there is no excess radiation at long wavelengths as would be predicted for a large black-body companion to ϵ Aur. The single 4.8-μ measure on ϵ Aur also confirms the low intensity found at 9.2 μ and supports the interpretation that this star radiates like a normal F supergiant in this region of the spectrum.

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REFERENCES

Kuiper, G. P., Struve, O., and Strömgren, B. 1937, *Ap. J.*, **86**, 570.
Low, F. J. 1961, *J.O.S.A.*, **51**, 1300.
Mitchell, R. 1964, *Ap. J.*, Vol. **140**, No. 4 (in press).
Wildey, R. L., and Murray, B. C. 1964, *Ap. J.*, **139**, 435.

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ON THE OPTICAL IDENTIFICATION OF ELEVEN NEW QUASI-STELLAR RADIO SOURCES

To the present time there have been positive identifications of nine quasi-stellar radio sources (hereinafter called "QSS"). These are 3C 48, 3C 186, 3C 196 (Matthews and Sandage 1963); 3C 273 (Schmidt 1963); 3C 9, 3C 216, and 3C 245 (Ryle and Sandage 1964); and 3C 47 and 3C 147 (Schmidt and Matthews 1964). We wish to report here on the positive identification of five additional sources and the probable identification of six others (Figs. 1 and 2). These results are from a continuing program of identification using a combination of three methods: (1) the radio and optical position coincidence of ultraviolet starlike images as seen on photographic plates using the two-color image technique; (2) the coincidence of radio positions with blue, starlike images on the Palomar Sky Survey plates; and (3) the confirmation of the identification by three-color photoelectric measurements using the 200-inch reflector.

The new identifications are the result of separate programs carried out by each of the authors. We have combined our results to give a more complete discussion of the data. The sources 3C 93, 3C 208, 3C 228, and 3C 287 were identified by the photographic two-color technique in January and February, 1964, using plates taken with the 100-inch reflector. Photoelectric confirmation was obtained for all but 3C 228, which could not be observed because the source is optically confused with a much brighter neighboring star 5″ distant. Although photoelectric confirmation is lacking, and will be very difficult to obtain, the identification of 3C 228 as a QSS is beyond reasonable doubt because (1) the estimated optical position determined by interpolation with a superposed grid on the Sky Survey prints is within the probable error of the radio position, and (2) the object has a very strong ultraviolet excess as seen from the two-color photograph. It should be mentioned that 3C 208 and 3C 287 were previously suggested as possible identifications by Davies and Longair (1965).

The sources 3C 279, MSH 13–0*11*, 3C 380, 3C 403, 3C 446, and CTA 102 were found in the course of an optical search being carried out by Wyndham (1965) in the right-ascension interval 12^h–24^h using the new radio positions recently determined at California Institute of Technology (Fomalont, Matthews, Morris, and Wyndham 1964 for α; Wyndham and Read 1965 for δ). Blue, starlike objects were found within the error rec-

