INTERIM REPORT ON THE TEXAS SURVEY

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The University of Texas Radio Astronomy Observatory (UTRAO) is engaged in a survey of the entire sky north of -35° declination at various frequencies in the range 335-380 MHz. Primary goals are (i) determination of accurate ($\sim$1") positions for about 50,000 sources, followed by (ii) optical identification of the sources on the basis of exact radio-optical position coincidence; (iii) provision of rough structure models for all listed sources; and (iv) monitor the sky for variable sources on the time scale of 1 to 2 years. The survey is not expected to be a reliable source of absolute flux density information except for those sources known to be unresolved from other work.

1. THE TEXAS INTERFEROMETER

The Texas Interferometer consists of 5 fan-beam meridian-transit antennas arranged in a 2 by 2 mile diamond as indicated in Figure 1. The antennas are interconnected to form 8 interferometer baselines: 2 are North-south and 6 are oblique. A large (30 MHz or 8%) bandwidth causes the UV plane response of each baseline to be spread along the baseline vector; the spatial frequency response of the eight baselines falls into three patches in the UV plane, as shown in Figure 2. Each patch is a sub beam in angle space; sub-beams A and C have oblique interferometer fringes, and envelope beamwidths of 4.82 x 7.44 arc-minutes; sub-beam B has a N-S baseline and an envelope beamwidth of 9.65 x 5.42 arcminutes. When the three sub-beams are added together to produce the synthesized beam, the envelope antenna solid angle is 20.18 square arcminutes, or 180 beams/square degree; this corresponds to about 144 beam areas per source at the surface density of the survey.

Instantaneous coverage of a declination strip about 10° wide (actually 9° at zenith to 17° at -26°) is achieved by operating 120 complex correlators at different time delays; this multi-beam back-end can handle either one north-south or two oblique baselines. Thus five days' observing are required to complete the instrument response to the total solid angle of the declination strip (e.g. 9° x 360° or 3081

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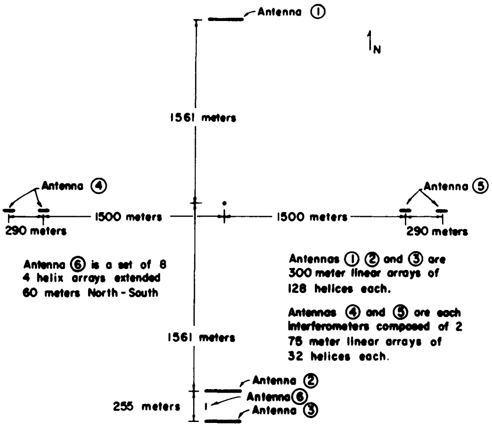

Figure 1. 6-element broadband synthesis interferometer, UTRAO.

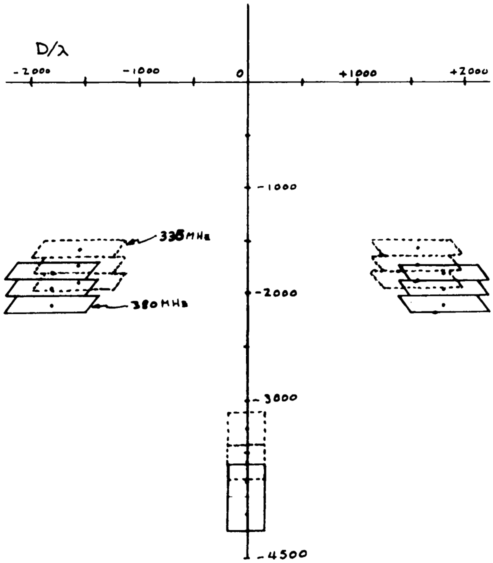

Figure 2. U-V plane response at zenith, UTRAO 5-element synthesis telescope.

square degrees for the 18° declination strip).

This five-day sequence produces data which is dominated by noise; to attain the sensitivity necessitated by our survey goals 8-12 such sequences must be averaged (40-60 days' observing); this averaged data is called one cycle for the declination strip in question. The sensitivity of a cycle is such that all sources ultimately included in the catalogue will appear at reasonable signal-to-noise ratio in one cycle. Quite apart from improved sensitivity, the averaged data has also smoothed out the effects of irregular ionospheric refraction which would otherwise limit performance, and has made negligible the effect of RFI and equipment malfunction in creating gaps in the data.

