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AT/05.11/002.

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A 'WORKING LIST' OF POTENTIAL CALIBRATION SOURCES FOR SOUTHERN HEMISPHERE RADIO OBSERVATIONS.

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A. GENERAL REMARKS

The availability of suitable calibration sources is an important factor in most radioastronomical observations. Over the last few years, observations at Tidbinbilla with the 2.3 GHz short baseline interferometer have highlighted the need for an extensive pool of suitable position calibrator sources in the southern hemisphere, particularly for optical identification work.

Experience has shown that the suitability of sources as position calibrators is not always commensurate with the quoted accuracy of published radio and optical positions. This is due to the presence of extended and/or frequency dependent structure, or mis-identification of optical counterparts. An examination of the often large discrepancies between short baseline radio, VLBI and optical positions (up to 10 arcseconds for some sources) highlights the care that is required in choosing suitable calibrators for position calibration at or below the 1 to 2 arcsecond level. The approach we have adopted at Tidbinbilla is to observe say 5 or 6 position calibrators near a region of interest. A comparison of the phase residuals quickly facilitates the identification of unsuitable calibrators.

The problem of position determination is compounded by the lack of a uniform radio-optical reference frame in the southern hemisphere. There are some indications that discrepancies of the order of 1 arcsecond may be present in some areas (e.g. Sullivan and Argue 1980). Whilst uncertainties of this order are probably just acceptable for optical identification work, they are clearly unsatisfactory for longer baseline astrometric position measurements. Eventually, observations of radio stars may be used to tie together optical and radio reference frames over the whole celestial sphere (Walter 1982); until the reference frame can be standardised, position calibration will usually involve some sort of "bootstrap" operation.

The source lists presented here are an attempt to compile a working list of radio sources which may be potentially useful as position or flux density calibrators for southern hemisphere instruments. Specifically, they have been selected as far as possible to be useful as calibrators for the Tidbinbilla interferometer at 2.3 or 8.4 GHz; however, the lists should prove valuable for other radio observations over the range ~1-10 GHz, both with single dish and interferometric instruments, including the AT. Approximately 1600 sources are listed, of which about 60 are classed as potential flux density calibrators.

A northerly declination limit of +45 degrees was chosen, corresponding to an elevation angle limit of 10 degrees at -35 degrees latitude. Below declination -40 degrees the list is probably fairly complete; it is in this zone that good position calibrators are most urgently needed. Above this limit, good positions are available from the VLA and other northern instruments, and the problems are less severe. North of declination -20 degrees, no attempt was made to produce a complete compilation, but the sky density of sources listed here should be adequate. Plots of the distributions of position and flux calibrators are shown in figures 1 and 2. The region near the galactic equator is somewhat deficient of both position and flux calibrator candidates, mainly due to confusion or optical obscuration effects. This may not present a serious problem in practice, as it is likely that sources clear of the galactic plane would be preferred for calibrations.

It should be emphasised that this working list is just that; many sources included here will prove unsuitable for particular applications. However, it is expected that users will be able to prune the list to their requirements; it is hoped that it will prove a useful resource for radio calibrations.

B. POSITION CALIBRATORS

The list of about 1600 possible position calibrators has been compiled from approximately 60 previously published lists of short and long baseline radio and optical positions. The majority of the sources have fairly flat radio spectra and are optically identified with QSOs.

The general criteria for inclusion in the list are (loosely) as follows:

(a) Angular diameter (where specified) less than ~15 arcseconds

(b) Quoted position measurement uncertainty less than 5 arcseconds; however, most are less than 1 arcsecond.

(c) If optically identified, an optical-radio offset of less than 5 arcseconds, unless the radio position uncertainty is greater than this value.

In particular, positions from the Molonglo 408 MHz catalog were excluded, since a large proportion of these sources are steep spectrum objects which are either extended or too weak at 2.3 GHz to be useful as calibrators. In addition, optical positions measured from transparent overlays only were excluded.

