VLBI MEASUREMENTS OF RADIO SOURCE POSITIONS AT THREE U.S. STATIONS

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ABSTRACT

Results of VLBI measurement of 14 radio source positions at three U.S. stations during the MERIT short campaign is presented. Comparisons with other solutions are given, together with the comparisons between several radio source catalogues.

During the MERIT short campaign, several observatories cooperated in VLBI measurements organized jointly by the U.S. National Geodetic Survey (NGS) and the National Aeronautics and Space Administration (NASA). There were two 7-day observations arranged from Sept.26 to Oct. 2 and from Oct. 16 to Oct. 22, with time span nearly 23 hours per day. Details of the observation and data reduction have been published elsewhere (1). This paper deals with radio source positions determined by three U.S. stations, the Haystack Observatory, the Harvard Radio Astronomy Station (HRAS) and the Owens Valley Radio Observatory (OVRO).

1. Calibrations and reference

It is the first time in VLBI observation that full account has been taken of the instrumental delay,i.e. the so-called "cable" delay, and the propagation medium delay. For the neutral atmosphere propagation delay, effects due to wet and dry components of the atmosphere were calculated by a model set up by the GSFC VLBI Group using surface pressure, temperature and humidity. For the ionosphere propagation delay, careful comparisons between S and x bands (around 2295.99, 8340.99 MHz) were made in order to eliminate the ionospheric effect in the X band observations. Adjustments of axis-offset of each antenna and atmospheric zenith correction of each site are included in the parameters solved for every day observation. Actually, the axis-offset adjustment does not seem to contribute anything to the solution. It implies that the model used and the value measured are perfect, and the formal error of the solution with and without allowing for the axis-offset are almost equal, but will increase about two times if the zenith correction

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has not been taken into account.

For the celestial reference coordinate system, the barycenter of the Solar system was taken as the origin, and the X-axis was pointing to the vernal equinox of 1950.0. To reduce the observed positions to those of standard epoch 1950.0, modified nutation coefficients were used. Differences between the adopted coefficients minus those of the Woolard's are given in Table 1, column A. For comparison, the values proposed as the MERIT standard minus the Woolard's ones are listed in Column B.

Table 1. Difference of Nutation Coefficients ($0\rlap{.}''0001$)

Argument	Period	Longitude		Obliquity	
ℓ ℓ' F D Ω	(days)	A	B	A	B
0 0 0 0 1	6798.4	441	504.7	-86	-84.1
0 0 2 -2 2	182.6	-411	-456.7	202	216.9
0 1 0 0 0	365.3	193	168.1	56	54
0 0 2 0 2	13.7	-43	-236.8	22	93.5

The origin of right-ascension is defined by assigned value of the radio source 3C273B as $12^h26^m33\rlap{.}^s246$.

2. Results

The average of the 14 days observations is almost free from the influence of short period term, i.e. the 9.1, 13.7, and 27.6 day components. Positions of the 14 radio sources observed in those 14 days are listed in Table 2, where the averages of the α,δ observed in these 14 days and their formal errors, standard deviation of the mean values σ_α and α_δ , which were estimated from every day's deviation, are shown.

3. Comparison with other solutions

In Table 3, for comparison, we listed the formal errors of two solutions, where 3A* represents the solution in Table 2, and 3 A represents the solution without allowing for the cable delay, atmospheric model and ionospheric effect, but adjusting the zenith correction of atmosphere 4 times per day, or every 6 hours. The formal errors σ are shown also.