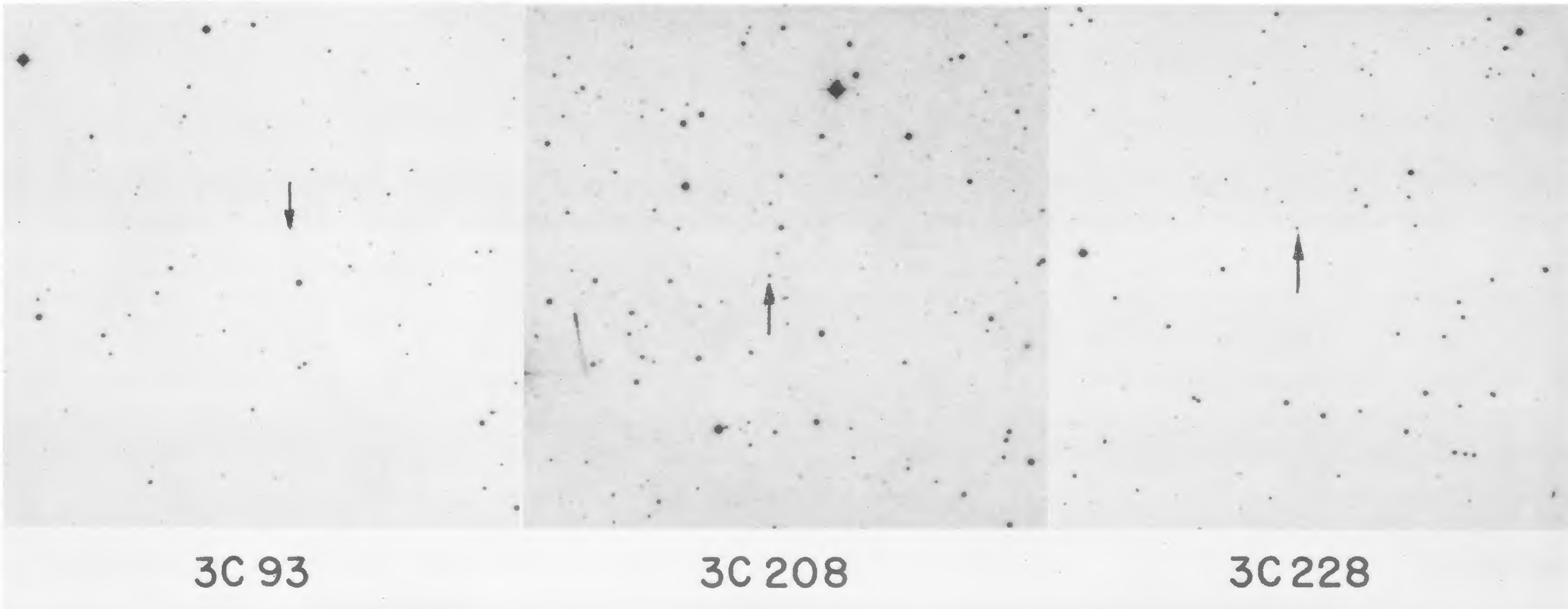

FIG. 1.—Finding charts for six QSS's made from the Palomar Sky Survey prints. North is at the top, west is to the right