In order to check for systematic diurnal refraction effects, investigate source variability, and improve sensitivity, three observing cycles are scheduled for each declination strip, spaced by 6-8 months. All the sources catalogued in a declination strip (∿5,000) can be used to reduce the systematic errors in position and flux to a standard systematic error system; say, that of the first observed cycle. The errors of this system are then removed by reference to external position and flux density calibrators.

One of the three observing cycles is scheduled to be at 335 MHz, while two are at 380 MHz. This procedure is necessary to reduce lobe-shift incidence for faint sources to an acceptable level; it additionally

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Strip	Steradians	Epoch of 380 MHz Obs. 1	2	3	Epoch of 335 MHz Obs.
-26	1.606	1975.30			
-12	1.293	1975.44			
-01	1.139	1975.94	(1976.66)		
+09	1.043	1975.78			
+18	0.949	1974.21	1974.99	1975.60	(1976.83)
+27	0.872	1973.20	1973.49	1973.82	
+36	0.794	1974.32	1974.79	1975.15	
+45	0.715	1976.10			
+55	0.622	1976.24			
+65	0.500	1976.36			
+77	0.320	1976.47			

Table 1. Progress of Texas Survey through 1976.

gives further information on source structure as one can see from Figure 2; overall UV plane coverage is increased by about 60%.

Final catalogued positions will be a mean of the three observing cycles; source models and spectral index will be based on sub-beam fringe visibilities at two frequencies, and sources that vary significantly over a 1-2 year period will be noted.

A more detailed description of the instrument may be found in Douglas _et al_. (1973).

2. PROGRESS OF OBSERVATIONS

This is plainly a time-consuming data-acquisition and a tedious data-analysis project. The status of the data acquisition phase (as projected through the end of 1976) is shown in Table 1. Data acquisition is not yet complete for any declination strip, although +18 will be complete by late fall, and +27 and +36 should be completed in early 1977. The entire sky available to us (9.89 ster) has been observed on one cycle, and 26% of that (or 2.62 ster) has been observed on three cycles. We are just at the half-way mark in observations; completion is estimated to be in 1978.

3. PRELIMINARY RESULTS OF DATA ANALYSIS

Data analysis (apart from quick-look procedures) has not yet been completed for any declination strip, or indeed for any cycle of any dec strip. However some indicative interim results from two cycles of the 18 degree strip are now available, which allow us to characterize instrument performance, particularly for the brighter (> 0.4 Jy) sources in the ultimate catalogue.

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Flux Density	# Compared	Observed Noise Error for 1 Cycle ΔS(%)	Δα(")	Δδ(")	Expected Noise Error for 3 Cycles ΔS(%)	Δα(")	Δδ(")
S<0.435 Jy	50	14.5%	2".75	1".95	8.4%	1".59	1".12
0.435≤S<0.761 Jy	225	8.5%	1".88	1".12	4.9%	1".09	0".65
S≥0.761 Jy	325	4.0%	0".92	0".52	2.3%	0".53	0".30

Table 2. Texas Survey, +18° strip noise error.

3.1 Internal position and flux accuracy

Let us start with the primary goal of the survey: accurate positions. An assessment of internal noise and systematic errors can be obtained by differencing positions obtained in those parts of the two 18 degree cycles already reduced. The data in each are totally independent, although calibration and data reduction procedures are identical. The results are summarized in Table 2. The estimates for a single cycle assumed the two cycles compared had the same variance; those for three cycles simply are single-cycle results reduced by $\sqrt{3}$. Not shown are the systematic differences. These are small (∿1") and slowly varying, and are both understandable and easily removable. The smaller error in δ than α is a direct consequence of the greater extent of our system in the NS direction, and a greater redundancy in δ-determination. All the observed noise errors in the table are consistent with the formal noise estimates produced by our reduction program. The position accuracy goal of the survey is being met.

3.2 External position accuracy and optical identifications

To assess external position errors, and check the rate and content of optical identifications, the region from 1417 to 1600 hours in right ascension (14° to 22°.3 in declination) was chosen for a pilot identification study. The preliminary survey listed 199 sources in this region; 5 were subsequently found to be lobe-shifted, leaving a sample of 194 sources to be studied.

Optical identifications were sought in each radio source field using the UTRAO computer-interactive laser measuring engine and the glass copies of the NGS-Palomar Sky Survey. Reference stars were taken from the SAO catalogue; following a 6-parameter adjustment, a finding photograph was taken at the radio source position. Such a photograph is shown in Figure 3, which illustrates the utility of accurate radio positions in optical identifications. The source name from the UT catalogue appears in the lower right hand corner (1559+173 = 4C 17.65); this object is a QSO with z = 1.944.