We can see that the σ of δ for 3C273B is abnormally large, not only because it is an equatorial source so that the declination would be rather hard to determine, but also because it was too close to the Sun during the 14 days, and made the observation even worse probably due to the effect of the Solar corona. Because this source is chosen to fix the origin of the right ascensions of all the sources, the

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Table 2. Radio Source Positions (1950.0)
(referred to the Barycenter of the Solar system)

Source name IAU	Alternate	Flux density (5Ghz,Jansky)	α	σ_α ($0^s.0001$)	δ	σ_δ (0".001)
0106+013		3.7	$1^h06^m04^s.5177$	±4.9	+01 19'01".047	±5.6
0224+671	4C67.05	2.0	2 24 41.1343	4.2	67 07 39.330	2.0
0235.164			2 35 52.6195	4.7	16 24 03.868	4.1
0355+508	NRAO150	10.2	3 55 45.2279	4.0	50 49 20.061	3.5
0552+398		5.0	5 52 01.3733	3.7	39 48 21.913	4.9
0851+202	OJ287	2.9	8 51 57.2295	3.5	20 19 58.592	5.1
0923+392	4039.25	7.4	9.28.55.2940	2.9	39 15 23.827	3.9
1404+286	OQ208	3.0	14 04 45.6286	3.4	28 41 29.525	3.2
1641+399	3C345	7.2	16 41 17.6409	4.2	39 54 10.991	2.1
1642+690		1.6	16 42 18.1437	5.1	60 02 13.433	1.8
2134+004		10.6	21 34 05.2264	4.8	00 28 25.006	6.9
2200+420	VR422201	3.0	22 00 39.3889	4.5	42 02 08.326	0.9
2251+158	3C454.3	9.0	22 51 29.5339	4.7	15 52 54.172	2.9
1226+023	3C273B	33.5	12 26 33.2460		02 19 43.456	14.8

Table 3. Formal Error of the solutions

Source	σ_α 3A*	σ_α 3A	ε_α 3A*	ε_α 3A	σ_δ 3A*	σ_δ 3A	ε_δ 3A*	ε_δ 3A
0106+103	±4.9	±5.2	±1.8	±1.2	±5.6	±3.4	±4.0	±2.1
0224+671	4.2	6.6	2.7	2.8	2.0	1.0	2.5	1.6
0235+164	4.7	6.3	1.6	0.7	4.1	2.7	2.1	1.7
0355+508	4.0	5.6	1.5	1.5	3.5	1.3	2.7	1.2
0552+398	3.7	5.2	1.2	1.1	4.9	2.1	3.8	1.0
0851+202	3.5	5.0	1.1	0.8	5.1	4.3	3.2	2.9
0923+392	2.9	4.8	1.8	1.1	3.9	2.8	2.6	1.6
1404+286	3.4	3.9	1.7	1.2	3.2	3.4	3.6	2.6
1641+399	4.2	3.8	2.3	1.8	2.1	2.3	3.3	1.5
1642+690	5.1	3.7	3.9	3.3	1.8	1.2	3.3	1.5
2134+004	4.8	5.0	1.7	1.4	6.9	3.2	5.8	2.4
2200+420	4.5	5.2	1.2	0.8	0.9	1.4	2.2	1.2
2251+158	4.7	5.0	1.4	1.0	2.9	1.6	1.7	1.4
1226+023					14.8	14.2		
Mean (0.1ms)	4.2	5.0	1.8	1.4				
(0".001)	6.3	7.5	2.8	2.1	3.6	2.4	3.1	1.7

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error of observation of this source $d\alpha_0$ will appear in all the other sources and with the same magnitude. Besides, daily effects due to imperfect calibration and errors in astronomical constants will also appear in the daily value of the α, δ of all the sources. Let α_δ be the observed α of the ith source at the jth day, and α_{ij} be the mean of those 14 days. We take

$$\Delta\alpha j = \frac{1}{13} \sum_{i=1}^{13} (\alpha_{ij} - \alpha_{im})$$

as the measure of the observation error of 3C273B plus some unknown daily effects, and the residual of each radio source is:

$$= \alpha_{ij} - \alpha_{im} - \Delta\alpha_j$$

Similarly, we have:

$$\Delta\delta_j = \frac{1}{13} \sum_{i=1}^{13} (\alpha_{ij} - \alpha_{im})$$

$$= \delta_{ij} - \delta_{im} - \Delta\delta_j$$

as the unknown daily effects in declination and the residual, the rms of the mean values of the observed α and δ estimated by and

are also given in Table 3 as ε. Where the ε and σ columns represent the standard deviation of α and δ with and without allowing for $\Delta\alpha_j$ and $\Delta\delta_j$ respectively.