FIG. 1.—*Continued*

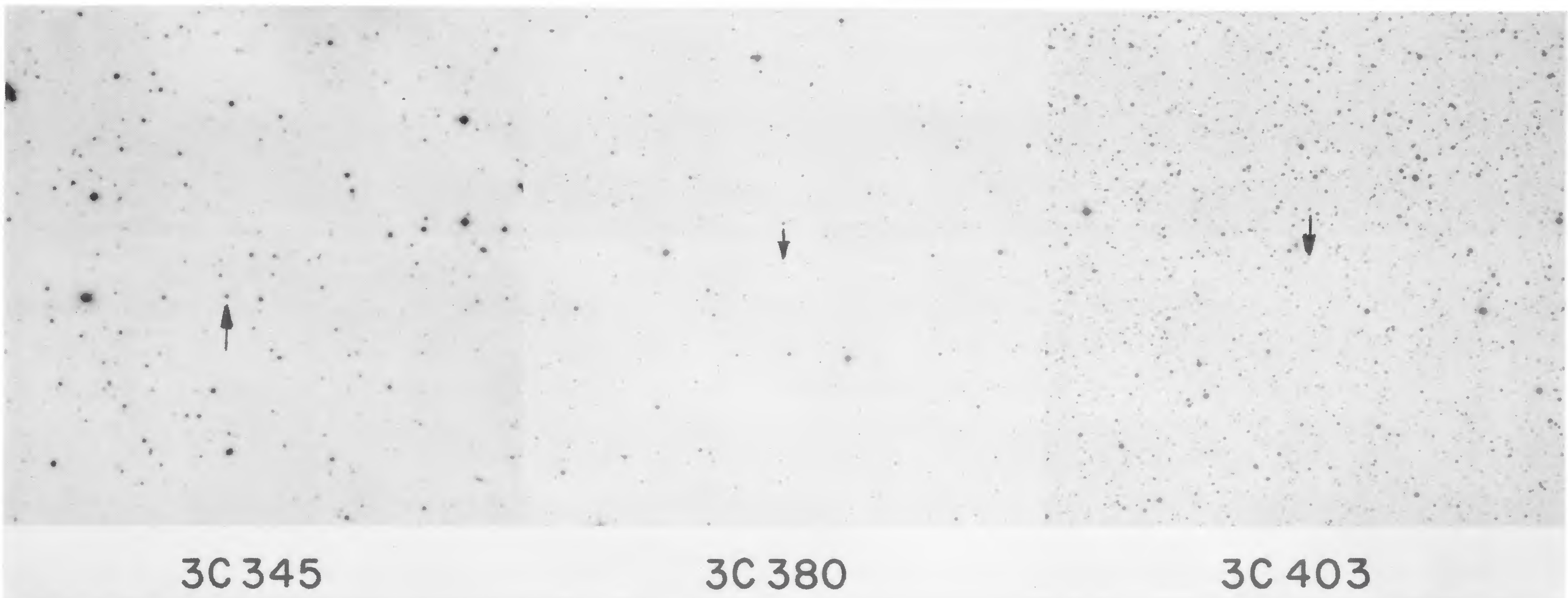

FIG. 2.—Same as Fig. 1 for the remaining five QSS's. As discussed in the footnote in the text, 3C 403 may be identified with the galaxy northeast of the arrow

