NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1603

JPL Development Ephemeris Number 96

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

February 29, 1976

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February 29, 1976

Preface

The work described in this report was performed by the Mission Analysis Division of the Jet Propulsion Laboratory.

Acknowledgment

The program for producing ephemerides at JPL has been in existence for many years. Therefore, it is not possible to acknowledge the many people who have contributed to the long succession of improvements. However, the authors wish to express their gratitude to a few people who have been most closely involved.

In the past, Dr. Jay H. Lieske was in charge of the ephemeris group. He has continued to show an interest in the ephemeris effort and has contributed many valuable discussions.

Similarly, Dr. James G. Williams, who is developing the lunar ephemerides, has lent much appreciated advice to our effort. He and W. S. Sinclair provided us with the lunar ephemeris.

At present, Dr. John D. Anderson directs the planetary ephemeris development. His advice and encouragement are greatly appreciated.

We owe our gratitude to those who have generously supplied us with observational data: to Dr. P. K Seidelmann (USNO), Dr. C. Oesterwinter (NWL), and Dr. D. A. O'Handley (JPL) for the optical data; Drs. G. H. Pettengill and I. I. Shapiro (MIT) and Drs. R. M. Goldstein, G. S. Downs, and P. E. Reichley (JPL) for the radar data; Dr. J. F. Jordan (JPL) for the Mariner 9 data; and D. L. Cain, A. Liu, and G. W. Null (JPL) for the Pioneer 10 and 11 data.

Finally, we express our gratitude to Mrs. Eunice L. Lau, who processed the Mariner 9 data for our use.

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Abstract

The fourth issue of JPL Planetary Ephemerides, designated JPL Development Ephemeris No. 96 (DE96), is described. This ephemeris replaces DE69 (Ref. 1), which has become obsolete since its release in 1969.

The improvements in DE96 are many. They include more recent and more accurate observational data, new types of data, better processing of the data, and refined equations of motion which more accurately describe the actual physics of the solar system. The descriptions in this report include these new features as well as the new export version of the ephemeris.

The tapes and requisite software will be distributed through the NASA Computer Software Management and Information Center (COSMIC) at the University of Georgia.

JPL Development Ephemeris Number 96

I. Introduction

The JPL Development Ephemeris 96 described in this report is the fourth official release from the JPL Ephemeris Tape System. It replaces DE69, which was released in 1969 (Ref. 1) and which has since become obsolete.

The JPL Ephemerides are produced by a system of programs referred to as the Solar System Data Processing System (SSDPS). Observational data are collected and compared against a base ephemeris. Partial derivatives are computed and used in a differential least-squares program to improve the values of the initial conditions of the planets at a given epoch, along with other associated parameters. The differential equations of motion, using the new initial conditions, are numerically integrated, thus producing the new ephemeris. Finally, the observational data are compared against the new ephemeris as a check.

This report discusses the main features that were present in the production of DE96. The following sections discuss the observations and how they are processed, the formation of the partial derivatives, the solution and its resultant constants and initial conditions, the numerical integration and equations of motion, the final residuals, and, lastly, the export version of DE96.

II. The Observational Data

There were 44002 observations used in the solution for DE96. These come from five major sources, which are described below. Different weights were assigned to various sets of observations according to the formula, $\sqrt{w} = 1/\sigma_0$, where σ_0 is the a priori standard deviation. From previous experience, we were able to assign values to these which were approximately equal to the post-fit rms residuals.

A. Optical

The optical observations come from the Six- and Nine-Inch Transit Circles of the U. S. Naval Observatory (USNO). They cover the time span, 1911–1971 and have been discussed by Oesterwinter and Cohen (Ref. 2) and by O'Handley et al. (Ref. 1).

All of the optical observations have been reduced to the FK4 Catalogue system using the tables given in the Second Series of the *Publications of the U. S. Naval Observatory*.

The a priori standard deviations in right ascension and declination were 1.″0 sec δ and 1.″0, respectively, for the Sun, Mercury, and Venus and 0.″5 sec δ and 0.″5, respectively, for Mars through Neptune.

The number of observations for each body and the rms post-fit residuals for the optical data are shown in Table 1.

B. Radar

Radar time-delay measurements from Mercury, Venus, and Mars have come from six sources: Arecibo Ionospheric Observatory, Haystack (MIT), Millstone Hill (MIT), Goldstone Deep Space Station (DSS) 13 (JPL), Goldstone DSS 13/DSS 14 Bistatic (JPL), and Goldstone DSS 14 (JPL). The a priori standard deviations assigned to these data varied according to source, planet, and year. The number of radar data points for each planet and their post-fit rms residuals are shown in Table 2.

C. Mariner 9 Range Points

The Mariner 9 Navigation Team combined 804 range points to the Mars Orbiter with positions of the orbiter to the center of mass of Mars in order to produce accurate Earth–Mars ranges from November 1971 to October 1972. These data, shown in Table 3, exist in four sets according to their proximity to the Martian solar conjunction (JD 2441568), when the 2200-MHz ranging signal passed within 4 solar radii of the Sun at the heliographic latitude of +79°. The uncertainties in the propagation of the signal through the corona are reflected by the post-fit rms residuals. The modeling of the corona is discussed in Section IIID.

D. Pioneer 10 and 11

The Pioneer Navigation Teams provided Earth–Jupiter ranges by combining Earth–spacecraft ranges with positions of the spacecraft relative to Jupiter's center of mass at the times of encounter (JD 2442020 and JD 2442385). The a priori standard deviations were 50 μs for each.

E. 1971/1973 Mars Radar Closure

There were 291 "closure points" from the Mars radar data taken during the oppositions of Mars in 1971 and in 1973. These closure points are pairs of days during which the observed points on the surface of Mars are nearly identical with respect to Martian longitude and latitude. Since the same topographical features are observed during each day, the uncertainty introduced by the topography of Mars may be eliminated by subtracting the residuals of one day from those of the other day. The remaining difference is then due only to the ephemeris drift between the two days. These points had a priori standard deviations of about 1 μs.

III. Processing of Observations

In addition to the standard calculations used when comparing the observations against corresponding values predicted by the ephemeris, there were some unique features in DE96, which are described below.

A. Day Corrections

The optical data from the USNO covering the years 1962–1971 have not yet had day corrections applied for the Sun, Mercury, and Venus; i.e., the bodies observed during daylight hours. Consequently, temporary corrections are applied in DE96, the coefficients being determined in the solution itself. The forms of the corrections are

$$\Delta\alpha = A_1 + A_2 \sin\delta + A_3 \cos h_\odot$$

$$\Delta\delta = D_1 + D_2 \sin\delta + D_3 \cos h_\odot$$

where δ is the declination and $h_\odot$ is the hour angle of the Sun (i.e., time of day). The corrections, $\Delta\alpha$ and $\Delta\delta$, are to be added to the *computed* values of α and δ.

B. Corrections to Drift in the Optical Data

In recent years, it has become apparent that the residuals for the inner planets (i.e., those observed by radar) have shown a secular-like drift in right ascension similar to what would be shown by inaccurate precession and equinox drift. As such, the corrections $\Delta\alpha = (\Delta m + \Delta n$

$\sin\alpha\tan\delta)T$ and $\Delta\delta = (\Delta n \cos\alpha)T$, similar to precession formulae (see, e.g., Ref. 12, paragraph 137), and $\Delta\alpha = (E)T$, similar to equinox drift, are combined into

$$\Delta\alpha = (\Delta k + \Delta n \sin\alpha \tan\delta)\, T$$

and

$$\Delta\delta = (\Delta n \cos\alpha)\, T$$

where E is the rate of drift and T is measured in centuries past 1950.0. The coefficients Δk and Δn are determined in the solution; the corrections $\Delta\alpha$ and $\Delta\delta$ are to be *subtracted* from the *observed* values of α and δ. These values are *not* incorporated into the precession parameters; they serve only as modifications to the optical data.

C. Corrections to Limb Biases for Mercury and Venus

Most of the transit observations of Venus and some of Mercury are taken not on the center of light but rather on the illuminated edge. The corrections to center of planet are then applied by the USNO, using values of parameters currently available. To account for corrections to these values, the following formulae are applied:

$$\Delta\alpha = \frac{\pm r_\alpha}{\rho} \text{ and } \Delta\delta = \frac{\pm r_\delta}{\rho}$$

where the corrections r_α and r_δ are determined in the solution, ρ is the Earth–planet distance, and the signs depend on which limb is being observed.

D. Solar Corona Time Delay

Besides the standard relativistic time delay in the radar signals between the Earth and a planet (Ref. 4), there is also a delay caused by the electron density in the solar corona. This has been discussed by Muhleman et al. (Ref. 5). The following formula for corona delay $\Delta\tau$ (μs) was used in processing the radar and Mariner 9 data in DE96:

$$\Delta\tau = \frac{40.3}{cf^2} \int_{P_1}^{P_2} N_e \, ds$$

where c is the speed of light (cm/s), f is the frequency (MHz) of the radio carrier signal, N_e is the electron density (cm^{-3}), and the integration is carried out over the linear distance (cm) from point P_1 to point P_2 in space. The electron density was assumed to have the following form:

$$N_e = \frac{A}{r^6} + \frac{B}{r^{2+\epsilon}}$$

with the solar distance r expressed in units of the solar radius.

The values of the arbitrary constants used for DE69 were

$$A = 1.13 \times 10^8 \text{ cm}^{-3}$$

$$B = 0.5 \times 10^6 \text{ cm}^{-3}$$

$$\epsilon = 0.0$$

These values are consistent with the corona derived from Mariner 6 and 7 data by Muhleman et al. (Ref. 5).

E. Mars Ellipsoidal Model

Occultation measurements of the Martian surface by Mariner 9 have shown that the shape of the surface may be approximated by a triaxial ellipsoid. This determination and its implications for radar ranging have been discussed by Standish (Ref. 6). The radar time delays from Mars have been computed using this model. The whole ellipsoid is scaled according to the mean equatorial radius of the planet, the only associated parameter in the solution for DE96. The shape and orientation of the ellipsoid are unaltered.

The surfaces of Mercury and Venus are approximated by spheres.

IV. Partial Derivatives

The partial derivatives used in the observation equations were obtained, for the most part, from the Set III formulation of Brouwer and Clemence (Ref. 7, p. 241). For a given observation α, say, this calculation invokes the following chain rule:

$$\frac{\partial\alpha(t)}{\partial \mathbf{S}(0)} = \frac{\partial\alpha(t)}{\partial \mathbf{r}(t)} \frac{\partial \mathbf{r}(t)}{\partial \mathbf{S}(0)}$$

where $\mathbf{r}(t)$ is the vector of Cartesian coordinates at time t, and $S(0)$ is the vector of Set III corrections at epoch ($t = 0$). The second factor on the right-hand side is the matrix given by Brouwer and Clemence where osculating elements are typically used. It is rigorously exact for only true Keplerian motion or at epoch. In the actual cases, the accuracy was found to be good enough to support nearly all of the observations. The exceptions are described below:

(1) The heliocentric orbit of Neptune is poorly approximated by Keplerian motion. A dramatic improvement is seen when the motion is with respect to the barycenter of all bodies interior to Neptune. Therefore, in the case of Neptune, the formula above was replaced by

$$\frac{\partial \alpha(t)}{\partial S(0)} = \frac{\partial \alpha(t)}{\partial \mathbf{r}^*(t)} \frac{\partial \mathbf{r}^*(t)}{\partial S^*(0)} \frac{\partial S^*(0)}{\partial S(0)}$$

where the starred quantities are computed with respect to the barycenter interior to Neptune. Here, the second factor is far more accurate than its unstarred counterpart above. The third factor needs to be computed only once. It comes from

$$\frac{\partial S^*(0)}{\partial S(0)} = \frac{\partial S^*(0)}{\partial \mathbf{r}^*(0)} \frac{\partial \mathbf{r}^*(0)}{\partial \mathbf{r}(0)} \left[\frac{\partial S(0)}{\partial \mathbf{r}(0)}\right]^{-1}$$

where one may see that

$$\frac{\partial \mathbf{r}^*(0)}{\partial \mathbf{r}(0)} = I$$

(2) The high precision of the Mariner 9 range data requires exceptionally accurate partials. For these, numerically integrated variational equations including the effect of Jupiter's orbit were used.

(3) The 1971–1973 Mars radar closure analysis also has an inherently high degree of precision. Numerically obtained partials were used here as well.

V. Solution for DE96

There were 64 parameters in the solution for DE96. A full rank solution of an eigenvalue–eigenvector analysis was applied to the osculating elements at epoch JD = 2440400.5. The parameters were

48 orbital elements (Pluto excluded)

4 limb corrections for Mercury and Venus

3 radii for Mercury, Venus, and Mars

1 scale factor (km/AU)

6 transit circle day corrections for the Sun, Mercury, and Venus covering 1962–1971

2 corrections for the drift in the optical data

Tables 4, 5, and 6 give heliocentric 1950.0 equatorial initial conditions for all nine planets plus the Moon for three different epochs. Tables 7 and 8 present values of the other parameters used in DE96.

We have adopted the set of planetary masses which are being recommended to the International Astronomical Union (IAU) by Commission 4, with the exception of the mass of the Earth–Moon barycenter, which has one more digit in DE96.