From Table 3, we can see that, for α determination σ_α is much bigger than the ε_α value, but for δ determination, values of σ_δ and ε_δ are about the same. Thus, the observing error of 3C273B cannot be neglected, especially for this period of observation, and it seems more reasonable to set up the origin of right ascension by a group of radio sources instead of by a single radio source only. The same philosophy has been adopted by the BIH to maintain the prime meridian on Earth by a set of observatories instead of a single one. Also, daily scatter of the 3A* seems even a bit larger than those without calibrations, that is, the 3A. It is desirable to study further the perfectness of the calibrations themselves and the improvement of the nutation terms used.

Besides daily solutions of α, δ such as 3A* and 3A, we have a combined solution which is solved with the whole 14 days data of the three U.S. stations without calibrations and is denoted by 3C. The calibration combined solution of those 3 stations and Onsala is denoted by 4C* for the second week observations. For comparison, the last figures of the α, δ of these wolutions are shown in Table 4. It seems the

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calibrations of cable delay, atmospheric modelling and the ionospheric effect, contribute very little to the average position of radio sources.

Table 4. Different solutions

Source	α $(0\overset{s}{.}0001)$				α $(0\overset{''}{.}0001)$			
	3A*	3A	3C	4C*	3A*	3A	3C	4C*
0106+013	5177	5172	5177	5176	047	043	036	041
0224+671	1343	1329	1338	1342	330	332	332	336
0235+164	6195	6188	6184	6194	868	870	866	860
0355+508	2279	2267	2274	2277	061	066	065	063
0552+398	3733	3724	3731	3733	913	928	920	916
0851+202	2295	2289	2295	2298	592	608	600	590
0923+392	2940	2933	2940	2944	827	838	834	825
1404+286	6286	6281	6286	6284	525	530	524	515
1641+399	6409	6404	6407	6401	991	994	992	986
1642+690	1437	1430	1431	1424	433	434	432	427
2134+004	2264	2260	2265	2259	006	998	991	002
2200+004	3889	3880	3886	3880	326	325	326	328
2251+158	5339	5333	5338	5334	172	169	167	171
1226+023	2460	2460	2460	2460	456	484	472	467

4. Comparison of different catalogues

Recently, several radio source catalogues have been published, namely :

4.1 JPL Catalogue (VLBI) (2)

Stations : DSN stations in Goldstone, Madrid and Australia.
Operation frequencies : 13.1 and 3.6 cm.
Time of observation : 1971 - 1978.
Reference system and nutation terms : Barycenter of Solar system, Woolard nutation.

4.2 NRL Catalogue (VLBI, fringe rate) (3)

Stations : OVRO, Maryland Point (April of 1976).
OVRO, Maryland Point, Green Bank, Haystack (September of 1976)
Time of observation : 48 hours for each period.
Operational frequancy : 18 cm.
Reference system and nutation terms : Heliocentric, Woolard terms.

4.3 York Catalogue (VLBI) (4)

Stations : Agonquin, Chilboton, OVRO.
Time of observation : May of 1977, January of 1978, 3 days for each period.
Operational frequency : 10 Ghz.
Reference system and nutation terms : Heliocentric, Woolard terms.

4.4 Catalogue used in Green Bank 35 km CERI (5)

Operational frequencies : 2695 Mhz.
Reference system and nutation terms : Heliocentric, Woolard terms.

4.5 Johnston's Catalogue

Given in Astronomical Almanac 1981.
Reference system and nutation terms : Heliocentric, Woolard terms.

For the sake of comparison, we reduced all the catalogues to the heliocentric system and Woolard nutation terms, and chose the JPL Catalogue as reference to get more sources in common, and forced all the catalogues to coincide in right ascension for 3C273B. Results are shown in Table 5.