In some cases up to 7 different position references were found for each source. Where the positions were generally consistent, the position with the highest quoted accuracy was selected. In some cases, the positional agreement was marginal, or clearly ficticious. In these cases, a position was selected in a priority order appropriate to the intended usage of the list at Tidbinbilla:

(a) VLA position (Perley 1982)

(b) Other shorter baseline radio position

(c) VLB radio position

(d) Optical position of identified counterpart.

The final source list is given in Appendix 1, with explanatory notes in Appendix 3.

Unfortunately, there is probably no such thing as a "universal" position calibrator, since a large proportion of sources exhibit structure at or below the 5-10 arcsecond level, or show extended low level structure over a much larger scale. It is therefore necessary to tailor the selection of calibrators for the particular application, such as medium or long baseline radio observations. Most of the sources listed by Perley(1982) have cores which were unresolved with beams of approximately 1.4 and 0.4 arcseconds at 1.5 and 4.9 GHz respectively (although see his notes for information on additional structure at the arcsecond level). These would appear to be potentially useful as calibrators for most medium baseline observations, whilst the VLBI positions listed by Morabito et.al.(1982) should be useful on longer baselines. Since many of the longer baseline radio and optical positions have been excluded from the present list by the selection criteria, an unedited version of the source list, containing all the original multiple references, is also available if required.

C. FLUX DENSITY CALIBRATORS

Suitable flux density calibrators are somewhat harder to find, particularly for high resolution observations. Firstly, it is highly desirable that the sources be unresolved, or nearly so, so that resolution corrections to the observed flux density are small. However, most small diameter sources are time variable (even over time scales of 3 to 4 days; see Heeschen 1981), thus negating their usefulness; the problem is clearly most acute with longer baselines and relatively poor (u,v) plane coverage. Secondly, the flux density should ideally be stable over a period of years, at a level of 1 or 2 percent. Thirdly, the flux density must be sufficiently high to provide a good signal-to-noise ratio for single dish integrated flux density measurements; typically at least 1 Jy over the range 1 to 10 GHz. In any practical situation, it is usually necessary to carry out a careful flux density calibration program with the instrument to determine suitable calibrators, define the flux scale and determine other systematic instrumental effects, such as antenna gain variations.

Initially, approximately 100 sources were selected from the catalog of Kuhr et. al.(1981). These have flux densities of at least 1 Jy near 2.3 GHz and no obvious evidence of variability, from examination of the available flux density data as plotted by the above authors. This preliminary list was then sifted by rejecting sources whose angular sizes were known to be greater than approximately 12 arcseconds. For a 1500 wavelength baseline (Tidbinbilla interferometer at 2.3 GHz) this source size corresponds to a fringe visibility of 0.95. For approximate flux density calibrations on this baseline, resolution corrections could be neglected, whilst they can be included for more accurate work. However, many of the sources have much smaller angular sizes, and should be suitable as calibrators for longer baselines.

A number of sources were excluded on the basis of clear evidence of variability at radio wavelengths, although for many far southern sources, measurements are rather scarce. References searched for structure and variability information were Bash(1968), Bridle and Fomalont(1978), Ekers(1969,1970), Fomalont and Moffat(1971), Jenkins, Pooley and Riley(1977), Kellermann et. al.(1970), Klein and Stelzried(1976), Kuhr et. al.(1981), Pacholczyk(1978), Palmer et.al.(1967), Perley(1982), Shimmins and Wall(1973), Shimmins and Bolton(1981), Turegano and Klein(1980), and Ulvestad et. al.(1981).

All the finally selected flux calibrators have steep radio spectra, in contrast to the majority of the position calibrators. The final source list is given in Appendix 2; explanatory notes are given in Appendix 3. The flux densities at 2.29 and 8.42 GHz were calculated from the best fit spectral parameters given by Kuhr et. al. These values have been normalised by Kuhr et. al. to the flux scale of Baars et. al.(1977). For the sources 0134+329, 0624-058 and 1328+307 very accurate flux density values at 2.295 or 8.42 GHz were available from Klein and Stelzried (1976) or Turegano and Klein (1980), and these could be considered as primary calibrators. There appear to be small but significant discrepancies between these values and those derived from Kuhr et. al.; consequently, it appears that the spectral parameters fitted by Kuhr et. al. should be treated with caution; in any case, the values quoted will need to be refined by observation.