For the orbit of Pluto, we have used the initial conditions from DE69.

VI. Covariance/Correlation Matrix of DE96

The formal standard deviations and the correlation matrix from the solution for DE96 are given in Table 9. The units are arc seconds for all parameters except for the astronomical unit and the three radii, which are in kilometers.

The following list provides identification of the computerized version of the parameter names:

DMW*i*	$\Delta \ell + \Delta r$	Brouwer and Clemence Set III elements for *i*th planet.
DP*i*	Δp	
DQ*i*	Δq	
EDW*i*	$e\Delta r$	
DA*i*	$\Delta a/a$	
DE*i*	Δe	
AU		Scale factor (km/AU)
RRA*i*	r_α	Limb corrections for *i*th planet
RDE*i*	r_δ	
ADAY1	A_1	Day corrections
•	•	
•	•	
•	•	
DDAY3	D_3	

DELK	Δk	Optical data drift corrections
DELN	Δn	
RAD*i*	R_i	Radius of *i*th planet

It must be emphasized that Table 9 gives formal values obtained directly from the solution. It is well known that the use of such formal covariances often leads to overly optimistic predictions of accuracy.

VII. Numerical Integration of the Planets

The dynamic evolution of the solar system was obtained by numerically integrating the equations of motion over the entire twentieth century. The gravity model used is the isotropic, Parameterized Post-Newtonian (PPN) *n*-body metric (Ref. 8) and the Newtonian gravity perturbations of the asteroids Ceres, Pallas, and Vesta regarded as following heliocentric Keplerian ellipses. The celestial bodies being integrated are the Sun and the nine planets. The geocentric lunar ephemeris LE-44 was obtained by an independent integration and was treated as input by the planetary program.

The *n*-body equations of motion were derived from the variation of a time-independent Lagrangian action integral formulated in a nonrotating solar-system barycentric Cartesian coordinate frame. For each celestial body, the *n*-body equations of motion are, to order $1/c^2$,

$$
\begin{aligned}
\ddot{\mathbf{r}}_i = \sum_{j \neq i} \frac{\mu_j (\mathbf{r}_j - \mathbf{r}_i)}{r_{ij}^3} \Bigg\{ 1 &- \frac{2(\beta + \gamma)}{c^2} \sum_{k \neq i} \frac{\mu_k}{r_{ik}} \\
&- \frac{2\beta - 1}{c^2} \sum_{k \neq j} \frac{\mu_k}{r_{jk}} + \gamma \left(\frac{v_i}{c} \right)^2 + (1 + \gamma) \left(\frac{v_j}{c} \right)^2 \\
&- \frac{2(1 + \gamma)}{c^2} \dot{\mathbf{r}}_i \cdot \dot{\mathbf{r}}_j - \frac{3}{2c^2} \left[\frac{(\mathbf{r}_i - \mathbf{r}_j) \cdot \dot{\mathbf{r}}_j}{r_{ij}} \right]^2 \\
&+ \frac{1}{2c^2} (\mathbf{r}_j - \mathbf{r}_i) \cdot \ddot{\mathbf{r}}_j \Bigg\} + \frac{1}{c_2} \sum_{j \neq i} \frac{\mu_j}{r_{ij}^3} \{ [\mathbf{r}_i - \mathbf{r}_j] \\
&\cdot [(2 + 2\gamma)\dot{\mathbf{r}}_i - (1 + 2\gamma)\dot{\mathbf{r}}_j] \} (\dot{\mathbf{r}}_i - \dot{\mathbf{r}}_j) \\
&+ \frac{3 + 4\gamma}{2c_2} \sum_{j \neq i} \frac{\mu_j \ddot{\mathbf{r}}_j}{r_{ij}} + \sum_m \frac{\mu_m (\mathbf{r}_m - \mathbf{r}_i)}{r_{im}^3} \\
&+ \sum_{j \neq i} 3 J_{2j} \mu_j \frac{a_j^2}{r_{ij}^4} \left[\left(\frac{5}{2} \left(\frac{\mathbf{r}_i - \mathbf{r}_j}{r_{ij}} \cdot \mathbf{p}_j \right)^2 \right. \right. \\
&\left. \left. - \frac{1}{2} \right) \frac{(\mathbf{r}_i - \mathbf{r}_j)}{r_{ij}} - \left(\frac{(\mathbf{r}_i - \mathbf{r}_j)}{r_{ij}} \cdot \mathbf{p}_j \right) \mathbf{p}_j \right] \qquad (1)
\end{aligned}
$$

where

$\mathbf{r}_i$, $\dot{\mathbf{r}}_i$, and $\ddot{\mathbf{r}}_i$ are the barycentric position, velocity, and acceleration vectors of body *i*

$\mu_j = Gm_j$, where G is the gravitational constant and m_j is the mass of body *j*

$r_{ij} = |\mathbf{r}_j - \mathbf{r}_i|$

β is the PPN parameter measuring the nonlinearity in superposition of gravity

γ is the PPN parameter measuring space curvature produced by unit rest mass (In this integration, as in general relativity, $\beta = \gamma = 1$.)

$v_i = |\dot{\mathbf{r}}_i|$

c is the velocity of light

J_{2j} is the second zonal harmonic coefficient of body *j*;

a_j is the equatorial radius of body *j*

$\mathbf{p}_j$ is the unit vector in the direction of the north celestial pole of body *j*

The index m in the next-to-last term on the right side of (1) runs over the asteroids. The quantity $\ddot{\mathbf{r}}_j$ appearing in two terms on the right side of (1) includes the Newtonian acceleration of each body *j* due to all other major celestial bodies and the three asteroids:

$$
\ddot{\mathbf{r}}_j = \sum_{k \neq j} \frac{\mu_k (\mathbf{r}_k - \mathbf{r}_j)}{r_{jk}^3}
$$

where *j* runs over the Sun and planets and *k* runs over the Sun, planets, and asteroids. The last term on the right side of (1) represents the contribution of the oblateness effects of each body. For this integration, all harmonic coefficients J_{2j} were set to zero. Normally, the only significant contribution arises from the oblateness of the Sun.

The independent variable of integration is the time coordinate in the n-body metric.

The masses and Keplerian elements of the asteroids are given in Table 10.

The definition of the relativistic barycenter (center of mass) of the solar system is somewhat modified from the usual Newtonian formulation (Ref. 9). From conservation of linear and angular momentum, the location of the barycentric origin is given by

$$\sum_j \mu_j^* \mathbf{r}_j = 0 \tag{2}$$

where

$$\mu_j^* = \mu_j \left\{ 1 + \frac{1}{2c^2} v_j^2 - \frac{1}{2c^2} \sum_{k \neq j} \frac{\mu_k}{r_{jk}} \right\} \tag{3}$$

Only the planets were actually integrated. At each step throughout the integration the relativistic masses μ_j^* were calculated from (3), and the position of the Sun was subsequently determined from (2). Because of substantial uncertainty in their masses, the asteroids were not included in the barycentric calculations.

VIII. Lunar Ephemeris

The construction of LE44 is similar to that of the LURE2 ephemeris, which is to be documented elsewhere.

Because there was no attempt to put the lunar and the planetary ephemerides on the same reference system, there may be rotations in all three axes amounting to no more than 0.1 arc second between the two. The improved masses of DE96 were used and the secular acceleration of the Moon's longitude was adopted, without fitting, to be $\dot{n} = -38''/\text{century}^2$.

IX. Residuals With Respect to DE96

The residuals for the observational data with respect to DE96 are shown in Figs. 1–4. The post-fit standard deviations have been given in Tables 1–3.

The optical residuals, plotted in Figs. 1a–h, appear similar to those given by Oesterwinter and Cohen (Ref. 2), whose ephemeris was formed from the optical data only. This seems to indicate that the other data in DE96 have not introduced any major inconsistencies. We have, however, noticed systematic errors in the optical data, as did Oesterwinter and Cohen. These are discussed in the next section.

The radar residuals are plotted in Figs. 2a–c. The early data have been severely down-weighted. There seem to be trends due to topography in the plots of Mercury and Venus, these having been modeled simply as spherical bodies. For Mars, the residuals are with respect to the ellipsoid referred to in Section III. In all three cases, the standard deviations are about 10 μs, amounting to about 1.5 km. This would increase to about 2.2 km for a spherical model of the Martian surface.

The Mariner 9 residuals are shown in Fig. 3. The poor fit at the Martian solar conjunction is apparent. Here the data are not only noisy but corrupted by large fluctuations in the solar corona. Further analysis of these data is still being performed.

The residuals in range for Pioneer 10 and 11 are -47 and $+67$ μs, respectively.

The residuals of the Mars closure analysis are shown in Fig. 4 by means of a histogram. Of the 291 residuals, 206 were less than 1 μs. The largest residual was 6.5 μs. Most of the 16 residuals greater than 3 μs come from observations where the altitude on the surface of Mars is rapidly increasing with changing latitude. If the two days being compared have significantly different latitudes (up to 1° was allowed), a 6.5 μs residual can arise from only a 1% incline.

X. A Systematic Trend in the Right-Ascension Residuals

The right-ascension residuals of the planets contain a systematic trend which is not evident in Figs. 1a–h because the plots are so compressed in time. Therefore, the right-ascension residuals of Mercury through Neptune are plotted again in Figs. 5a–g, where this time the abscissa corresponds to the heliocentric difference in right ascension between the Earth and the planet; i.e., degrees past opposition (degrees past inferior conjunction for Mercury and Venus).

The cause of this trend is unknown, but it is definitely a universal one—not due to one particular planet, ephemeris, or set of observations. The reasoning for this is as follows:

(1) The trend is obvious in Figs. 5a–d for Mercury through Jupiter.

(2) The trend has been noted in the residuals for the USNO Ephemeris (Ref. 10), in the Dahlgren Ephemeris, where it was actually discussed for Venus by Oesterwinter and Cohen (Ref. 2), and in Laubscher's dissertation for Mars (Ref. 11), as well as in the JPL Ephemerides to date.

(3) The trend is present in the Tokyo and Greenwich transit data as well as the USNO data, these three sources being present in Laubscher's dissertation.

This systematic trend, the "opposition effect" or "phase effect," is presently being investigated.

XI. Export Ephemeris

The DE96 ephemeris, along with all requisite software, has been put on magnetic tape in a format suitable for a wide range of computers.

The new format is more than four times as compact as the previous "Type 50" used for DE69. Furthermore, the interpolation error is below 10 cm for all bodies—an improvement of 10^4 from before.

The range of data is from December 16, 1944, to January 25, 2000.

Copies of the tape, software, and user instructions are available from the NASA Computer Software Management and Information Center (COSMIC) at the University of Georgia.

