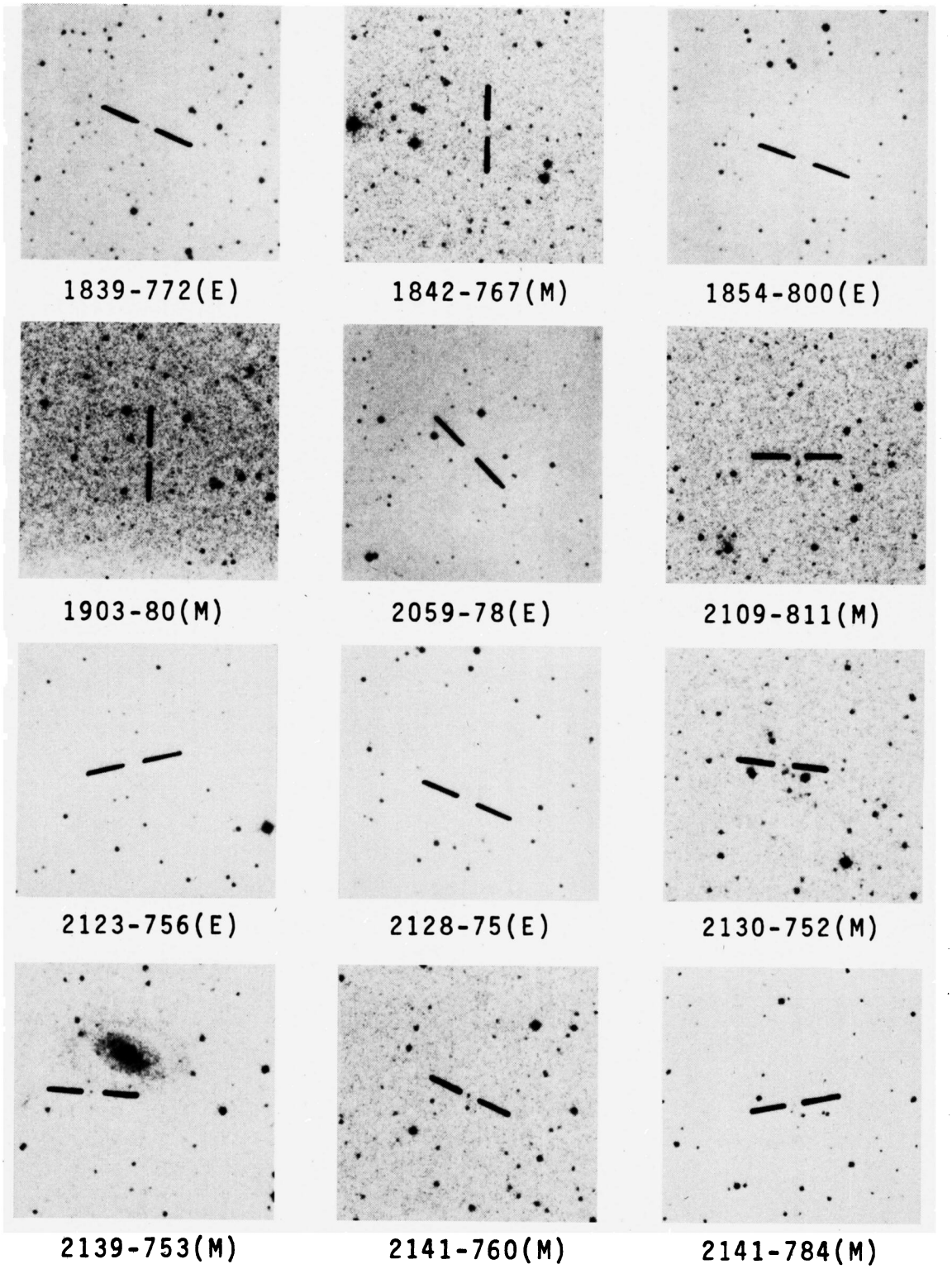

FIG. 2 (continued)

