RELATING THE JPL VLBI REFERENCE FRAME AND THE PLANETARY EPHEMERIDES

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ABSTRACT. A series of VLBI observations of planet-orbiting spacecraft and angularly nearby quasars has provided an estimate of the relative orientation of the JPL VLBI reference frame and the ephemeris frame of the inner planets. We find the two frames to be coincident in both right ascension and declination to less than 20 milliarcseconds (mas).

I. INTRODUCTION

Contemporary astronomy has led to the development of three principal celestial coordinate systems, each derived from observations of a particluar class of objects:

1. The optical frame (FK4/FK5) is based on positions of galactic stars.

2. The planetary frame is formally defined from the equations of motion of the major celestial bodies in the solar system. It is related to the optical frame most commonly by transit circle observations. The accuracy of this tie is estimated to be 0.05 arc seconds in right ascension and 0.01 arc seconds in declination (Standish, 1986).

3. The radio frame is constructed from observations of extragalactic objects (quasars). This frame has been tied to the optical frame by means of observations of the optical counterparts of 50 quasars. The one-sigma accuracy of the radio-optical tie is about 0.1 arc seconds in right ascension and declination (Fanselow et al., 1981).

One means of tying the radio frame to the planetary frame employs a method devised by I. I. Shapiro: differential VLBI observations are made of planet-orbiting spacecraft and angularly nearby quasars. That effort is the subject of this paper (see also Newhall et al., 1983).

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II. OBSERVATIONS

From 1976 through 1983 a series of VLBI observations was made of the Viking-Mars and Pioneer-Venus orbiters and angularly nearby quasars. Single baselines between antennas of the Deep Space Network were used. During any one observation the two antennas received signals alternately from spacecraft and quasar, with a cycle time of five minutes. Each observation lasted from two to four hours. The data were digitized and recorded at 4 megabits per second (the Mark II VLBI system).

Independent of the VLBI observations themselves, stations of the Deep Space Network received and recorded spacecraft doppler tracking data for a complete spacecraft revolution about the planet. These data were later used to establish a precise spacecraft orbit.

III. DATA REDUCTION

Upon completion of each observation the tapes were cross-correlated on the Caltech VLBI correlator. In the correlation process the digital data streams from each of the antenna tapes were corrected to account for the earth's motion, time-adjusted, and cross-correlated until maximum correlated signal amplitude was reached. The cross-correlation phase was saved for later use as the observable in least-squares estimation. (For a further discussion of the correlation process, see Shapiro et al., 1979.)

After correlation the phases from each source were separately connected (adjusted by integer numbers of cycles) to restore coherence lost by the interruptive nature of these observations. The form of the data used in estimation was the history of the observed phase of each source (spacecraft and quasar) throughout the entire observation.

IV. LEAST-SQUARES ESTIMATION

The final step in the process was the determination of planetary-frame coordinates of the quasar. An estimation program used a detailed model of all physical and geometrical parameters affecting spacecraft and quasar phase observables. The program produced a history of residual phase (observed minus computed) for each source. These residuals were differenced, removing the signatures due to common unmodeled effects. This differenced residual phase was then used to obtain a least-squares estimate of quasar position in the planetary frame.

V. EXPERIMENT PARTICULARS

Between 1980 and 1983 eleven successful spacecraft-quasar

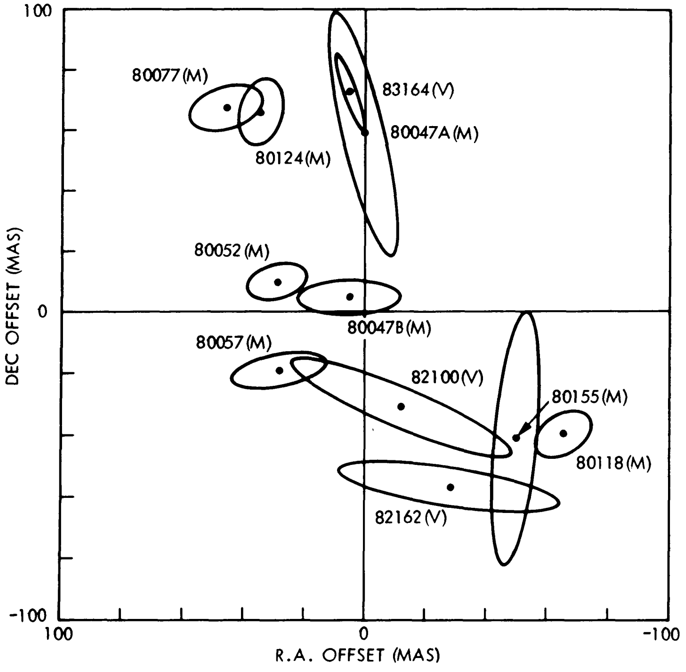

Figure 1. Offsets and standard deviations of quasar ephemeris-frame coordinates from a priori VLBI-frame coordinates.