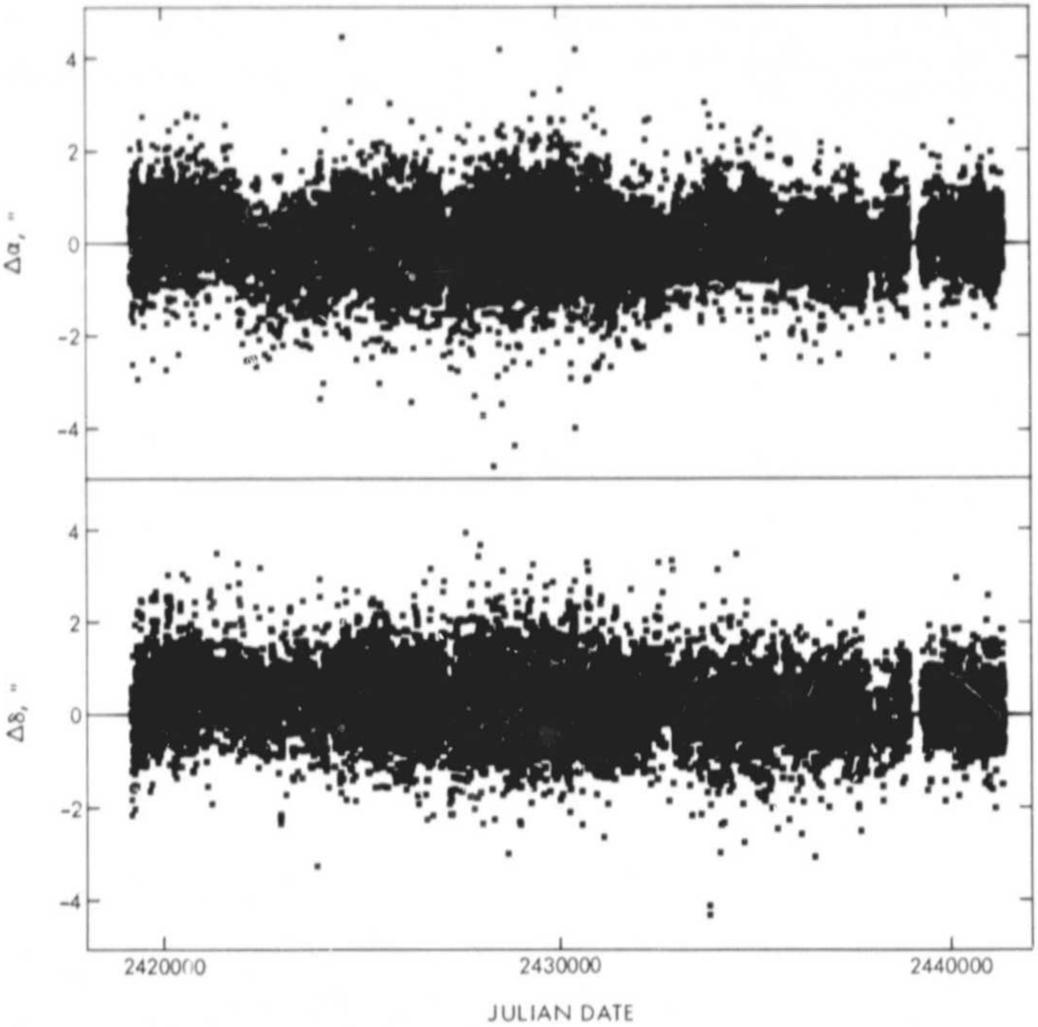

Fig. 1a. Optical residuals for the Sun

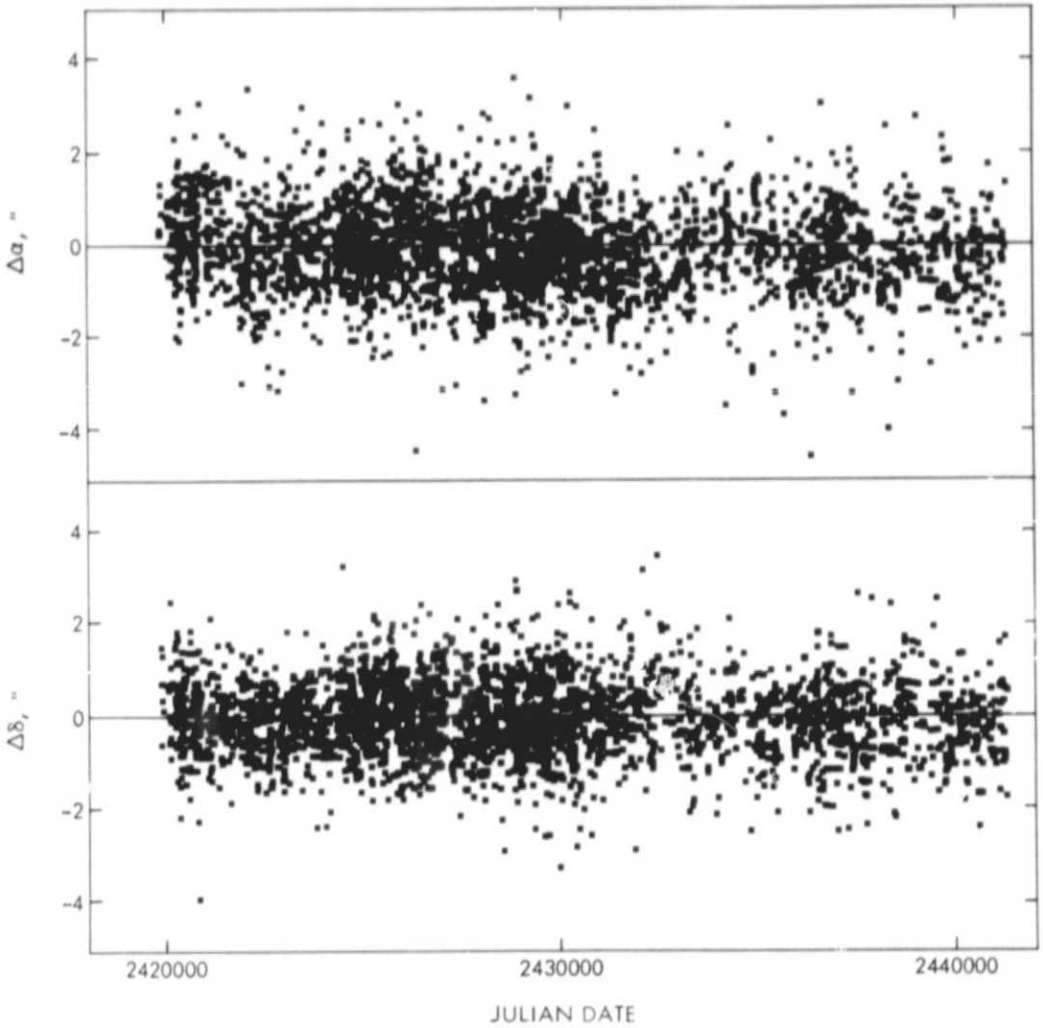

Fig. 1b. Optical residuals for Mercury

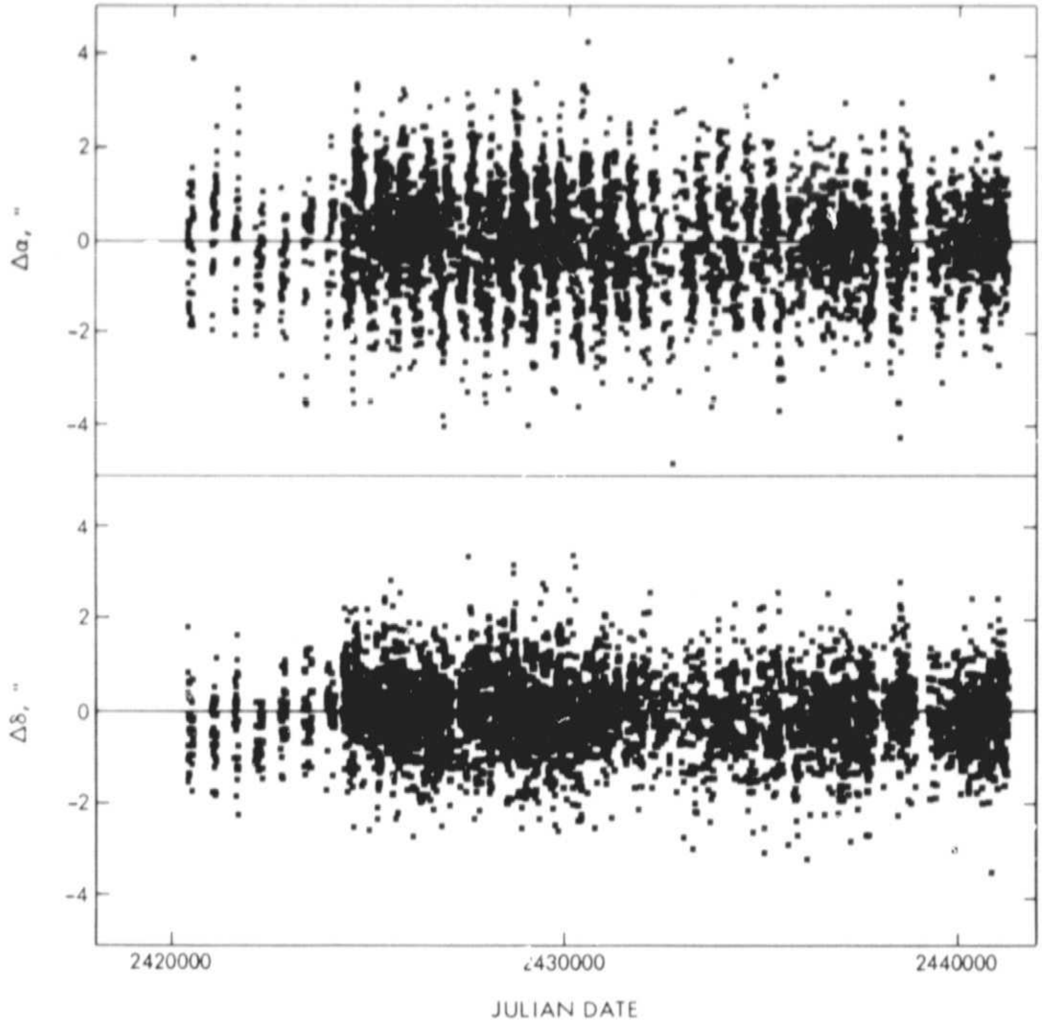

Fig. 1c. Optical residuals for Venus

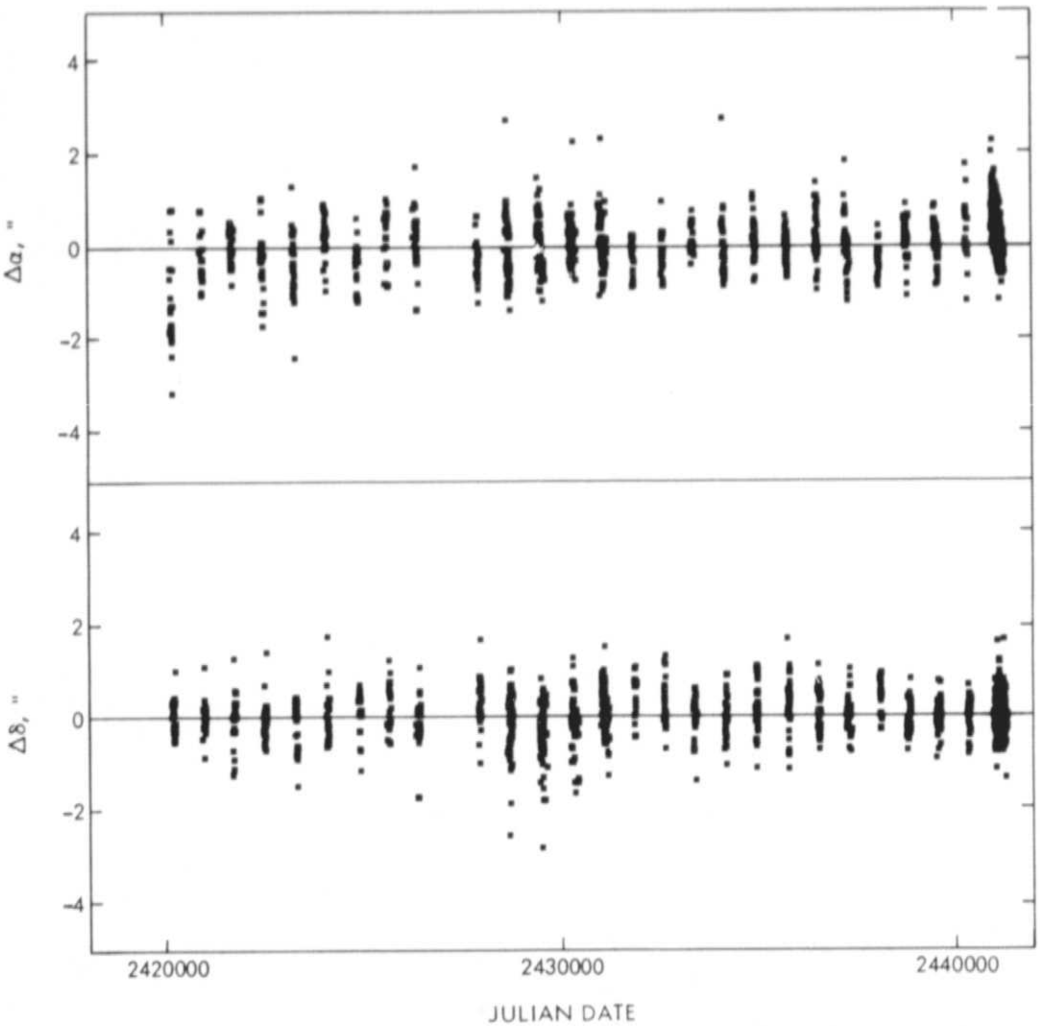

Fig. 1d. Optical residuals for Mars

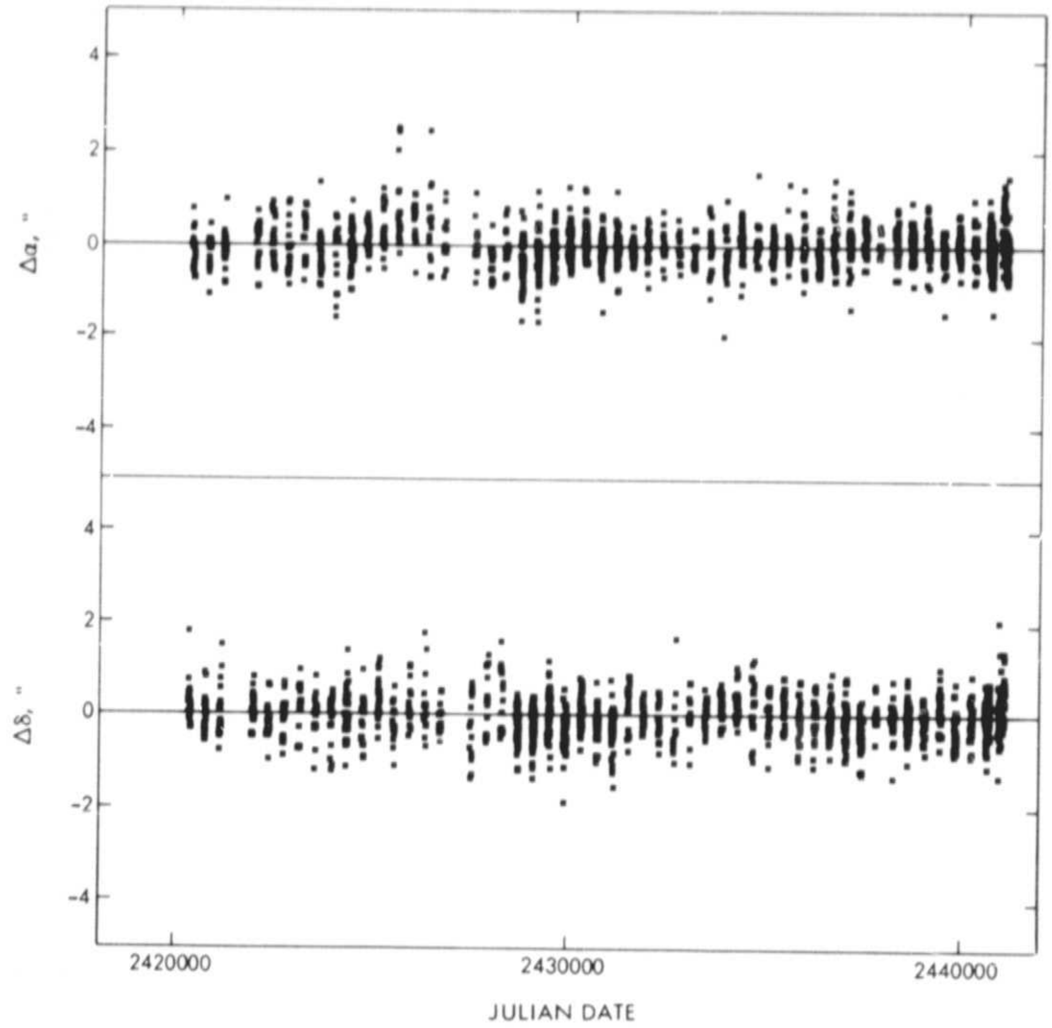

Fig. 1e. Optical residuals for Jupiter

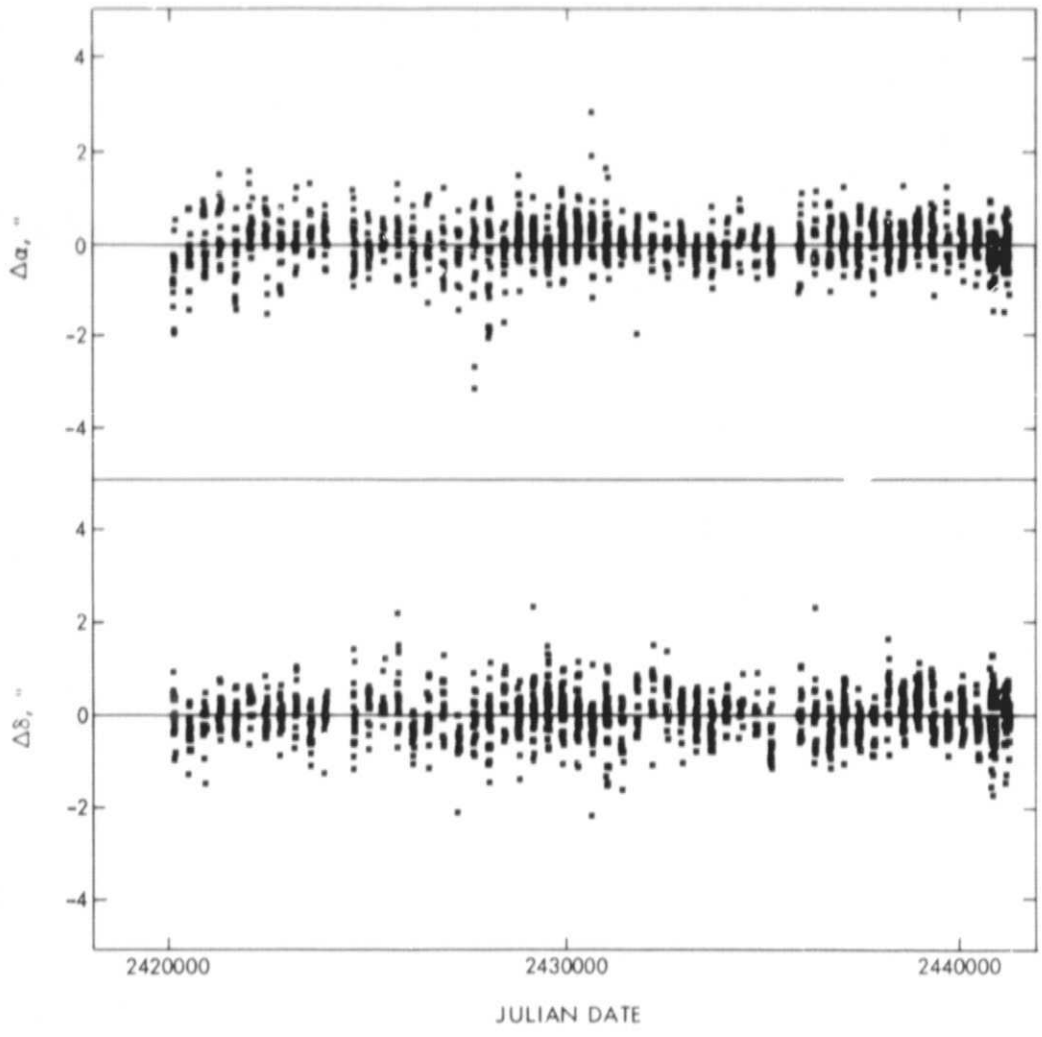