D. OBTAINING A COPY OF THE POSITION CALIBRATOR LIST

A copy of the position calibrator list is available on the Epping VAX, in the username AT area, subdirectory CALSRC (i.e after logging in under AT, type SET DEF [.CALSRC]). The position calibrators are on the file POSCAT.VAX. This may be edited as required for updating the list. To obtain a nicely formatted copy on the line printer, run the program PRNTCAT; in addition, a copy of Appendix 3 (explanatory notes) is obtainable by printing the file CALCAT.APP.

E. ACKNOWLEDGEMENTS

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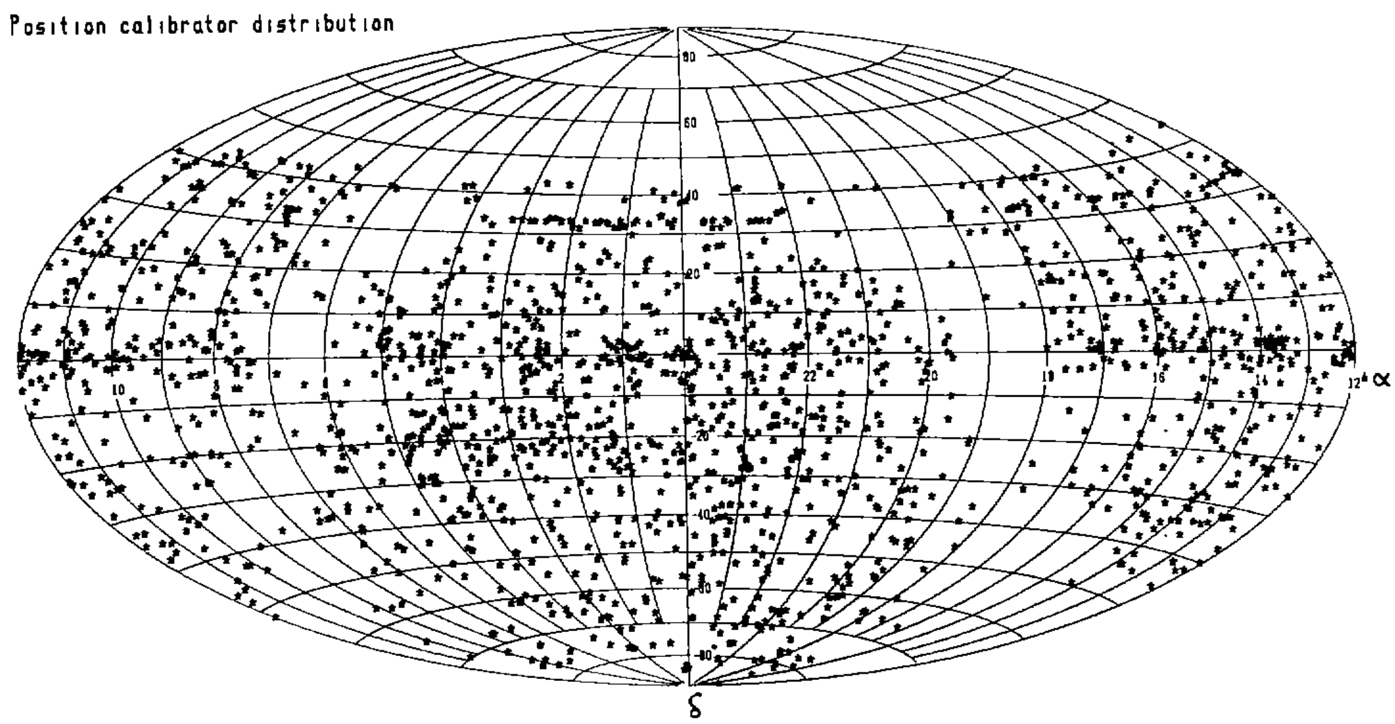

Figure 1. Distribution of the potential position calibrators.