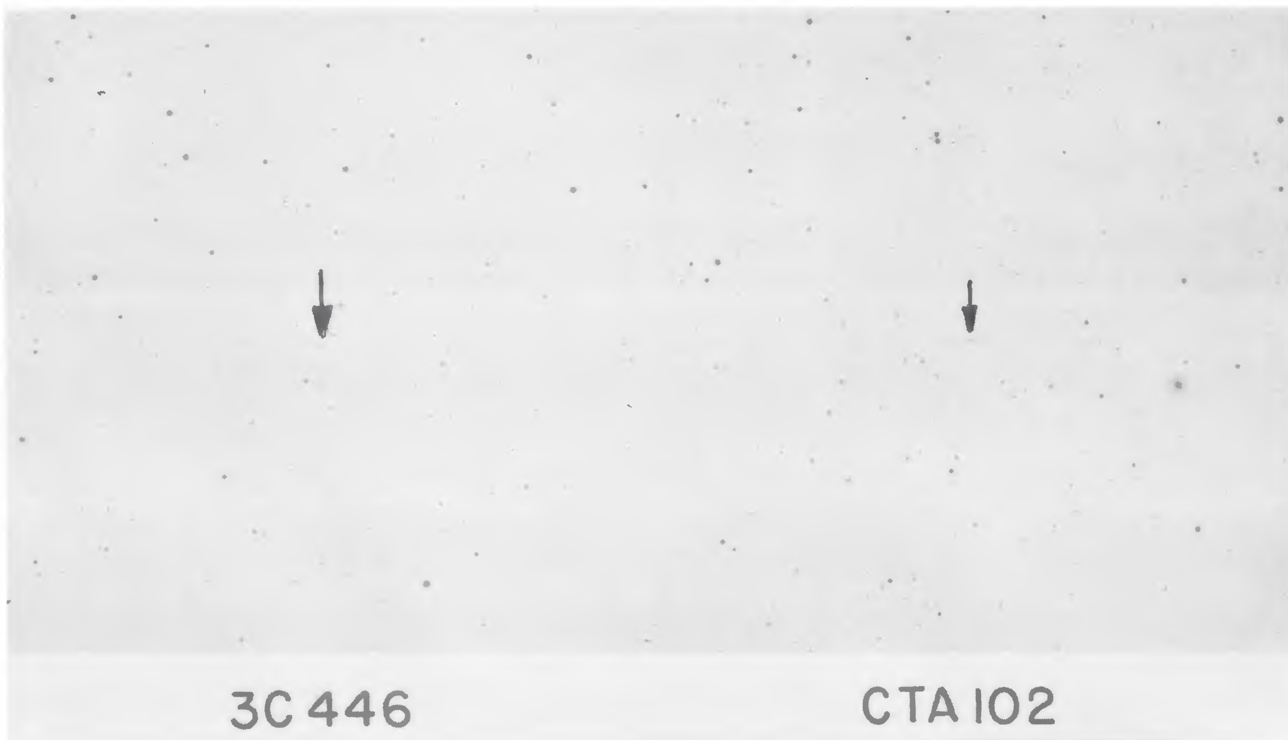

FIG. 2.—*Continued*

tangle of each of these source positions except in the case of 3C 446, where the object lay just outside the error rectangle defined by one mean error position. Photoelectric confirmation has been obtained so far for 3C 446 and CTA 102 making their identification certain. Optical positions measured by P. Veron, reported in the following letter, have been obtained for 3C 93, 3C 287, 3C 380, 3C 403,[1] 3C 446, and CTA 102 and the excellent positional agreement (all within twice the mean error of the radio positions) makes the identification either certain or highly probable. Furthermore, the objects are all abnormally blue as judged by comparison of the O and E Sky Survey plates.

Finally, 3C 345 has been independently identified as a probable QSS by Veron and by Wyndham. Again the optical and radio positions agree within the error of the radio data and the object is decidedly blue on the Schmidt plates.

Table 1 gives the radio positions, determined at the California Institute of Technology

TABLE 1

RADIO POSITION DATA FOR THE ELEVEN SOURCES

SOURCE	α(1950)	δ(1950)	RADIO DIAMETER* EW	RADIO DIAMETER* NS	B ESTIMATED	REMARKS
3C 93.	03h40m50s9	+04°48′13″				NRAO position
3C 208	08 50 26 9±0s8	+14 03 17±26″	... ...	... ...		Confused by 3C 208 1
3C 228	09 47 28 3±0 6	+14 34 06+11	23″ (A)	48″ (M2)	. . .	
3C 279	12 53 35 9±0 8	—05 31 14±14	<36″ (M2)	<10″ (W)	16 8	Faint jet going south
3C 287.	13 28 15 7±0 4	+25 24 31±10		<10″ (W)	. . .	
MSH 13–0*11*†	13 35 30 1±0 5	—06 11 36±16		<42″ (M2)	18 0	Very blue
	35.5±0 6					
3C 345	16 41 18 4±1 3	+39 54 10±8	<10″ (W)	<10″ (W)	16 3	
3C 380	18 28 12 2±0 7	+48 42 36±9	<10″ (W)	<10″ (W)	17 0	
3C 403	19 49 43 5±0 6	+02 22 14±11	Double (M2)		17 5	Separation Ew =1′.6
3C 446	22 23 11 3±0 6	—05 11 59±11	<14″ (W)	<20″ (W)		
CTA 102	22 30 07 5±0 6	+11 28 19±9	<10″ (W)	≲12″ (W)		

* Radio diameter data from (A) Allen *et al* (1962); (M2) Maltby and Moffet (1962); (W) Wyndham (1964 unpublished).

† MSH 13–0*11* Two α's were obtained at spacings of 195 λ and 283 λ, respectively Optical position is approximately 13h35m31s

for all but 3C 93 where the position has been taken from a recent position catalogue by Heeschen, Pauliny-Toth, and Wade at NRAO (1965). Also given in Table 1 are notes on angular diameters discussed below. Estimates of the B magnitude for those objects which have not been observed photoelectrically are given in the seventh column.