Of the 194 fields examined, optical candidates within 5 arc-seconds of the radio position were noted in 84 cases; a more detailed breakdown is shown in Table 3.

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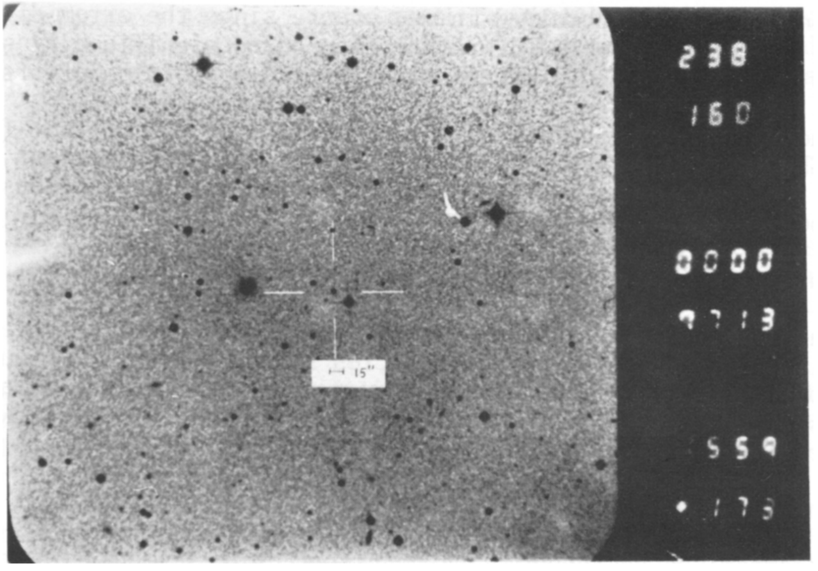

Figure 3. Finding chart for 1559+173.

Of these 84 objects within 5", 50 were within 3". An estimate of reliability is based on the work of Frank Ghigo (1976) who using the same instrument investigated the incidence of objects to the PSS plate limit in 600 random fields near radio sources. He found $4.76(10)^{-4}$ objects per square arcsecond in random fields; thus in 194 5" radius fields one would expect 7.25 objects (84 observed) and within 3" one would expect 2.61 objects (50 observed). The 84 objects are thus about 90% reliable; the 50 about 95% reliable.

As can be seen from Table 3, the mean optical-radio position difference is negligible, and the position scatter is approximately 2 arcseconds in each coordinate. This scatter is significantly higher than the sum of radio and optical position errors, and may reflect an intrinsic variance in radio and optical centroid position. The radio

	S≥0.761 Jy	0.435≤S<0.761 Jy	S<0.435 Jy	Total
# Sources	83	85	26	194
# Objects	45	29	10	84
Mean $\Delta\alpha$	0".56±0".28	0".02±0".47	-1".35±0".83	0".14±0".24
Mean $\Delta\delta$	0".03±0".27	-0".42±0".45	0".76±0".56	-0".08±0".22
$\sigma_{\Delta\alpha}$	1".83	2".43	2".34	2".18
$\sigma_{\Delta\delta}$	1".78	2".35	1".60	1".98

Table 3. Texas Survey optical sample region
1417<α<1600 14°.0<δ<22°.3

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positions seem to be absolved in any event, since the error distribution is symmetric in α and δ, rather than being significantly smaller in δ as would have been expected from the radio position errors.

The identification rate of 84/194 = 43% is close to that found by Frank Ghigo in his dissertation (48%). Identification content of this sample is not yet fully determined, but preliminary indications are that about half are galaxies, and half QSO's.

3.3 Source variability

The 600 sources which were intercompared to estimate systematic and noise errors were observed in cycles 9 months apart; no sources were found to vary by more than 25% over this time scale. A few sources may vary at the 20% level; the best case is 0119+191, whose flux density increased by 22±6% in 9 months.