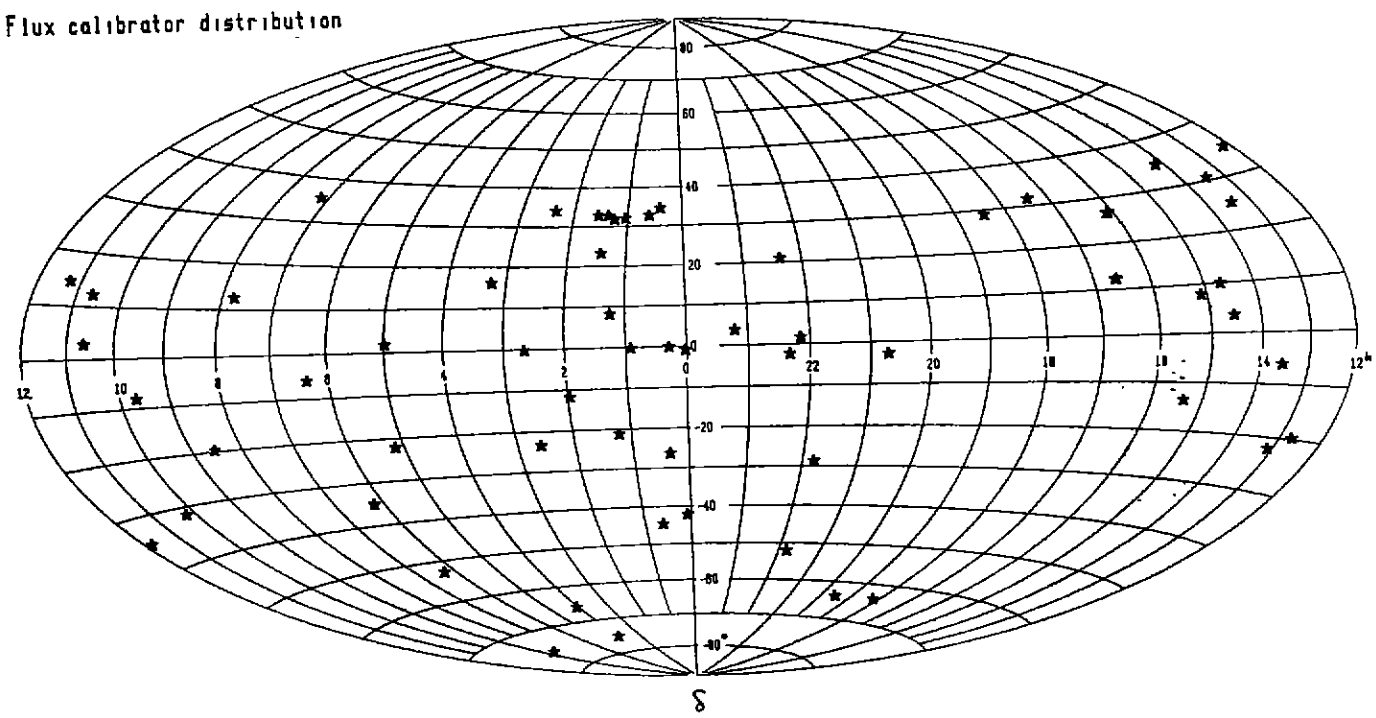

Figure 2. Distribution of the potential flux density calibrators.

APPENDIX 1. (For a copy see section D).

APPENDIX 2.