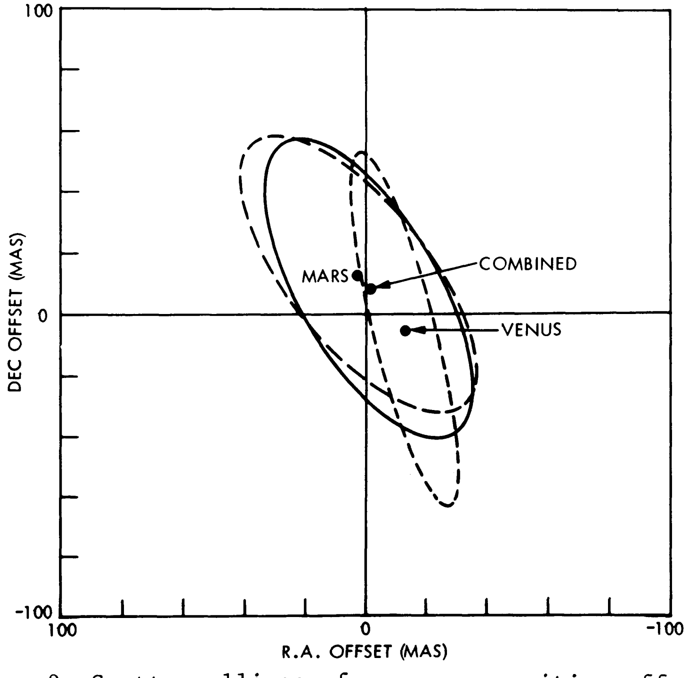

Figure 2. Scatter ellipses for quasar position offsets.

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differential VLBI observations were completed: eight using the Viking-Mars orbiter and three using the Pioneer-Venus orbiter. The details are shown in Table 1.

TABLE 1. COMPLETED DIFFERENTIAL VLBI OBSERVATIONS

Year and Day	Spacecraft	Quasar	Baseline
1980-047A	Viking	3C 245	Calif-Spain
1980-047B	"	"	Calif-Australia
1980-052	"	"	"
1980-057	"	"	"
1980-077	"	GC 1004+14	"
1980-118	"	"	"
1980-124	"	"	"
1980-155	"	OL 064.5	"
1982-100	Pioneer	OY-172.6	"
1982-162	"	GC 0235+16	"
1983-164	"	OJ 287	"

The observations were made at S-band (2293 MHz) and X-band (8408 Mhz), permitting dual-frequency media calibration.

VI. RESULTS

For each of the observations listed in Table 1, the a priori quasar radio-frame coordinates were subtracted from the corresponding estimated values in the planetary frame. Figure 1 is a plot of the resulting offsets for all eleven observations. The dot denotes the value of the offset derived from the indicated observation; the surrounding ellipse is the formal standard deviation error. The initial letter of the planet involved in each observation is in parentheses following each experiment label.

Figure 2 shows the rms scatter ellipses for the Mars and Venus offsets separately and for the combined set. The size and orientation of these ellipses is contained in Table 2.

TABLE 2. OFFSET RMS SCATTER ELLIPSES

	Center(mas)		Semi-major	Semi-minor	Orientation
	RA	Dec	Axis (mas)	Axis (mas)	(Degrees)
Mars	3.9	13.4	54.8	21.8	51
Venus	-11.3	-5.0	58.2	10.6	76
Combined	-0.2	8.5	54.8	22.0	59

VII. CONCLUSIONS

The magnitude of the rss scatter in right ascension for both the Mars and Venus observation sets is less than 12 mas, and the sets of observations agree to 15 mas. The calculated right ascension offset between the two frames from all the data is very nearly zero (-0.2 mas). The uncertainty in this offset is estimated to be about 20 mas (obtained from the scatter ellipse dimensions scaled by the square root of the number of observations).

For declination, the magnitude of the rss scatter for both sets of ob-servations is less than 14 mas, and the sets of observations agree to 19 mas. Two quantities -- an inclination and line of nodes -- are needed to specify a declination difference between two coordinate systems. The scatter in the individual offsets precludes a firm determination of these values, but the mean absolute value of the declination difference is less than about 20 mas.

The scatter in the results is primarily due to uncertainties in the spacecraft orbits. The orbits are derived from range rate data and provide only poor determination of their angular orientation about the Earth-planet line of sight.

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Discussion:

KOVALEVSKY: How many years does it take to establish effectively the difference between the two reference frames?
NEWHALL: Three to five years.
ELSMORE: Can you please tell us what your future plans are for connecting these reference planes?

NEWHALL: 1. Short baseline (400 km) observations of Pioneer Venus, 2. Differential VLA observations of Jovian satellites and quasars, 3. Possibly additional AVLBI observations of Pioneer Venus Orbiter and quasars.

THORNBURG: What was the main source of the 0".1 errors found?

FANSELOW: The internal consistency of the VLBI frame is better than 0".01. However, we are comparing the VLBI reference frame with the planetary ephemerides, corrupted by the orbit determination of a spacecraft about the planet. It is this planetary ephemeris and the orbit determination that contributes the major part of scatter in the difference.

WALTER: Why is it not possible to use the side bands of the orbiter's signal to obtain time delay?

NEWHALL: The bandwidth is too small (300 KHz) to give an effective delay measurement, and the telemetry modulation is often not on, leaving the spacecraft with only the main carrier.

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