Fig. 1f. Optical residuals for Saturn

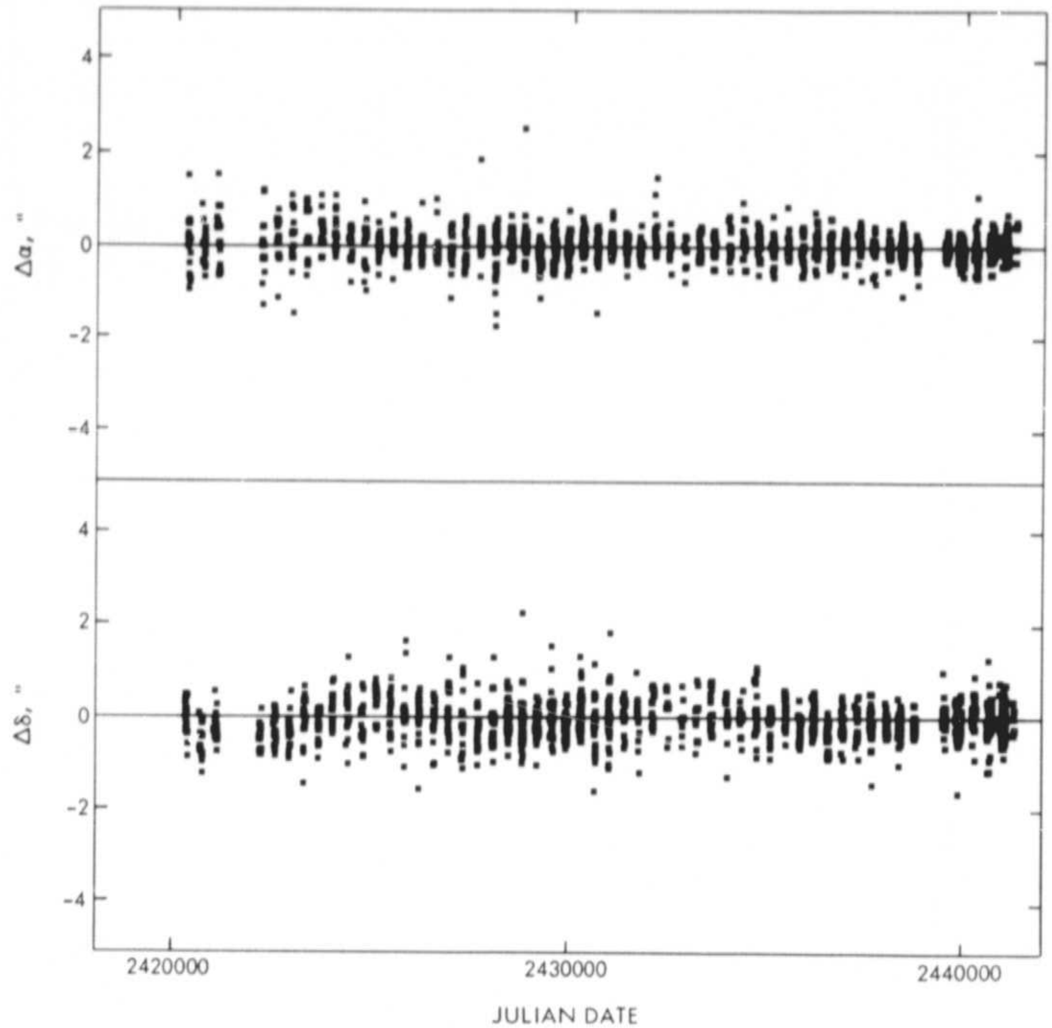

Fig. 1g. Optical residuals for Uranus

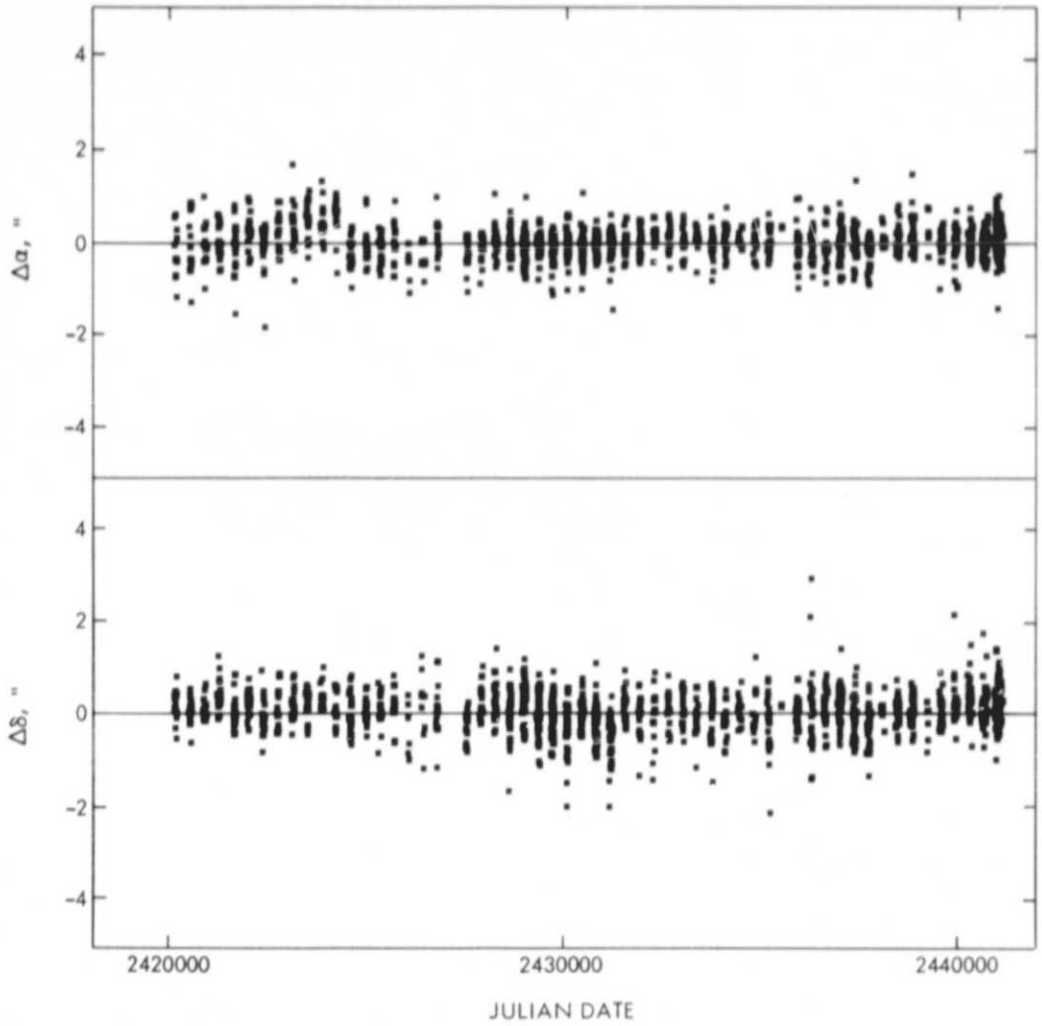

Fig. 1h. Optical residuals for Neptune

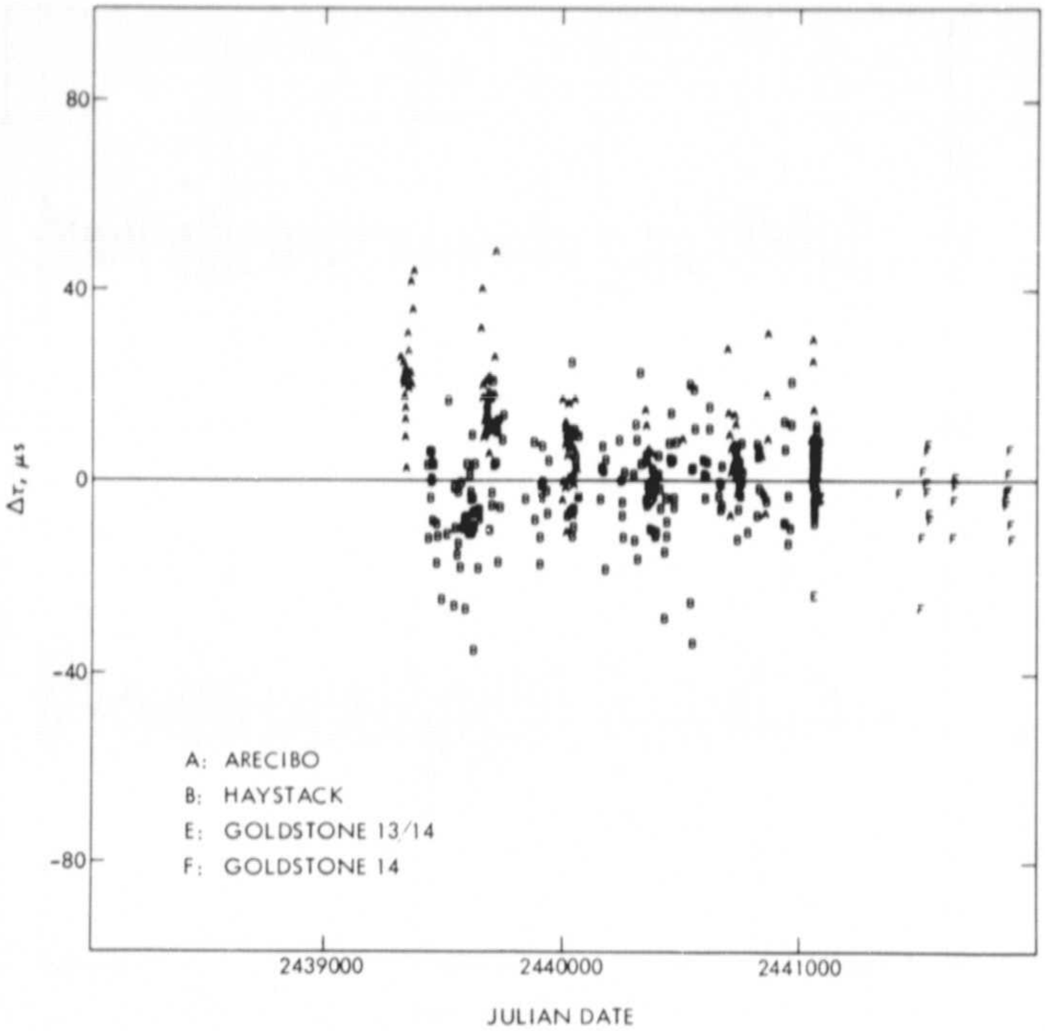

Fig. 2a. Radar residuals for Mercury

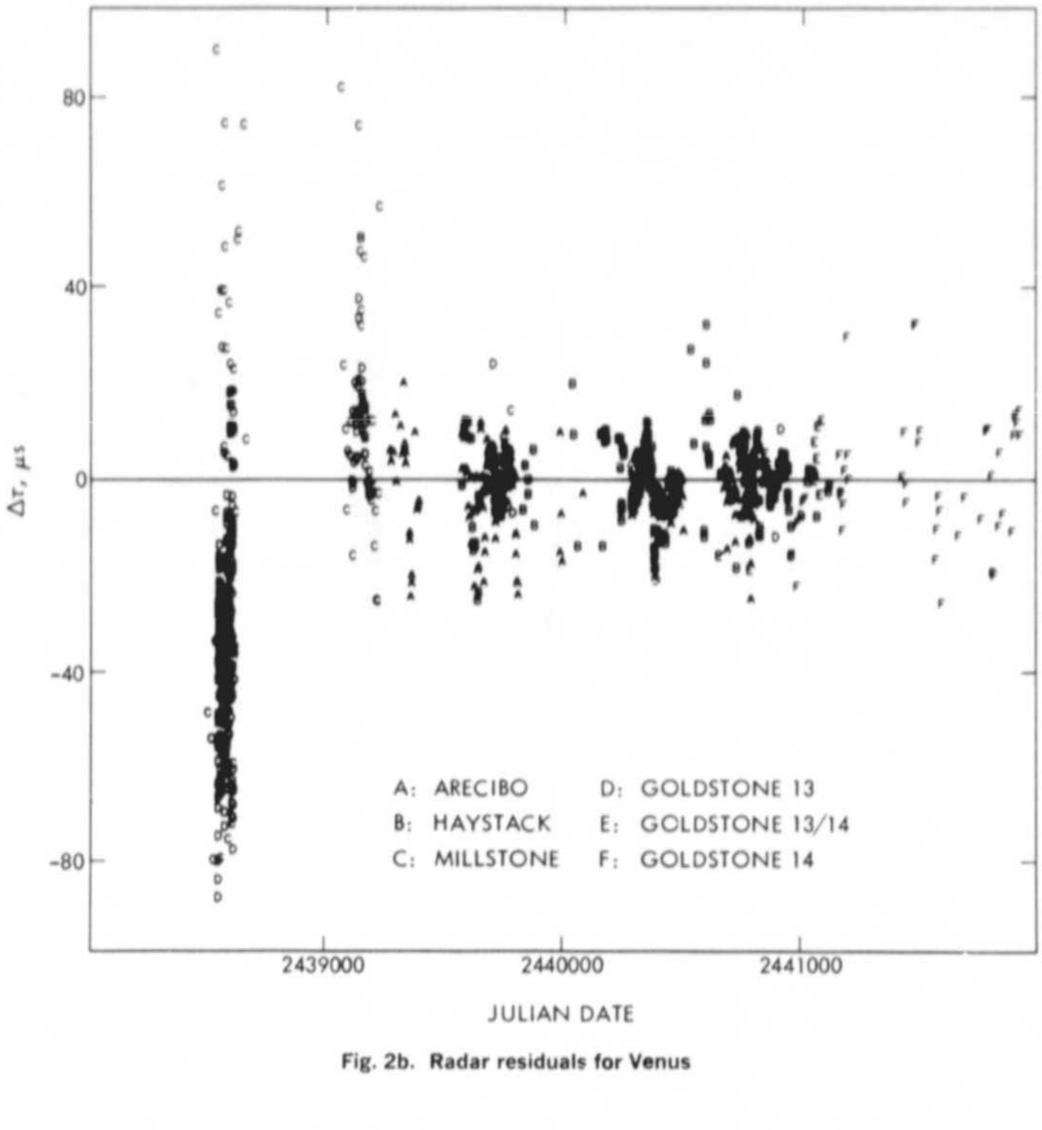

Fig. 2b. Radar residuals for Venus

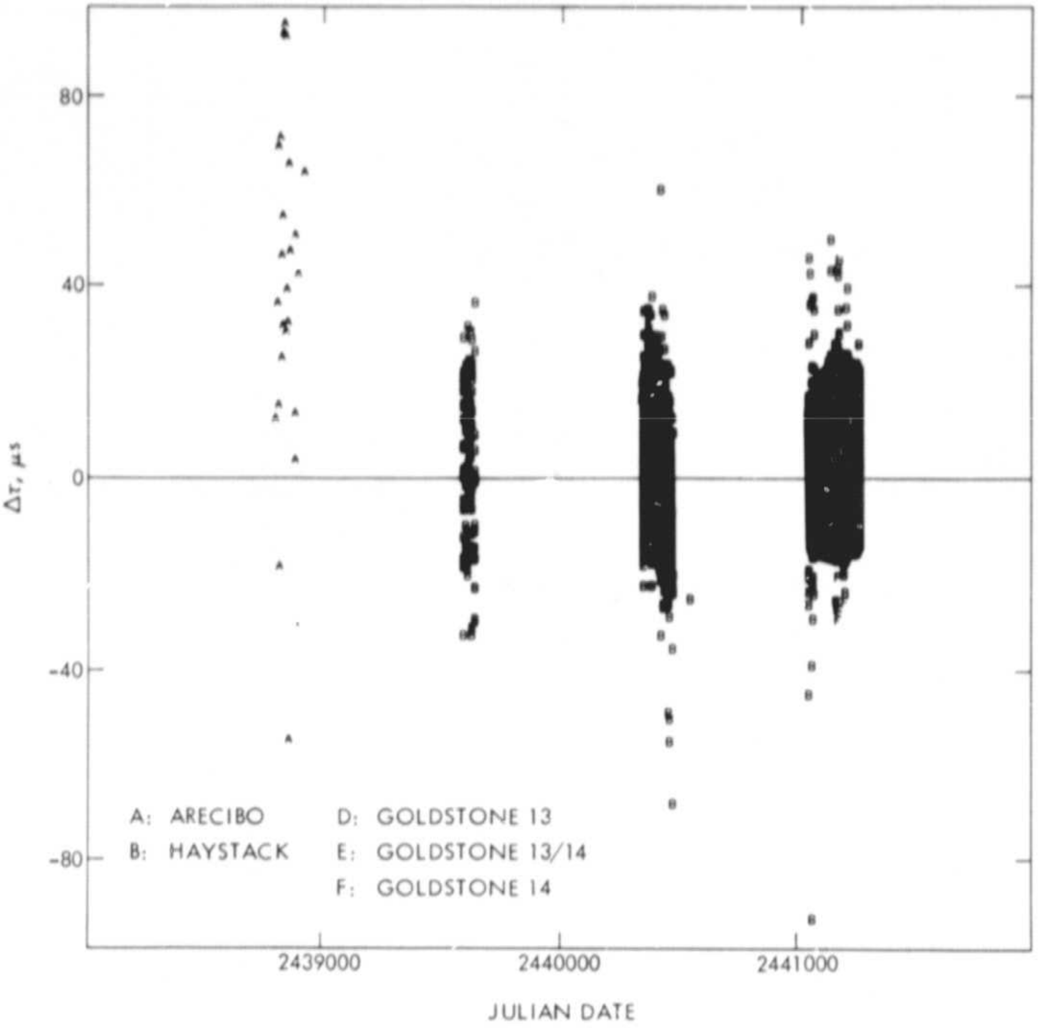

Fig. 2c. Radar residuals for Mars