POTENTIAL FLUX DENSITY CALIBRATORS

IAU name	Other name	Cal typ	R.A. (1950.0)	Decl. (1950.0)	MHz	Flux mJy	MHz	Flux mJy	Position Ref.	Notes
0003-008		B	00 03 12.030	-00 51 25.70	2290	2665	8420	952	CBJ 76	
0008-421		B	00 08 21.300	-42 09 50.60	2290	2966	8420	565	PERLEY 82	d<15"EW (FM 71)
0019-000		B	00 19 51.650	-00 01 41.77	2290	2098	8420	620	PERLEY 82	<21"x<21" (FM 71)
0023-263	00-210	B	00 23 18.914	-26 18 49.25	2290	6188	8420	2242	PERLEY 82	<18"x<15" (FM 71)
0026+346	0B343	B	00 26 34.834	+34 39 57.70	2290	1682	8420	1039	PERLEY 82	
0038+328		B	00 38 13.830	+32 53 41.20	2290	2182	8420	671	ACG 72	<15"x<15" (FM 71)
0039-445		B	00 39 46.700	-44 30 27.80	2290	2297	8420	779	SAVAGE 76 OPT	ID=G 19.5M, 9"dble (UJPF 81)
0056-001	4C-0.06	B	00 56 31.762	-00 09 18.80	2290	1960	8420	1149	PERLEY 82	ID=Q 17M Z=.717 V? <15"x<21"(FM71)
0104+321	3C31	B	01 04 39.247	+32 08 44.33	2290	3856	8420	1600	MPBJ 82 VLB	<1"x<1.7"+ext struct (JPR 77)
0114-211	01-24	B	01 14 25.954	-21 07 55.00	2290	2693	8420	710	PERLEY 82	ID=E 16.5M, <18"x<15" (FM 71)
0116+082	4C08.06	F	01 16 24.203	+08 14 05.26	2290	1786	8420	873	MPBJ 82 VLB	ID=G 20.5M Z=.594, <18"x<15" (FM)
0116+319	4C31.04	B	01 16 47.249	+31 55 05.83	2290	1891	8420	1168	PERLEY 82	
0123+329		B	01 23 55.040	+32 57 30.40	2290	2551	8420	884	CBJ 75	<15"x<15" (FM 71)
0127+233	3C43	B	01 27 15.080	+23 22 52.70	2290	1934	8420	719	acg 72	ID=Q 19M Z=1.459, core d"3"(UJPF81)
0134+329	3C48	B	01 34 49.832	+32 54 20.52	2290	10710	8420	3320	PERLEY 82	Flux KS 76, TK 80, d<1.5" 82.76 (Bash 68)
0159-117	01-121	B	01 59 30.350	-11 46 59.70	2290	2282	8420	1033	HUN 71 OPT	ID=Q 16M Z=.669, d<1.5"(Bash 68)
0223+341		B	02 23 09.740	+34 08 01.50	2290	1884	8420	1076	UJPF 81	
0237-233	00-263	B	02 37 52.789	-23 22 06.27	2290	5640	8420	2004	PERLEY 82	ID=Q 16.6M Z=2.230 Flux KS,KWPN,d".002"(K70)
0240-002	4C-0.13	B	02 40 07.090	-00 13 30.70	2290	3474	8420	1133	ACG 72	ID=S 10M Z=.004 V?, 8"trip (UJPF81)
0316+162	CTA21	B	03 16 09.135	+16 17 40.40	2290	5997	8420	1703	PERLEY 82	d<0.05" (P 67)
0407-658	0408-65	B	04 07 57.400	-65 52 45.90	2290	9040	8420	2022	ADAM 77 OPT	d<24"(Ekers 69)
0409-752	0410-75	B	04 09 59.000	-75 15 07.00	2290	8923	8420	2912	FWRG 76	d<24"(Ekers 70)
0500+019		B	05 00 45.176	+01 58 53.82	2290	2381	8420	1372	PERLEY 82	
0511-220	0G-220	B	05 11 41.815	-22 02 41.20	2290	1088	8420	1296	PERLEY 82	ID=Q? 19.5M
0614-349	06-36	B	06 14 48.810	-34 55 08.60	2290	2130	8420	1027	BWH 73	ID=DB 18M Z=.329, d"2" (UJPF81)