3.4 Comparisons with MC3

A comparison has been made of the available segments of the survey with the Molonglo MC3 catalogue (Sutton et al., 1974) to assess the relative completeness and lobe-shift incidence in our preliminary data. The results are summarized in Table 4. Of the 445 MC3 sources in our survey region, 321 were found; the number we missed is consistent with the angular structure selection effect in the Texas Interferometer. Of the 321 found, 196 were sufficiently unresolved to produce good positions without structure modeling; 4% of these were lobe shifted. Most of the lobe shifts were of course at low flux density, and in all but one case, the second most likely position based on our data was correct. It should be emphasized that the powerful additional help of the 335 MHz observations has not yet been brought into play; this should bring a further order-of-magnitude reduction in lobe shift incidence. Complete elimination of lobe-shifts in a dilute transit interferometer is of course impossible; one can only demand (1) that the probability a position is affected by lobe-shift is both small and calculable and (2) that the second most likely position is correct in a majority of the lobe-shift cases.

A number of sources (∿40) were found in the MC3 region which were not in the MC3 catalogue; in most cases these sources fell below their

	MC3 Flux Density			
	S<0.4 Jy	0.4 Jy≤S<0.7 Jy	0.7 Jy≤S	Total
# MC3 Sources	91	178	176	445
# found	33	122	166	321
# positions	7	71	118	196
% lobe shifts	∿30%	15%	2%	4%

Table 4. Texas Survey 18C1, comparison with MC3.

0.4 Jy completeness limit. Position differences of the common sources shows the Molonglo positions to be free of systematic error, and to have a scatter approximately correctly described by their estimated error.

3.5 Remaining data analysis problems and prospectus

The preliminary results thus far available refer mostly to the brightest 2/3 of sources in the ultimate catalogue (surface density of 3500/steradian); our automatic reduction programs need a further stage of fine adjustment to achieve reliable operation at the 5000 source/steradian level ultimately desired.

Furthermore, structure modeling has not yet been incorporated into the automatic program; when available it will increase the number and reliability of the positions listed, as well as giving the most likely asymmetric double model for moderately resolved sources.

Both of these problems should be solved during this year, and the first completed section of the survey will be available in January of 1977.

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DISCUSSION

Webster: I am interested in analysing surveys for evidence of clustering of sources, and wish to enquire how uniform this survey is likely to be, and how many sources per beamwidth you expect at the catalogue limit.

Bash: This survey which is made with interferometers is sensitive to the angular structure of radio sources. Although the brighter, resolved sources can be recovered, we will lose the resolved sources near the bottom of the catalogue.

G. Burbidge: Can you say how many sources you have looked at for variation. You have apparently found only one variable if I understand you correctly.

Bash: We examined 600 sources and found only one which varies by more than 20% (by at least 3 sigma). This is a smaller number of variables than that suggested by Cotton (1976, Ap. J., 204, L63); however, our two measurements are separated by only 9 months which is a shorter time than the typical time scale for variations found by him.

Cannon: Would not part of the scatter between the radio and optical positions be due to the inclusion of spurious optical identifications?

Bash: Yes, but only a very small part. Ghigo has measured the background density in random fields as a function of galactic latitude to the Palomar Sky Survey plate limit. From the background counts we would expect 7 of the 84 identifications within 5" of the radio source and 3 of the 50 identifications within 3" of the radio source to the background objects.

Baldwin: For sources which are seen to be extended, what information do you plan to publish?

Bash: We are considering publishing the best-fitting double source model for the resolved sources and the centroid position for the double.

LOW FREQUENCY VARIABLES

W.D. Cotton

A sample of about 1500 radio sources selected from surveys with both long and short baseline interferometers was monitored for about two years (1973-1975) at 365 or 380 MHz at the University of Texas Radio Astronomy Observatory. About 800 were small enough, strong enough and well enough observed for variability on the order of 20% to 50% to be detected. Twenty two sources appear likely variables: 0051+317, 0113+154, 0127+233 (3C43), 0251+200, 0348+175, 0402+160, 0422+178, 0618+145, 0631+191, 0735+178, 0958+256, 1019+222, 1123+303, 1422+202, 1611+343, 1633+382, 1729+211, 2015+131, 2033+187, 2056+445, 2147+145 (3C437.1), 2338+132 (Cotton, 1976, Ap. J., 204, 163). Analysis of a sample relatively unbiased towards small angular size indicates that at least 2% of all sources selected at low frequency are variable.

Most of the variable sources were observed in June 1976 at 7.8 and 15.5 GHz to determine the high frequency spectrum. A few spectra were flat but most were steep at low frequency becoming flat at high frequency. A couple of sources appear to have steep spectra out to 15.5 GHz, which according to the usual interpretation indicates the absence of a strong high frequency compact component.