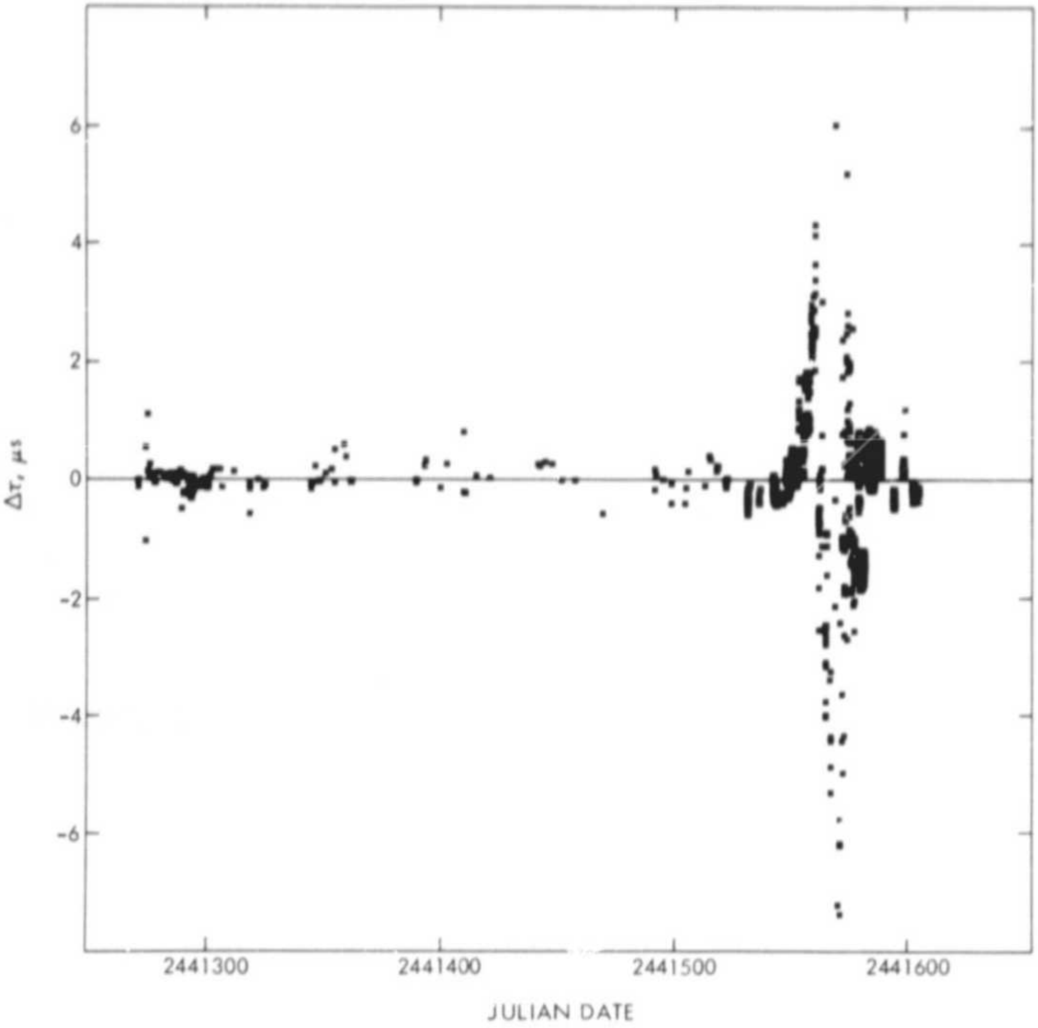

Fig. 3. Mariner 9 range residuals for Mars

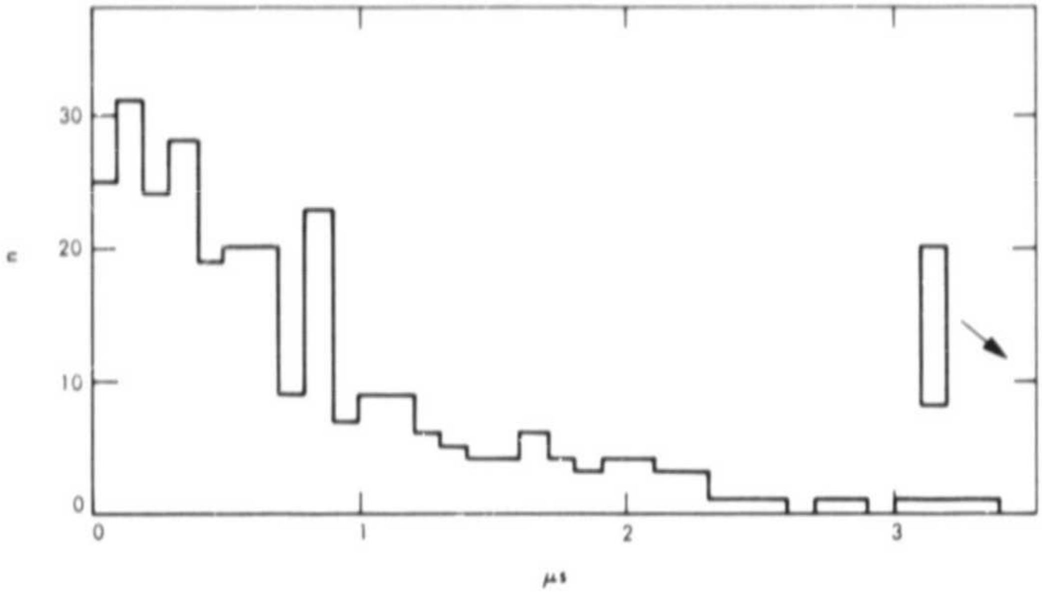

Fig. 4. 1971/1973 M s closure analysis—histogram of residuals

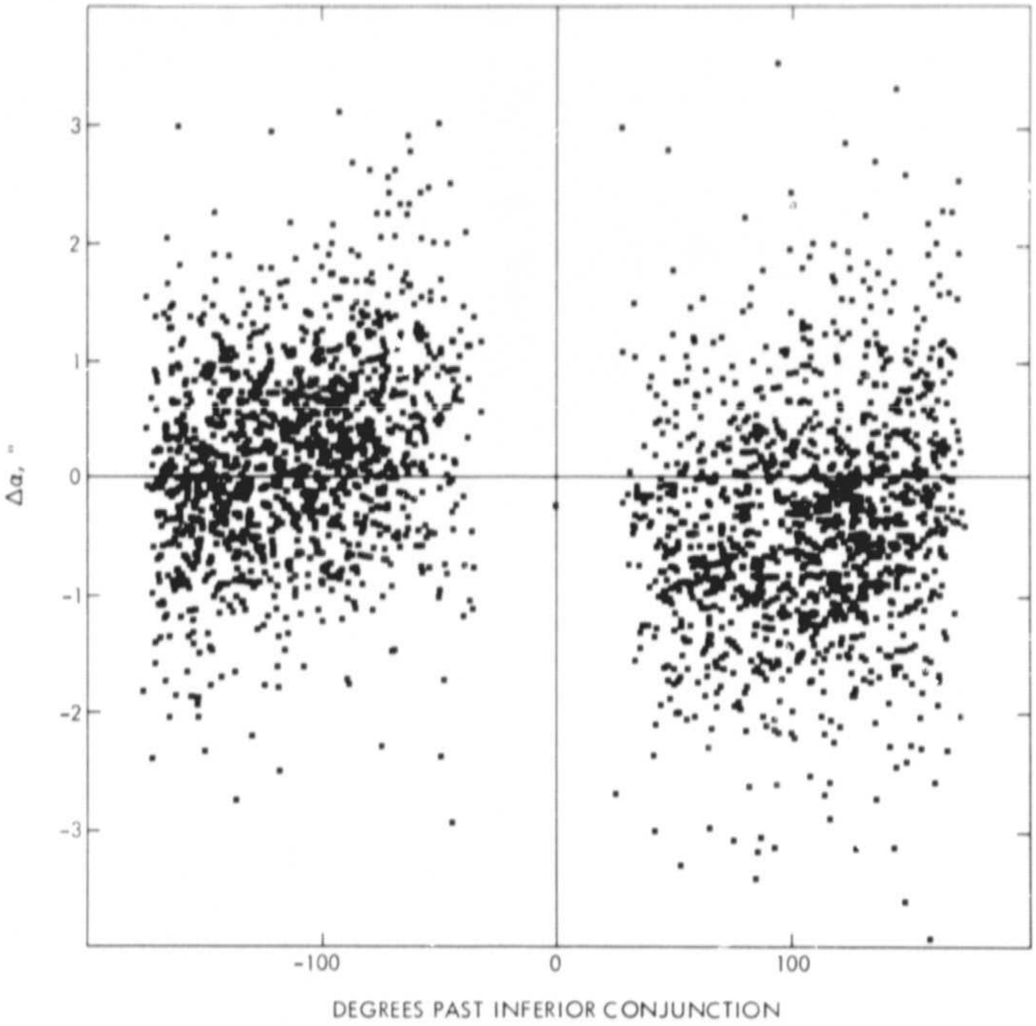

Fig. 5a. Optical residuals illustrating the "opposition effect" for Mercury

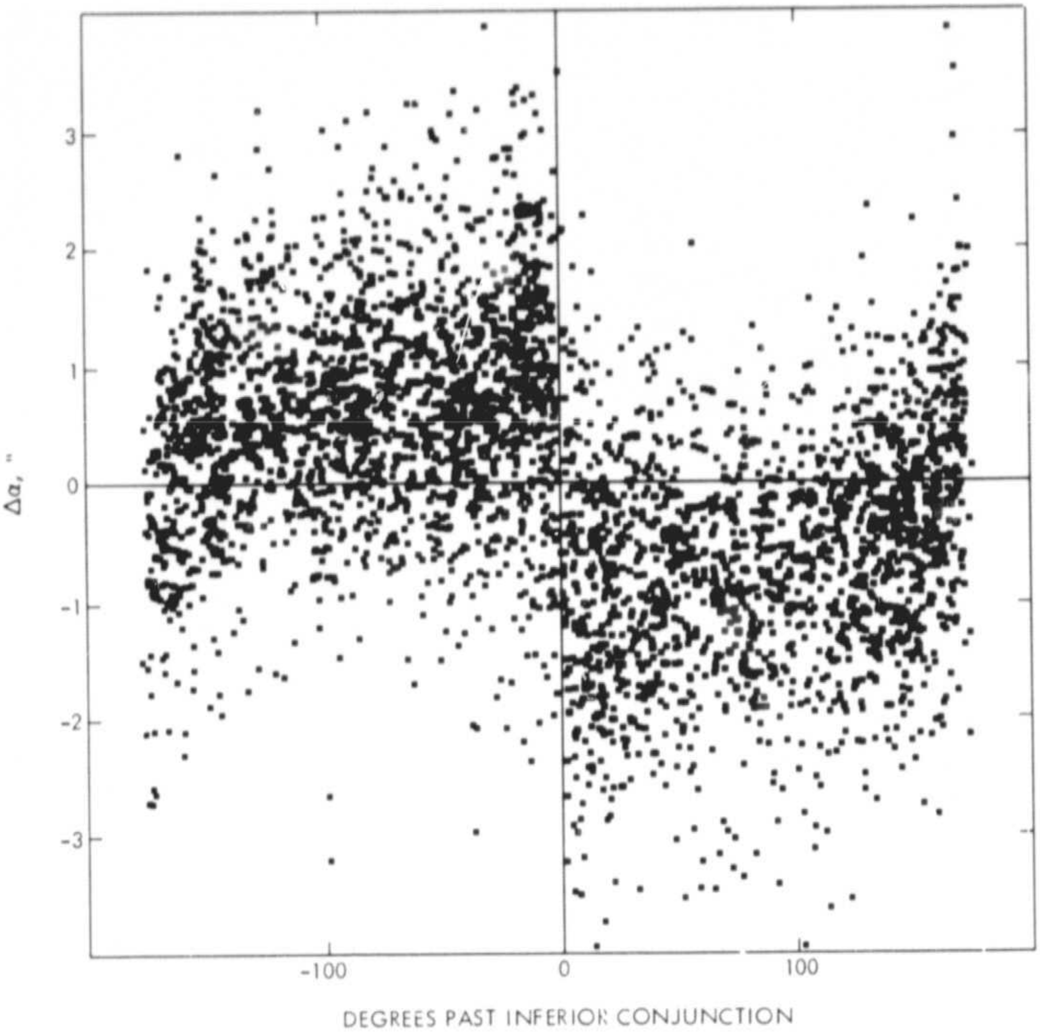

Fig. 5b. Optical residuals illustrating the "opposition effect" for Venus