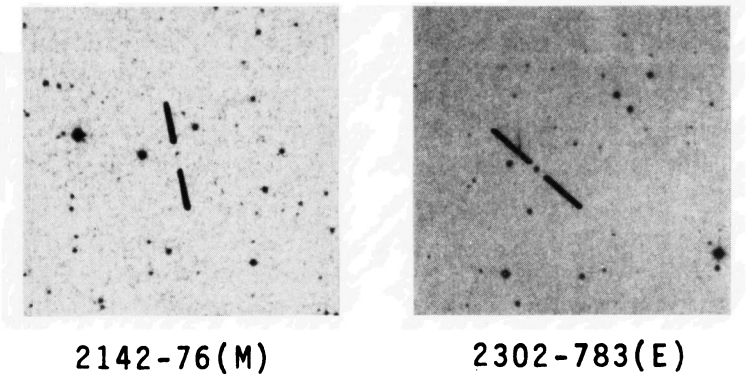

FIG. 2. Finding charts for the objects listed in Table II and for the blank fields listed in Table III. They were taken from Maksutov telescope plates (M) with a scale of 12.3 arcsec/mm or from the ESO film copies (E) with a scale of 10.3 arcsec/mm; northeast is at the top left-hand corner, except for the chart of PKS 1337–875 where it is at the top right-hand corner.

that 12 of them (or 11%) show a stellar object with ultraviolet excess, two (or 2%) show a stellar object in positional agreement, which are here suggested as QSO candidates, 11 sources (or 10%) show one galaxy which is suggested as the optical counterpart for these radio sources, and 5 (5%) do not show any object inside and hence are classified as blank fields.

Shimmins and Bolton (1972) did not succeed at all in a search of UV-excess objects as optical counterparts for ten radio sources with flat or inverted radio spectra in the region between 11^h and 23^h in right ascension and south of declination $-75°$, in contrast with the positive results obtained in other southern regions, and therefore they suggested that a considerable obscuration extending from the galactic plane to the south polar cap may seriously impede attempts of identifications in the area. Since the observations of Shimmins and Bolton were in the zone covered in this work, we may use our percentage of galaxy identifications found in the mentioned region to evaluate roughly the importance of the suggested obscuration through the comparison with the corresponding percentage in an unobscured region. For this purpose we have chosen the declination zone from $-35°$ to $-45°$ of the Parkes 2700-MHz survey (fifth part) (Bolton and Shimmins 1973), which does not have evidence of obscuration and where 10% of the 885 radio sources were identified with galaxies. However, a straightforward comparison with the results of Bolton and Shimmins is not possible for the following reasons. First, they made their galaxy identifications when the catalog position and the estimated position of the optical counterpart did not exceed the rms error in the radio position plus 6 arcsec, in contrast to the 2 rms errors criteria employed by us. And second, the rms errors employed in this work are smaller than those used by them, specially for radio sources with $S_{2700} > 0.40$ Jy. Nevertheless we may consider a flux density of 0.20 Jy as approximately representative of the population of the fourth and fifth parts of the Parkes 2700-MHz catalog, and in such a case our search area is 1.36 times the one used by Bolton and Shimmins, implying that the percentage of galaxy identifications detected by us should have been at least 1.2 times the one found by them, i.e., 12%. Deleting field number 8 of this work, because of its right ascension close to 2^h, we remain with 100 radio sources, of which 9 have a galaxy inside the search area. Since this proportion of galaxy identification is slightly smaller than the lower limit just mentioned, we may conclude that if any substantial obscuration is present in the region between 11^h and 23^h, it would be restricted to much more localized parts of the sky, parts not affecting considerably the whole region. In fact, two of the explored fields, numbers 10 and 11, which are close to the galactic plane, do show evidence of strong patchy obscuration covering less than one-fourth of each field. This kind of obscuration is probably connected with the lack of success in the search of UV-excess objects carried out by Shimmins and Bolton.

The question whether a substantial obscuration is really affecting the southern polar cap as a whole is of much importance, and must be clarified before any