POTENTIAL FLUX DENSITY CALIBRATORS

IAU name	Other name	Cal typ	R.A. (1950.0)	Decl. (1950.0)	MHz	Flux mJy	MHz	Flux mJy	Position Ref.	Notes
0620-526	06-53	B	06 20 37.080	-52 40 01.70	2290	2070	8420	888	TW 73 OPT	ID=D 15.5M Z=0.051
0624-058	3C161	B	06 24 43.190	-05 51 11.80	1465	18000	8420	4075	PERLEY 82	8420 flux TK 80, 20"x<15" (FM71),V? (SW 73)
0711+356		B	07 11 05.603	+35 39 52.56	2290	1847	8420	1105	PERLEY 82	
0748+126		B	07 48 05.060	+12 38 45.35	2290	1539	8420	2600	PERLEY 82	ID=Q 17.9M Z=0.885
0834-196		B	08 34 56.150	-19 41 25.40	2290	3143	8420	831	UJPF 81	d<0.05" (P 67)
0842-754	08-71	B	08 42 11.470	-75 29 36.20	2290	2428	8420	1001	HUN 71 OPT	ID=Q 18M Z=.524, d<24"(Ekers 70)
0941-080		B	09 41 08.646	-08 05 44.03	2290	2022	8420	651	PERLEY 82	ID=D 19M
1015-314	10-35	B	10 15 53.388	-31 29 11.33	2290	2487	8420	889	PERLEY 82	d<18" (Ekers 69)
1039+029	4C03.18	B	10 39 04.180	+02 58 14.70	2290	1805	8420	671	MBC 75	4" dble, conf? (UJPF 81)
1040+123	3C245	B	10 40 06.020	+12 19 15.90	2290	2375	8420	1078	HUN 71 OPT	ID=Q Z=1.029, 3"db(Bash68),V?(SW)
1117+146	4C14.41	B	11 17 50.992	+14 37 21.08	2290	1837	8420	726	PERLEY 82	<21"x<15" (FM 71)
1151-348	11-314	B	11 51 49.443	-34 48 47.15	2290	4969	8420	1980	PERLEY 82	ID=Q 18M Z=.258, d<24", conf?(Ekers 69)
1213+350	4C35.28	B	12 13 24.826	+35 04 54.95	2290	1341	8420	861	PERLEY 82	
1245-197	ON-1762	B	12 45 45.218	-19 42 57.51	2290	4245	8420	1705	PERLEY 82	d<24",Conf?(Ekers 69),d<.05"(P67)
1308-220	3C283	B	13 08 57.400	-22 00 46.70	2290	3022	8420	542	UJPF 81	<35"x<15" (FM 71)
1328+254	3C287	B	13 28 15.927	+25 24 37.38	2290	5159	8420	2250	PERLEY 82	ID=Q 17.7M Z=1.055, d<.05"(P 67)
1328+307	3C286	B	13 28 49.657	+30 45 58.59	2290	11780	8420	5435	PERLEY 82	Flux KS 76, TK 80, <15"x<15" (FM 71)
1335-061	4C-6.35	B	13 35 31.180	-06 11 57.10	2290	2093	8420	592	HUN 71 OPT	ID=Q 17.7M Z=.625, <15"x<50"(FM)
1413+349		B	14 13 56.270	+34 58 29.35	2290	1874	8420	824	PERLEY 82	
1434+036	4C03.30	B	14 34 25.870	+03 37 11.30	2290	2097	8420	854	MBC 75	<18"x<15" (FM 71)
1442+101	0Q172	B	14 42 50.483	+10 11 12.10	2290	1985	8420	874	PERLEY 82	ID=Q 18M Z=3.540
1508+080	3C313	F	15 08 33.300	+08 02 58.00	2290	2552	8420	822	KWPN 81	ID=E 19.5M Z=0.461
1524-136		B	15 24 12.875	-13 40 34.90	2290	1934	8420	719	PERLEY 82	ID=Q? 20M
1607+268	CTD93	B	16 07 09.289	+26 49 18.60	2290	3485	8420	853	PERLEY 82	<15"x<15" (FM 71)
1638+124	4C12.60	B	16 38 27.923	+12 25 46.32	2290	1504	8420	805	PERLEY 82	