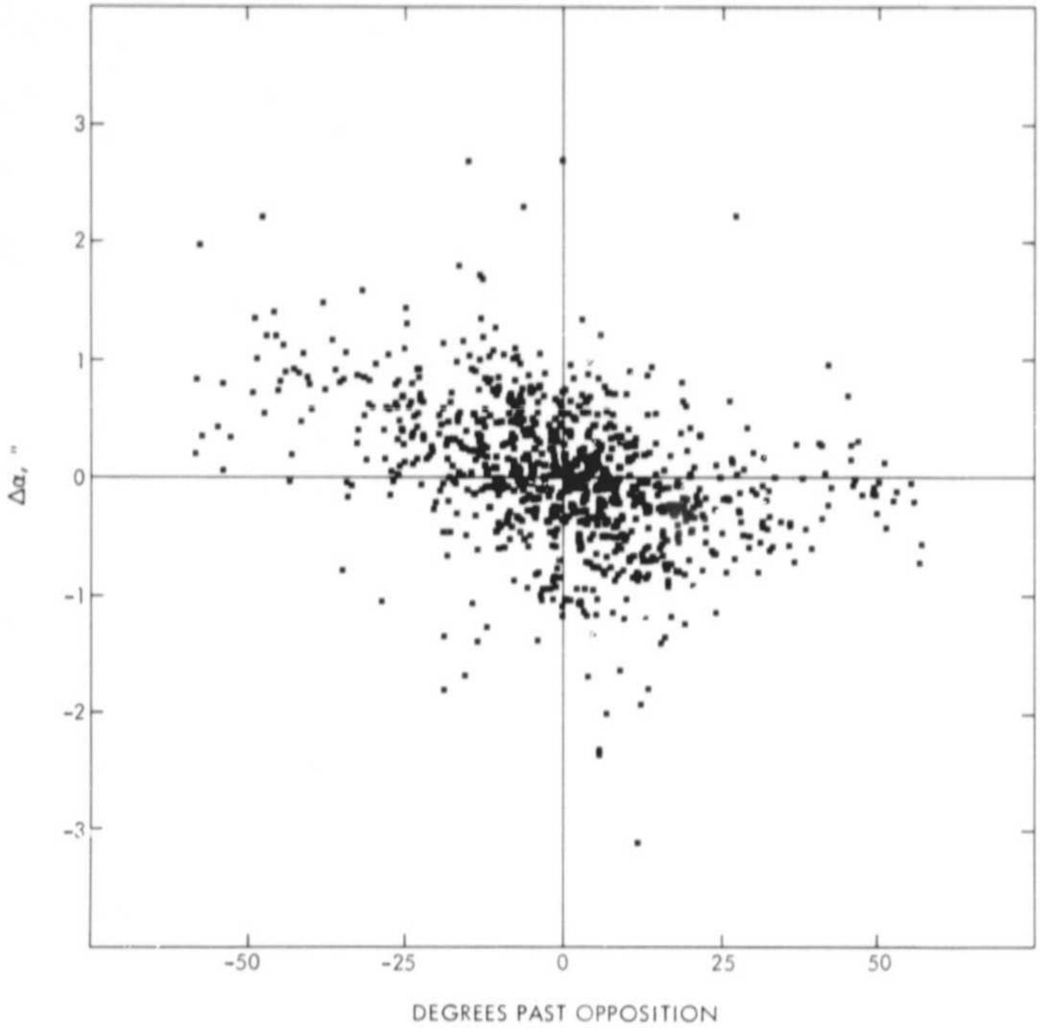

Fig. 5c. Optical residuals illustrating the "opposition effect" for Mars

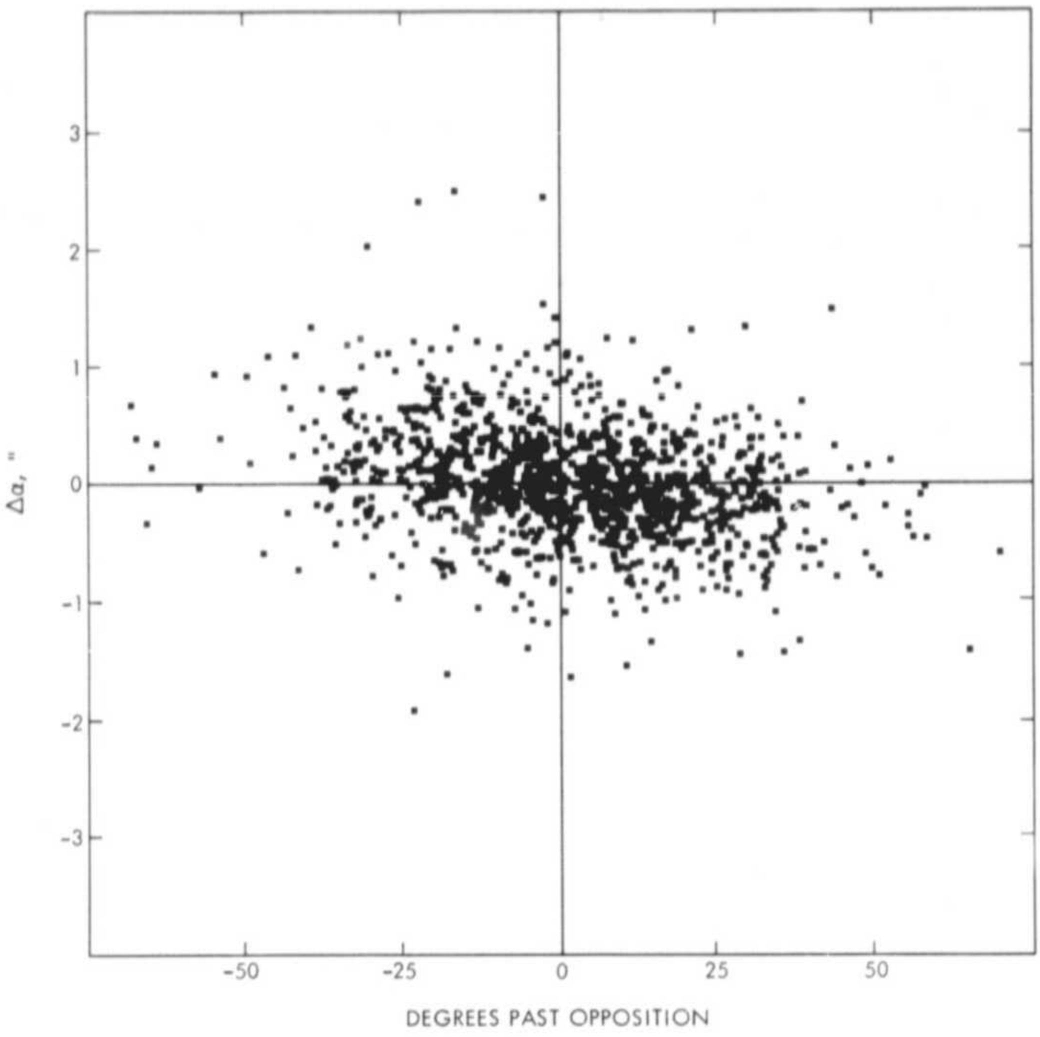

Fig. 5d. Optical residuals illustrating the "opposition effect" for Jupiter

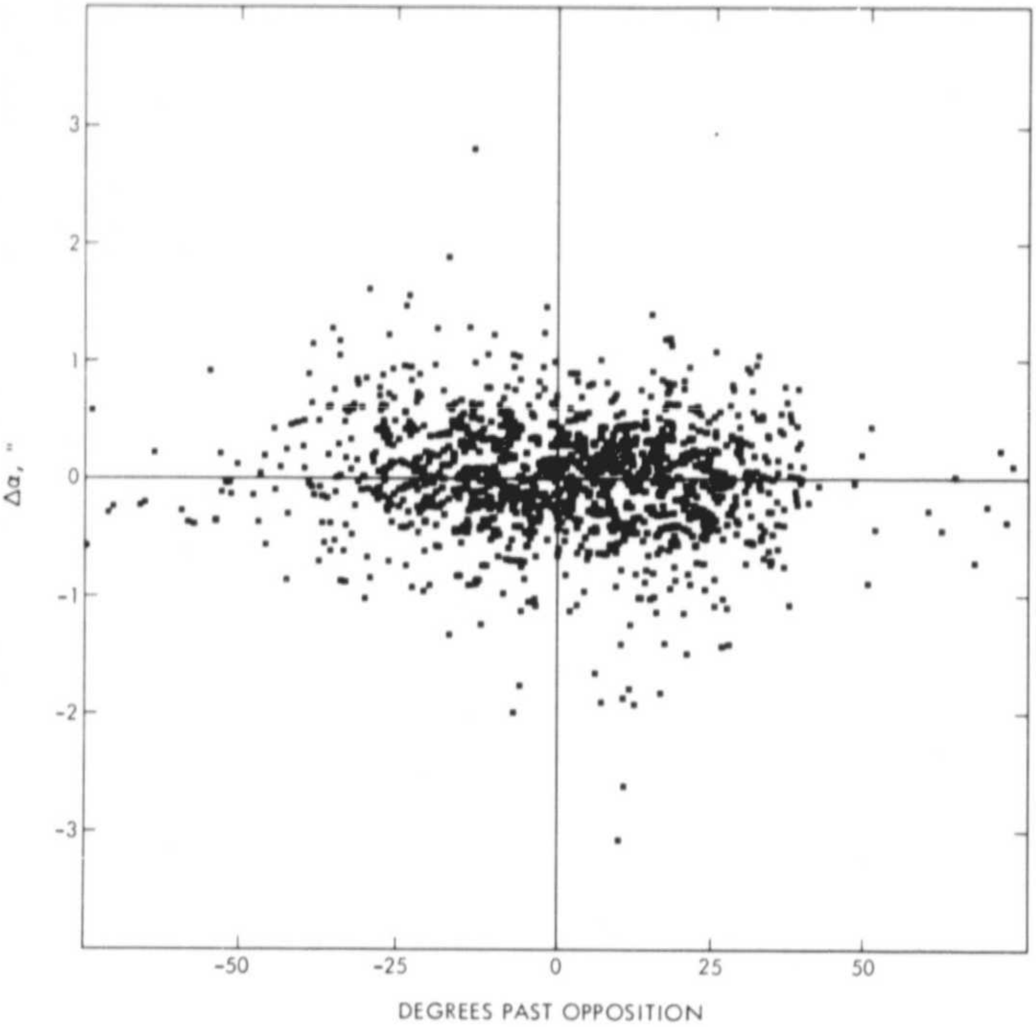

Fig. 5e. Optical residuals illustrating the "opposition effect" for Saturn

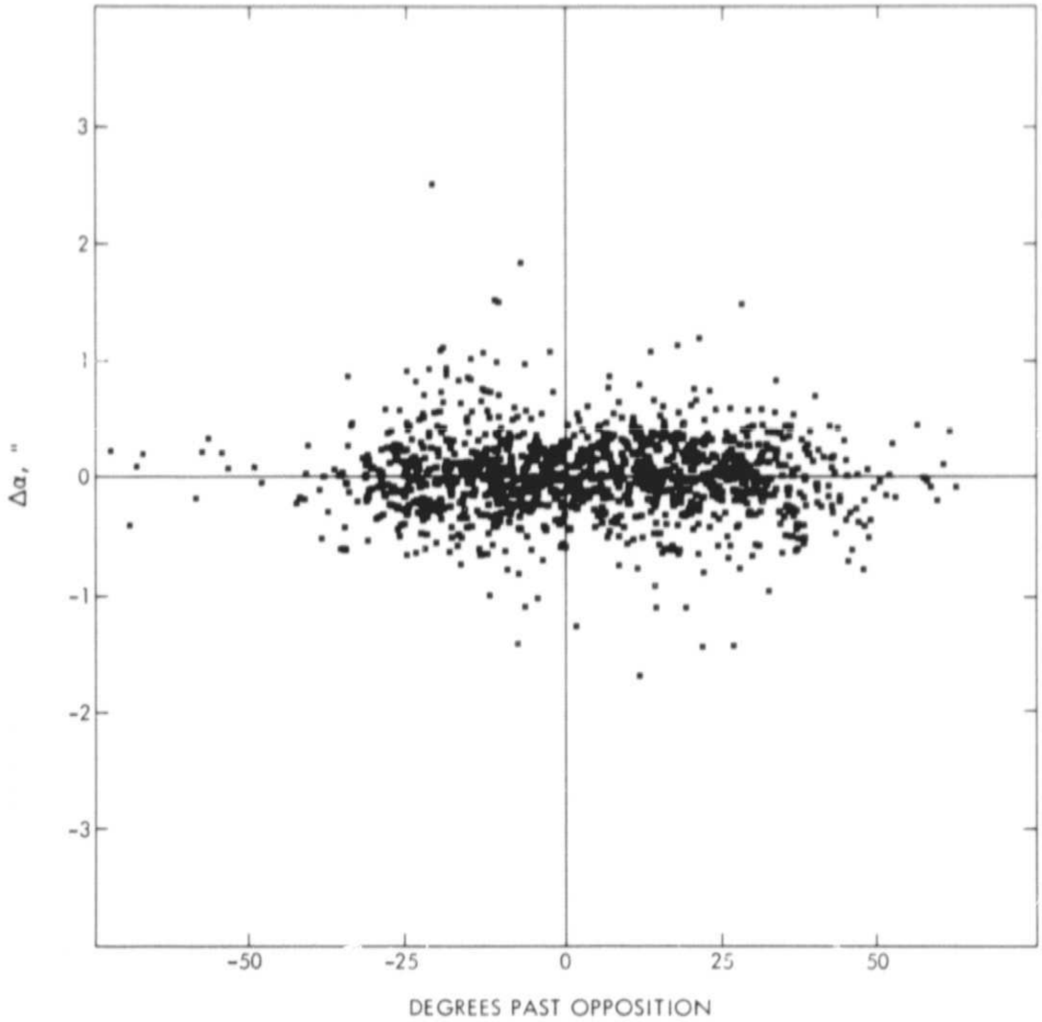