From Table 5, we can see that all these catalogues agree very well, especially for the JPL, 3A* and York Catalogue, even though the 3A* and York Catalogue are based upon very short observations of only 14 days and 6 days respectively. As for the NRL Catalogue, the mode of observation, i.e. fringe rate, is proved to be subject to larger error, especially for equatorial and low latitude sources, such as CTA26, 3C273B, 1555+001 and 2134+004, but the positions of middle and high latitude sources still agree closely enough to the catalogues.

The Green Bank 35 km CERI Catalogue and the Johnston Catalogue also coincide very well with the JPL, although the ways of observation are quite different.

According to the investigations on the sources structure conducted by the Caltech VLBI Group and elsewhere for 3C84, 3C120, 3C273B, 3C279, 3C345 and 3C371 etc. they found that some of these sources have extended fine structures with scale around 10 mas. Some of them showed variations in flux density and brightness distribution for different epochs. Although many of the $\Delta\alpha$, $\Delta\delta$ listed in Table 5 are larger than 10 mas, yet some of them are small enough. Studies on sources structures and determination of source positions would help. Some of the positions of radio sources given by different catalogues may not be referred to the same component, such as the case of CTA26, whose component observed by JPL might not be the same as the other catalogues.

In conclusion, we are happy to see that, at present, for radio

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Table 5. Catalogue Minus JPL (1950.0)

Source Name		Flux	Δ_α ($0\overset{s}{.}001$)					Δ_δ ($0\overset{''}{.}001$)				
IAU	Alternate	(5HGz)	3A*	York	NRL	GB	Alm	3A*	York	NRL	GB	Alm
0106+013		3.7	-3					10				
0224+671		2.0	32		16	-20	-38	22		-10	4	0
0316+413	3C84	50.0			-22		1			- 7		10
0333+321	NRA0140	2.4			0		-5			-48		-16
0336-019	CAT26	2.2			292	2900	254			-1143	42	-38
0355+508	NRA0150	10.2	11	-31		-11	-18	-13	-21		-31	-39
0430+052	3C120	6.0			-86		-11			-424		-24
0552-398	DA193	5.9	1				-2	-6				-21
0742+103		3.6				50	-4				-56	-22
0831+557	4C55.16	5.6					-9					15
0851+203	OJ287	2.9	-7	-11	27	29	3	-12	-34	-69	-24	-45
0923+392	4C39.25	7.4	-9	-11	-3	9	-27	-18	39	-21	-31	0
1226+023	3C273B	33.5	0	0	0	0	0	-33	-33	-1634	-43	43
1253-055	3C279	14.0			959		1			-2602		-2
1502+106	OR103	2.2				-2					-89	
1555+001		2.1			-102					(?)		
1611+343	DA406	2.3					-49					-9
1638+398	NRA0512	0.6			21		18			31		5
1641+399	3C345	7.2	0	2	-7	15	20	21	39	10	-11	33
1730-130	NRA0530	5.2					1					89
1741-038		2.2					13					93
1749+701		2.1				22					-2	
1807+698	3C371	1.9					1					-28
2021+615	OW637						-49					-23
2134+004		10.6	13	22	288		35	5	-18	(?)		650
2200+420	VR422201	3.0	10		18	32	13	6		-31	-28	-20
2230+114	CTA102	4.0			-225		54			-161		-52
2251+158	3C454.3	9.0	3		-99	7	19	13		-204	-69	-44

source catalogues, determined independently and even entirely different in the mode of observation, close agreements have been obtained for individual positions. We are more confident of the goal of an uniform, consistent, high precision, zero-proper motion radio source catalogue to provide the fundamental needs of astronomy, geodesy and geodynamics.

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DISCUSSION

Yatskiv : When comparing the catalogues, have you applied the corrections due to differences in observational frequencies ?

Ye : It is impossible because we have no approach to do that.

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