IAU name	Other name	Cal typ	R.A. (1950.0)	Decl. (1950.0)	MHz	Flux mJy	MHz	Flux mJy	Position Ref.	Notes
1726+318	3C357	B	17 26 25.680	+31 48 36.50	2290	1822	8420	594	GO 73	
1814-637	18-61	B	18 14 46.340	-63 47 05.00	2290	8506	8420	2669	HLMS 71 OPT	ID=G 18M,d<24",conf?(Ekers69),
1829+290		F	18 29 18.110	+29 04 59.40	2290	2156	8420	717	KWPN 81	core d~1" @5GHz (UJPF 81)
1934-638		B	19 34 47.601	-63 49 37.71	2290	13153	8420	2688	SHEVE 82 VLB	slow var, d<18" (Ekers 70)
2044-027	4C-2.80	B	20 44 34.230	-02 47 26.00	2290	1611	8420	623	MBC 75	ID=Q 20M Z=.942, <21"x<15"(FM71)
2149-287	21-214	B	21 49 10.570	-28 42 36.50	2290	2476	8420	682	BWH 73	core d~2" @5GHz (UJPF 81)
2150-520	21-58	B	21 50 46.520	-52 04 51.40	2290	2239	8420	843	LU 74 OPT	<30" EW (SB 81)
2210+016	4C01.69	B	22 10 05.120	+01 37 59.40	2290	2084	8420	701	UJPF 81	<18"x<15" (FM 71)
2221-023	3C445	F	22 21 15.600	-02 21 57.00	2290	3877	8420	1350	KWPN 81	
2223+210		B	22 23 14.768	+21 02 50.03	2290	2032	8420	993	MPSJ 82 VLB	ID=Q 18M Z=1.959
2314+038	3C459	B	23 14 02.240	+03 48 55.20	2290	2765	8420	711	MBC 75	ID=N Z=.221, 8" dble (UJPF81)

APPENDIX 3

EXPLANATORY NOTES ON SOURCE LISTS

a) 'Caltyp' (col 3) :

- P — position calibrator
- F — flux calibrator
- B — (both) position and flux calibrator

b) Optical identifications, magnitudes and redshifts have been taken from the Parkes catalog, where a matching source name was found. Identification codes are:

- Q — confirmed QSO
- Q? — probable QSO
- S,D,DB, E,SC,N, SO — galaxy of corresponding type
- G — faint galaxy
- BLC — BL Lac
- RSO — Red stellar object

c) Flux densities:

- 2700, 5000 MHz : from Parkes catalog.
- 1465, 4885 MHz : VLA fluxes (Perley 1982).
- 2695, 8085 MHz : NRAO interferometer.
- 2290, 8420 MHz : calculated from Kuhr et. al.(1981), unless otherwise noted.

If no fluxes were given in the references and no Parkes values were available, flux densities were omitted.

d) Other notes:

* V? indicates possible variable
* angular sizes and limits are N-S by E-W

e) Reference codes for positions, fluxes, variability and structure:

(Optical position references are suffixed by OPT, VLBI by VLB)

- ACG 72 — Adgie Crowther and Gent (1972)
- ACTP 79 OPT — Anguita Campusano Torres and Pedreros (1979)
- AP 77 OPT — Anguita and Pedreros (1982)