Fig. 5f. Optical residuals illustrating the "opposition effect" for Uranus

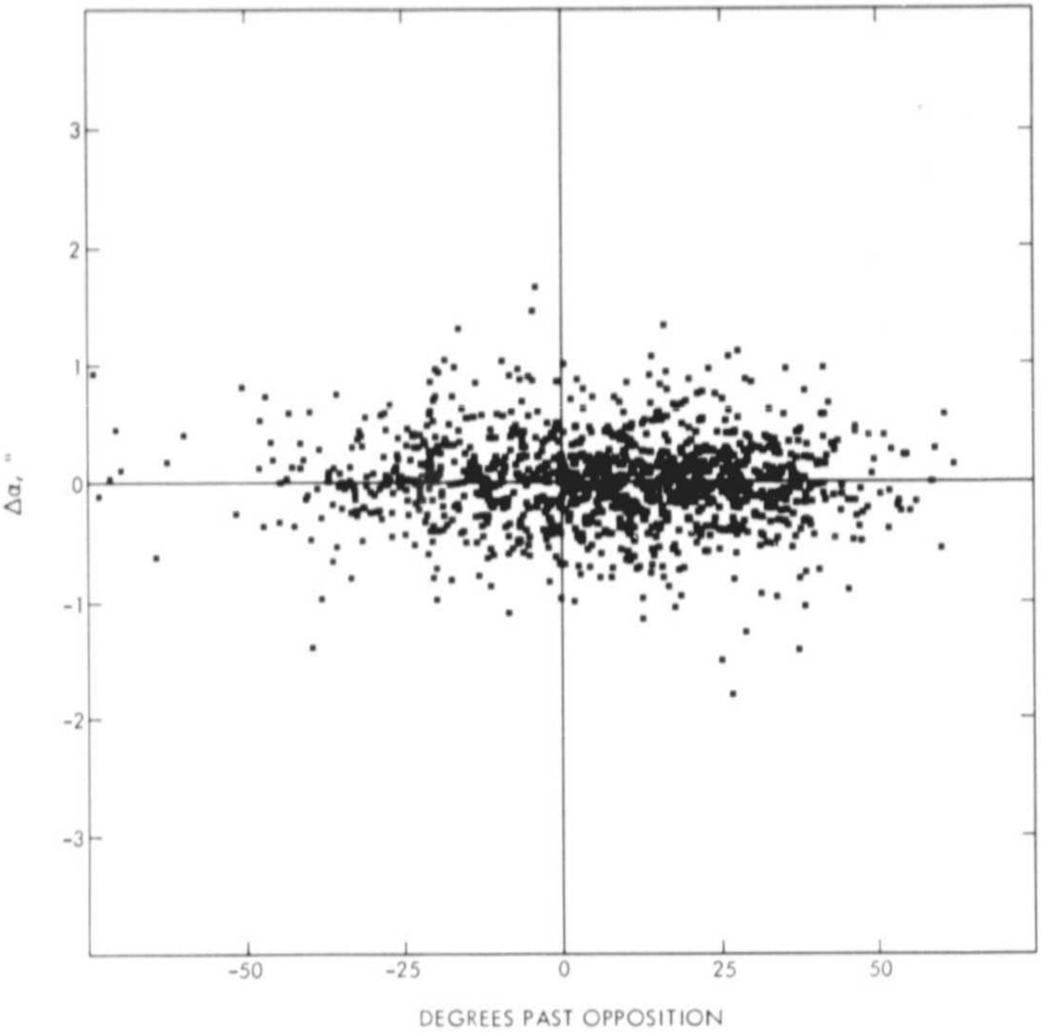

Fig. 5g. Optical residuals illustrating the "opposition effect" for Neptune

Table 1. Optical observations

Planet	N_α	σ_α, "	N_δ	σ_δ, "
Sun	8223	0.81	7930	0.83
Mercury	2412	0.98	2339	0.85
Venus	3566	1.17	3386	0.89
Mars	330	0.63	804	0.55
Jupiter	1068	0.50	1030	0.51
Saturn	1091	0.53	1040	0.54
Uranus	1048	0.37	1034	0.45
Neptune	1037	0.40	1015	0.50