G. Burbidge: Is any one of the variable sources identified with a genuine Galaxy of stars whose redshift may not be in question?

Cotton: One of the sources is identified with a galaxy but it is one of the more questionable variables.

Conway: What are the names of the 2 variables with steep, straight spectra?

Cotton: 3C 43 and 437.1

Stannard: Two comments on low frequency variability from Jodrell Bank studies at 408 and 962 MHz:

1) 3C454.3, which Hunstead reports to vary by about 30% at 408 MHz, shows double structure at low radio frequencies, with an extended steep spectrum component 5.3 arc sec from the nuclear component in position angle 131°. Studies with LB interferometers show, however, that it is the flat spectrum nuclear component which is responsible for the variations at 408 MHz.
2) One of the most active sources at low frequencies is BL Lac, which has varied between ~ 2 and 5.5 Jy at both 408 and 962 MHz.

Turtle: Bruce McAdam and myself have made regular transit observations with the Molonglo Cross (408 MHz) of a fixed sequence of over 250 sources for 3 or 4 days every month for a year. We included about 30 sources which were suspected to vary. A partial analysis (W.B. McAdam (1976), Proc. Astron. Soc. Austral. 3, (in press)) has revealed at least 13 sources which show marked (> 8%) changes in flux density compared to their neighbours in the sequence. These changes occur over a period of a few months - all sources remaining constant during a 3-4 day session.

0056 - 001	8%	1148 - 001	16%
0101 - 128	11%	1504 - 167	25%
0736 + 017	39%	1510 - 089	9%
0753 + 023	10%	1854 - 663	9%
0833 - 450	54%	2052 - 474	10%
(Vela Pulsar)		2251 + 158	15%
1036 - 697	9%		
1055 + 018			

Swarup: What is your estimate of the diameter of these variable sources at meter wavelengths? If it's less than a milli-arc second, there are possibilities of observing interstellar scintillations.

Cotton: The estimated diameters from the timescale of the variations are on the order of a milli-arc second or less.

Condon: Bob Brown, Dave de Young, and I have made a survey of several dozen compact sources to search for evidence of interstellar scintillation. Flux densities in 100 5 MHz-wide channels from 500-1000 MHz were measured; intensity fluctuations would appear as departures (on the scale of the scintillation decorrelation bandwidth) from a power-law spectrum. Upper limits of $\mu \leqslant 0.05$ were set, which limit source brightness temperatures to less than 10^{18} K. New observations are planned which should go as low as 10^{15} K.

Murdoch: 1504-16.7 which varied by a ratio 2 to 1 continues to vary at the same rate. It was originally identified in the PKS catalogue as a galaxy but it is almost certainly a quasar.

Readhead: Wilkinson, Purcell and I have made VLBI observations, at 610 MHz and on three baselines, of a number of sources - some of which are suspected of showing low frequency flux density variation. The observations were made at two epochs: December 1973 and March 1975. We found no evidence of variation in either the total flux density or the visibility of these sources with the possible exception of 3C 273 in which there is a hint of variation on the longest baseline. The ratio of the mean visibilities $\frac{1}{n} \sum_{IHA} \frac{\gamma(1973)}{\gamma(1975)}$ for each source on each baseline are as follows:

Source	NRAO-OVRO	NRAO-Ft. Davis	OVRO-Ft. Davis
CTA 21	1.03 ± 0.02	1.03 + 0.01	1.03 ± 0.01
3C 84	1.06 ± 0.04	1.03 ± 0.05	1.03 ± 0.03
3C 147	0.94 ± 0.04	0.97 ± 0.04	0.96 ± 0.05
3C 273	0.93 ± 0.02	0.96 ± 0.02	1.00 ± 0.01
3C 286	0.98 ± 0.02	0.98 ± 0.02	0.98 ± 0.01
3C 345	1.02 ± 0.02	1.04 ± 0.02	1.03 ± 0.04
CTA 102	1.05 ± 0.04	0.99 ± 0.01	0.95 ± 0.02
3C 454.3	0.99 ± 0.02	0.99 ± 0.01	0.99 ± 0.02

Thus no variation was seen in the three sources CTA 21, CTA 102 and 3C 454.3 which is curious in view of the very large (~ 50%) variations reported for these sources at earlier epochs.

Goldstein: Are there no stars among the Texas variable sources?

Cotton: None of the variable sources have been identified as stars.