AS 80 OPT	Argue and Sullivan (1980)
AS 81 OPT	Argue and Sullivan (1981)
ADAM 77 OPT	Adam (1977)
Bash 68	Bash (1968)
BCA 73	Browne Crowther and Adgie (1973)
BOZYAN 79 OPT	Bozyan (1979)
BOLT OPT	Bolton J G (private communication, circa 1979)
BOLT 68 OPT	Bolton (1968)
BTCB 81 OPT	Bolton Trett Carignan and Binette (1981)
BS 77	Bolton and Savage (1977)
BWH 73	Brosche Wade and Hjellming (1973)
CBJ 75	Condon Balonek and Jauncey (1975)
CBJ 76	Condon Balonek and Jauncey (1976)
CHJ 77	Condon Hicks and Jauncey (1977)
CJW 78	Condon Jauncey and Wright (1978)
EKERS 69	Ekers (1969)
EKERS 70 OPT	Ekers (1970)
EB 65 OPT	Ekers and Bolton (1965)
EKM 75 OPT	Edwards Kronberg and Menard (1975)
FM 71	Fomalont and Moffat (1971)
FWRG 76	Frater Watkinson Retallack and Goss (1976)
GO 73	Ghigo and Owen (1973)
HLMS 71 OPT	Hunstead Lasker Mintz and Smith (1971)
HMS 78 OPT	Hunstead Murdoch and Shobbrook (1978)
HUN OPT	R W Hunstead (private communication)
HUN 71 OPT	Hunstead (1971)
JBGS 82 OPT	Jauncey Batty Gulkis and Savage (1982)
JKGSS 73	Joshi Kapahi Gopal-Krishna Sarma and Swarup (1973)
JPR 77	Jenkins Pooley and Riley (1977)
K 70	Kellermann et. al. (1970)
KS 76	Klein and Stelzried (1976)
KWPN 81	Kuhr Witzel Pauliny-Toth and Nauber (1981)
LS 74 OPT	Lasker and Smith (1974)
LU 70 OPT	Lu (1970)
LU 74 OPT	Lu (1974)
MBC 75	McEwan Browne and Crowther (1975)
MHW 77 OPT	Mitton Hazard and Whelan (1977)
MSB 78 OPT	Morton Savage and Bolton (1978)
MPSJ 82 VLB	Morabito Preston Slade and Jauncey (1982) (VLBI)
P 67	Palmer et. al. (1967)
PB 72 OPT	Peterson and Bolton (1972)
PBS 76 OPT	Peterson Bolton and Savage (1976)
PPLGW 81	Peacock Perryman Longair Gunn and Westphal (1981)
PRES VLBI	Preston (private communication)
PERLEY 82	Perley (1982) (VLA)
SAVAGE 76 OPT	Savage (1976)
SW 76 OPT	Savage and Wall (1976)
SBW 76 OPT	Savage Bolton and Wright (1976)
SBW 77 OPT	Savage Bolton and Wright (1977)
SW 81 OPT	Savage and Wright (1981)
SBPW 71 OPT	Shimmins Bolton Peterson and Wall (1971)
SKH 79 OPT	Spinrad Kron and Hunstead (1979)

SW 80 OPT	Smith and Wright (1980)
SHEVE 82 VLB	Southern hemisphere VLBI experiment (1982)
SW 73	Shimmins and Wall (1973)
SB 81	Shimmins and Bolton (1981)
TW 73 OPT	Tritton and Whitworth (1973)
TK 80	Turegano and Klein (1980)
UJPF 81	Ulvestad Johnston Perley and Fomalont (1981) (VLA)
VH 76 OPT	Vander Haegen (1976)
VV 75 OPT	Veron and Veron (1975)
VV 77 OPT	Veron and Veron (1977)
VVAG 76 OPT	Veron Veron Adgie and Gent (1976)
WABC 75	Warner Assousa Balick and Craine (1975)
WADE 70	Wade (1970)
WHITE OPT	G L White (private communication)
WALL 73 OPT	Wall (1973)
WW 80 OPT	Walter and West (1980)
WW 82 OPT	Walter and West (1982)
WWD 73 OPT	Wills Wills and Douglas (1973)
WJ 82	Witzel and Johnston (1982) MPI preprint #122
WMH 80 OPT	White Murdoch and Hunstead (1980) (Molonglo Deep Survey)