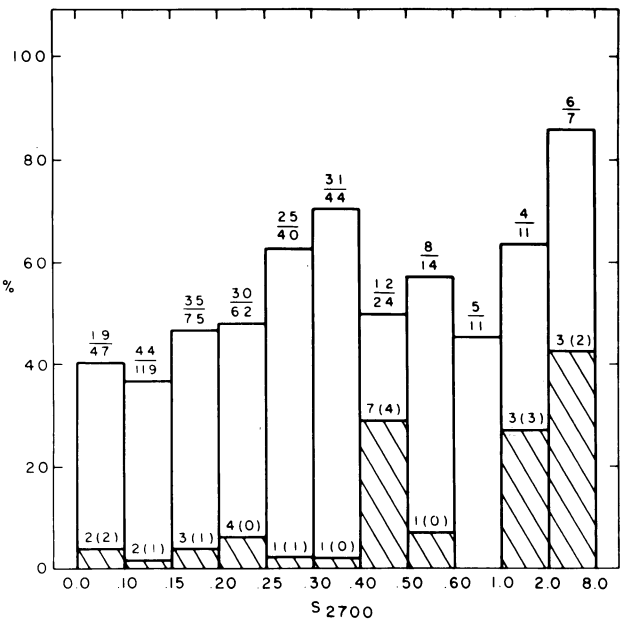

FIG. 3. Present status of the search of optical counterparts for the 454 radio sources of the 2700-MHz Parkes survey (fourth part): the fraction examined for optical identification. Hatching denotes QSO candidates.

statistical consideration on the optical candidates for the population of the Parkes radio sources is attempted. It appears that such is not the case for the semizone centered at 17^h in right ascension, and for the remaining zone it was suggested in paper I that if any obscuration is present it is not sufficiently strong as to prevent the detection of QSO candidates and radio galaxies. Therefore, it seems that no significant obscuration can be attributed with certainty to this area of the sky.

Figure 3 gives for flux density intervals the fraction of radio sources in the Parkes 2700-MHz survey (fourth part) that have been examined for optical identification. The percentage and number of radio sources with QSO candidates, including UV-excess objects and positional candidates of stellar appearance, are also given. In addition, the number of QSO candidates with spectroscopic data is given in parenthesis. The 28 QSO candidates suggested up to now as optical counterparts for radio sources of the above mentioned survey are included in Table II of this paper and that of paper I, with the exception of PKS 0230 − 790 (Browne and Savage 1977) and PKS 1610 − 77 (Hunstead 1971), which are outside the areas covered by this program, and PKS 0637 − 75 (Hunstead 1971; Savage 1976), which was not included in Table II of paper I because it did not show apparent ultraviolet excess in the survey and because positional candidates were not given in the paper.

With this work, the program of optical identification for the Parkes 2700-MHz survey (fourth part) has covered 47% of the radio sources. Considering that it appears that no substantial obscuration is present in the zone of this radio survey ($\delta < -75°$), it is of interest to complete the identification work for sources stronger than a given limit of radio flux, since with spectra for the QSO candidates a complete sample of quasars as defined by Schmidt (1974) can be formed in this area of the sky. Such a sample would constitute valuable data for the study of the space distribution of quasars.

We are grateful to S. Barros and M. Wischnejwsky for their assistance during the course of this work, and to A. Fuentes for the preparation of the drawings. M. Fajardo carefully typed the manuscript. This work has been partially supported by the Servicio de Desarrollo Cientifico, Artístico y de Cooperación Internacional, de la Universidad de Chile.

REFERENCES

Anguita, C., and Pedreros, M. (1977). Astron. J. **82,** 102 (paper I).
Bolton, J. G. (1978). Private communication.
Bolton, J. G., and Shimmins, A. J. (1973). Aust. J. Phys. Astrophys. Suppl. **30,** 1.
Butler, C. J. (1977). Mon. Not. R. Astron. Soc. **178,** 159.
Browne, I. W. A., and Savage, A. (1977). Mon. Not. R. Astron. Soc. **179,** 65p.
Campusano, L. E., and Pedreros, M. (1979). *Actas de la Reunión Astronómica Regional Latinoamericana,* edited by A. Gutiérrez-Moreno and H. Moreno (in press).
Ekers, R. D. (1970). Aust. J. Phys. **23,** 217.
Hunstead, R. W. (1971). Mon. Not. R. Astron. Soc. **152,** 277.
Jauncey, D. L., Wright, A. E., Peterson, B. A., and Condon, J. J. (1978). Astrophys. J. Lett. **219,** L1.
Savage, A. (1976). Mon. Not. R. Astron. Soc. **174,** 259.
Savage, A., Bolton, J. G., and Wright, A. E. (1976). Mon. Not. R. Astron. Soc. **175,** 517.
Savage, A., Bolton, J. G., and Wright, A. E. (1977). Mon. Not. R. Astron. Soc. **179,** 135.
Schmidt, M. (1974). In *Conference on Research Programs for the New Large Telescope,* edited by A. Reiz (European Southern Obs., Geneva), p. 253.
Shimmins, A. J., and Bolton, J. G. (1972). Aust. J. Phys. Astrophys. Suppl. **26,** 1.