Table 2 gives the photoelectric data for those sources which have been observed so far. The characteristic ultraviolet excess is evident for all five. No evidence for variability is indicated by the data. The quoted mean errors for the magnitudes are *internal* errors computed from consistency of the individual direct current deflections. The true errors are undoubtedly larger by a factor of at least 2 due to errors in the extinction coefficients and in the transformation from the natural color system to the *UBV* system. The difference of 0m.09 in *V* for 3C 93 does not indicate variability because the data for March 8–9, 1964, are unreliable by at least ±0m.05 due to fluctuations of the sky noise on this night. That *V* for this data is probably faulty is suggested by the constancy of *B* and *U* for 3C 93 on the two tabulated dates.

No 200-inch direct plates of these sources are available except for 3C 287. No peculiar features such as jets are seen on the short-exposure blue plate of 3C 287, although there

[1] A new radio position by NRAO for 3C 403 at α (1950) = 19h49m44s.0, δ (1950) = +02° 22′48″ gives the possibility that the Galaxy at α (1950) = 19h49m 44s.45, δ (1950) = +02° 22′37″ which appears northeast of the arrow in Figure 2 is the correct identification. The large angular size of the radio source is added evidence. Photoelectric data are needed for a decision.

is a suggestion of a faint jet on the Sky Survey prints. The optical image of 3C 287 is double with a star that is $3^m.5$ fainter than the QSS image and 3".0 south of it.

The most interesting optical feature of the eleven sources is a faint jet extending 30" south from 3C 279. If the jet is associated with 3C 279, it is of great linear extent. Assuming $q_0 = +1$ for simplicity, and $\Delta\lambda/\lambda_0 = 0.4$ by analogy with 3C 48, we obtain the linear dimension y to be about 120000 pc compared with about 40000 pc for the jet in 3C 273. These linear dimensions follow from the exact equation

$$y = \frac{c z \theta}{H_0(1+z)^2} \tag{1}$$

for metric diameters using $q_0 = +1$ and $H_0 = 75$ km/sec 10^6 pc (Sandage 1961, eqs. [49] and [50]). The north end of the jet appears slightly displaced from the optical image of 3C 279 and may not be associated with the source. Plates obtained with the 200-inch reflector are needed to settle the question.

TABLE 2

PHOTOELECTRIC DATA FOR FIVE OF THE NEW QSS

Source	Date (1964)	V	$B-V$	$U-B$	Mean Error		
					V	B	U
3C 93	Mar. 8– 9	$18^m.18$:	$0^m.30$	$-0^m.47$	$\pm 0^m.030$	$\pm 0^m.019$	$\pm 0^m.020$
	Oct. 3– 4	18 09	39	−0 54	± 013	± .008	± .019
3C 208 . .	Feb. 13–14	17.42	.34	−1.00	± .011	. .	± .012
3C 287 . .	Feb. 13–14	17 67	55	−0 69	± 008	± 006	± .011
	May 9–10	17 68	.72	−0 61	± .012	± .007	± 008
3C 446	Oct. 2– 3	18 42	45	−0.93	± 008	± 014	± .014
	Oct. 4– 5	18 36	43	−0 88	± 029	± 014	± 034
CTA 102 .	Oct. 2– 3	17 33	42	−0 82	± 009	± .007	± .013
	Oct. 4– 5	17 32	0 42	−0 76	±0 009	±0 006	+0 008

Limits on the angular diameters of a few of the sources are available from (1) fringe visibility studies at Jodrell Bank and at California Institute of Technology; (2) curvature of the spectrum at low frequencies interpreted as synchrotron self-absorption; and (3) radio scintillation measurements by Hewish, Scott, and Wills (1964).

Radio diameters, interpreted from the fringe visibility patterns assuming a simple Gaussian brightness-distribution, are listed in Table 1. They cannot be taken as definitive because the data are not extensive enough. The measurements of Allen, Anderson, Conway, Palmer, Reddish, and Rowson (1962) suggest that 3C 208, 3C 228, and 3C 380 may have a core-halo structure, while 3C 287 may be double. 3C 403 is similar to 3C 47 in that its radio size is large compared with other known QSS's.

The most interesting new identification is CTA 102 (Harris and Roberts 1960), which has a peculiar spectrum broadly peaked at $\nu = 10^9$ Hz with decreasing flux density toward higher and lower frequencies. If the decrease toward lower frequencies is interpreted as synchrotron self-absorption, an angular diameter of about 0".01 is required (Slish 1963; Williams 1963). On this basis, CTA 102, CTA 21, and the very unusual southern source 1934–63 (Bolton, Gardner, and Mackey 1963) are among the sources with the smallest angular diameters known. The available evidence favors the self-absorption explanation, at least for the source 1934–63, because the variation of the flux density for frequencies smaller than the turnover frequency follows closely $F(\nu) \propto \nu^{2.5}$, which is characteristic of synchrotron self-absorbers with a uniform brightness temperature across the disk (LeRoux 1960, 1961) but is not characteristic of H II absorption or of a low-energy cut-off of the electron reservoir (cf. Kellermann 1964).

Synchrotron self-absorption occurs at a given frequency only under the apparently rare circumstance that the brightness temperature of the source at this frequency is equal to or greater than the kinetic temperature of the relevant gyrating electrons. This can occur only for sources of very small diameter such as most of the quasi-stellar objects. The identification of CTA 102 as a QSS is therefore not completely unexpected. If the angular diameter of CTA 102 is indeed as small as 0".01, then the linear diameter must be of the order of 50 pc if the redshift is taken as 0.5, assumed by scaling the redshift of 3C 48 by the apparent-magnitude factor. Because of the nature of the quantity being measured, it is clearly the metric diameter and not the isophotal diameter which is involved, and therefore equation (1) applies.

The final source for which diameter data exists is 3C 208, which is a scintillator in the solar wind (Hewish, Scott, and Wills 1964). Only an upper limit on the diameter of from 0".8 to 0".3 can be derived from these data, and the source may indeed be considerably smaller. Spectral data are not numerous enough at low frequencies to apply the criterion of synchrotron self-absorption.

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REFERENCES

Allen, L. R., Anderson, B., Conway, R. G., Palmer, H P., Reddish, V. C., and Rowson, B. 1962, *M.N.*, **125**, 477.
Bolton, J. G., Gardner, F. F., and Mackey, M. B. 1963, *Nature*, **199**, 682.
Davies, M. E., and Longair, M. S. 1965, *M.N.* (in press).
Fomalont, E. B., Matthews, T. A , Morris, D., and Wyndham, J. D. 1964, *A.J.* (in press).
Harris, D. E., and Roberts, J. A. 1960, *Pub. A.S.P.*, **72**, 237.
Heeschen, D. S., Pauliny-Toth, I., and Wade, C. M., 1965 (in preparation).
Hewish, A., Scott, P. F., and Wills, D. 1964, *Nature*, **203**, 1214.
Kellermann, K. I. 1964, *Ap. J.*, **140**, 969.
LeRoux, E. 1960, *Ann. d'ap.*, **23**, 1010.
———. 1961, *ibid.*, **24**, 71.
Maltby, P., and Moffet, A. T. 1962, *Ap. J. Suppl.*, **7**, 141.
Matthews, T. A., and Sandage, A. R. 1963, *Ap. J.*, **138**, 30.
Ryle, M., and Sandage, A. 1964, *Ap. J.*, **139**, 419.
Sandage, A. 1961, *Ap. J.*, **133**, 355.
Schmidt, M. 1963, *Nature*, **197**, 1040.
Schmidt, M., and Matthews, T. A. 1964, *Ap. J.*, **139**, 781.
Slish, V. I. 1963, *Nature*, **199**, 682.
Williams, P. J. S. 1963, *Nature*, **200**, 56.
Wyndham, J. D. 1965 (in preparation).
Wyndham, J. D., and Read, R. B. 1965, *A.J.* (in press).