Table 2. Radar observations

Source	Mercury		Venus		Mars	
	N	σ, μs	N	σ, μs	N	σ, μs
Arecibo	106	17.1	248	8.1	30	83.3[a]
Haystack	217	10.0	219	9.2	2745	12.8
Millstone			101	91.8[a]		
Goldstone 13			294	38.2[a]	4	10.0
Goldstone 13/14	9	9.2	14	7.6	300	11.4
Goldstone 14	22	8.6	44	13.4	699	10.7

[a]These data are mostly pre-1967 and are therefore of inferior quality. They were severely down-weighted in the solution for DE96.

Table 3. Mariner 9 range points

N	Julian date	σ, μs
77	2441272 – 2441361	0.25
81	2441389 – 2441540	0.29
487	2441541 – 2441555 2441577 – 2441602	0.78
159	2441556 – 2441575	2.50

Table 4. Initial conditions for DE96 at JED = 2440000.5

	X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$
Mercury	-.39613212152212402	-.07992249271906621	-.00210472644821684	-.00065068177349635	-.02334496959482579	-.01243509127932027
Venus	.51314496534407696	.47569311696366166	.18195103289848097	-.01430395390425983	.01268998424173737	.00662179814461211
E–M barycenter	-.46560528150753017	-.82519996260935337	-.35783545693101644	.01499701589608436	-.00731148534216278	-.00317060837122165
Mars	.37962076027589121	1.35704574564607161	.61271727151903939	-.01300955944175007	.00409016370735938	.00222665371074983
Jupiter	-5.00319484519892979	1.82688075283407510	.90602247007006308	-.00293019707629372	-.00613064736625428	-.00255843388108078
Saturn	8.96742825251964510	2.64555399235593838	.70618378072282999	-.00191923432569552	.00489 48077881151	.00210622175450133
Uranus	-18.27980664272406345	.55129788603856273	.49985225679319031	-.00018608178020526	-.00377332452204415	-.00165064743411798
Neptune	-17.40588807261312355	-23.12846930183423506	-9.03617989688445189	.00254753898492655	-.00163212016561988	-.00073280091550904
Pluto	-30.54206443486996224	.72846598993191850	9.48536191616126237	.00016695687538702	-.00315129249824488	-.00104741357093554
Moon	.00241507021913819	.00109691667563689	.00051657959182900	-.00024037598607113	.00044399757611900	.00024714640572278

Table 5. Initial conditions for DE96 at JED = 2440400.5

	X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$
Mercury	.35579225802852818	-.09553558795038100	-.08771341781617990	.00370878085075952	.02404978478002579	.01292686708342975
Venus	.60335039103368874	-.35590627403346386	-.19848792149401189	.01115692320275806	.01548890175644374	.00627515242044276
E–M barycenter	.10369343609917386	-.92783405459100837	-.40233969418894512	.01683353411416213	.00155502989800035	.00067422930170243
Mars	-.13247798511420306	-1.32698491837590848	-.60555416413326086	.01448220287768023	.00007535316752924	-.00035412072748302
Jupiter	-5.39419589360612898	-.77099130630934636	-.19891034640604549	.00100563213273023	-.00653502483791158	-.00282810724754165
Saturn	7.94825659222305001	4.50716451784081462	1.51995150656620628	-.00315918649938017	.00436628069094962	.00194190840814613
Uranus	-18.28274953224057165	-.95838029508928623	-.16157384510723329	.00017136827054677	-.00376985232669572	-.00165419831467837
Neptune	-16.37169530238563224	-23.76164286400216318	-9.32162501287255551	.00262280859635046	-.00153293150139815	-.00069406324451172
Pluto	-30.45234996429795698	-.53244506611606822	9.05948968049085383	.00028204868379326	-.00315213325233073	-.00108164477606805
Moon	-.00083570230400173	-.00198544033336024	-.00108326741801347	.00059875220638771	-.00017415339206388	-.00008847729948662

Table 6. Initial conditions for DE96 at JED = 2440800.5

	X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$
Mercury	-.34728269561965779	-.25381986218864915	-.10025263498815027	.01164351062650545	-.01796891116169349	-.01081911400871376
Venus	-.272925866304963801	-.61910740902651846	-.26178891568528682	.01860072818427010	-.00659050914891825	-.00414466035444846
E-M barycenter	.63882263318717906	-.72346636913903414	-.31372001668906114	.01308702020817010	.00988058239124062	.00428446489160722
Mars	-1.04327[illegible]45071490276	1.14960956706884462	.55569172568390742	-.01028575666404713	-.00707637525666370	-.00297212078404506
Jupiter	-4.2411[illegible]916644777000	-3.14910678678419728	-1.24730472084339510	.00462631146681421	-.00505962643185183	-.00228365398826359
Saturn	6.45961075831318936	6.10113012489479580	2.24336224732550775	-.00425223434082256	.00355926591661656	.00165556582938204
Uranus	-18.14311868095883828	-2.46053133735052510	-.82172654002059815	.00052619244645336	-.00373578223608604	-.00164431746628520
Neptune	-15.30833404391927475	-24.35427381300139223	-9.59118895464151705	.00269330269679694	-.00142947750428933	-.00065342805740851
Pluto	-30.31628535964815481	-1.79242607536033235	8.62025335983048894	.00039861158425064	-.00314665447539976	-.00111423522166506
Moon	-.00160130304746343	.00195720791406307	.00096848254655875	-.00045840878259171	-.00027869746488587	-.00017069695004873

Table 7. Radii and masses in DE96

Planet	Radius, km	Inverse mass
Sun	696000	1
Mercury	2440.12[a]	6023600
Venus	6052.06[a]	408523.5
E-M barycenter		328900.53
Mars	3397.51[a,b]	3098710
Jupiter	71350	1047.355
Saturn	60400	3498.5
Uranus	23800	22869
Neptune	22300	19314
Pluto	7200	3000000
Earth	6378.156	
Moon	1738	

[a]Result of solution for DE96.

[b]Mean equatorial radius of triaxial ellipsoid.

Table 8. Miscellaneous constants used in DE96

	DENUM	96.
	JDEPOC	2440400.5
	CLIGHT	299792.458
	EMRAT	81.3007
	BETA	1.
	GAMMA	1.
	J2SUN	0.
*	AU	149597871.41056
*	RRA1	.09270
*	RDE1	.04203
*	RRA2	.53056
*	RDE2	.22865
*	ADAY1	.31050
*	ADAY2	.20547
*	ADAY3	-.27266
*	DDAY1	-.53091
*	DDAY2	-1.40953
*	DDAY3	.68113
*	DELK	-1.19073
*	DELN	.14768
*	RAD1	2440.12173
*	RAD2	6052.05827
*	RAD4	3397.51482
	RAD5	71350.
	RAD6	60400.
	RAD7	23800.
	RAD8	22300.
	RAD9	7200.
	RADS	696000.
	RADM	1738.
	RE	6378.156

* THESE PARAMETERS ARE FROM THE SOLUTION FOR DE96

Table 9. Covariance/correlation matrix for DE96

	σ	DMw1	DP1	DQ1	EDw1	DA1	DE1	DMw2	DP2	DQ2	EDw2	DA2	DE2	DMwB	DPB	DQB	EDwB
DMw1	.99672865-002	1.000	.028	.010	.985	-.282	-.004	.995	-.045	-.009	.613	-.388	.090	.989	-.061	-.076	.972
DP1	.12414716-001	.028	1.000	.018	.032	-.060	.023	.093	.525	-.725	.058	-.012	.019	.093	.817	-.385	.093
DQ1	.12185161-001	.010	.018	1.000	-.013	-.080	-.029	.064	.760	.553	.056	-.064	.017	.128	.409	.849	.132
EDw1	.20968352-002	.985	.032	-.013	1.000	-.261	-.005	.982	-.042	-.008	.611	-.396	.095	.976	-.059	-.073	.964
DA1	.96878842-005	-.282	-.060	-.080	-.261	1.000	.078	-.289	-.010	-.018	-.168	.635	-.102	-.290	.012	-.006	-.301
DE1	.30159148-003	-.004	.023	-.029	-.005	.078	1.000	-.006	.001	-.002	-.035	.013	-.008	-.006	.002	-.002	-.023
DMw2	.99846108-002	.995	.093	.064	.982	-.289	-.006	1.000	.037	-.030	.615	-.388	.093	.998	.023	-.055	.981
DP2	.11577049-001	-.045	.525	.760	-.042	-.010	.001	.037	1.000	.018	.048	-.033	-.026	.093	.869	.486	.095
DQ2	.11424654-001	-.009	-.725	.553	-.008	-.018	-.002	-.030	.018	1.000	.002	-.029	-.035	.010	-.464	.871	.012
EDw2	.11146406-003	.613	.058	.056	.611	-.168	-.035	.615	.048	.002	1.000	-.245	-.018	.616	.019	-.018	.656
DA2	.17184404-004	-.388	-.012	-.064	-.396	.635	.013	-.388	-.033	-.029	-.245	1.000	-.045	-.388	.013	-.009	-.405
DE2	.10018625-003	.090	.019	.017	.095	-.102	-.008	.093	-.026	-.035	-.018	-.045	1.000	.091	.013	-.003	.121
DMwB	.99972998-002	.989	.093	.128	.976	-.290	-.006	.998	.093	.010	.616	-.388	.091	1.000	.053	.007	.984
DPB	.11360189-001	-.061	.817	.409	-.059	.012	.002	.023	.869	-.464	.019	.013	.013	.053	1.000	.014	.054
DQB	.11439646-001	-.076	-.385	.849	-.073	-.006	-.002	-.055	.486	.871	-.018	-.009	-.003	.007	.014	1.000	.011
EDwB	.17498452-003	.972	.093	.132	.964	-.301	-.023	.981	.095	.012	.656	-.405	.121	.984	.054	.011	1.000
DAB	.26095554-004	-.415	-.013	-.071	-.424	.677	.013	-.415	-.019	-.026	-.241	.938	-.152	-.416	.012	-.011	-.434
DEB	.15506337-004	.240	.056	.045	.242	-.242	.071	.244	.050	-.023	.056	-.331	.162	.245	.050	-.009	.229
DMw4	.10029225-001	.994	.078	.097	.980	-.296	-.006	.999	.057	.004	.615	-.397	.092	.999	.023	-.016	.982
DP4	.11491115-001	.070	-.179	-.921	.067	.012	-.001	.003	-.903	-.419	-.009	.018	-.007	-.064	-.603	-.804	-.065
DQ4	.11313089-001	.016	.889	-.184	.016	-.009	.004	.071	.403	-.899	.031	-.015	.013	.058	.793	-.596	.052
EDw4	.96633976-003	.991	.077	.099	.979	-.333	-.006	.996	.057	.005	.611	-.449	.100	.997	.022	-.015	.981
DA4	.41780337-004	-.415	-.021	-.079	-.426	.673	.021	-.417	-.030	-.024	-.264	.932	-.162	-.418	.002	-.015	-.449
DE4	.25960616-004	-.086	-.022	-.047	-.110	.126	.085	-.089	-.033	-.012	-.304	.177	-.190	-.091	-.019	-.023	-.258
DMw5	.18051642-001	.143	.005	.017	.143	-.177	-.005	.144	.003	.005	.074	-.238	.015	.143	-.005	-.001	.135
DP5	.18453470-001	.005	.071	-.083	.005	.003	-.001	.006	-.026	-.115	.004	.004	.000	-.000	.032	-.113	.000
DQ5	.18152235-001	-.009	.110	.057	-.008	.002	.000	.003	.119	-.061	.004	.003	.003	.007	.135	.004	.008
EDw5	.46853976-002	-.193	-.026	-.020	-.188	-.059	-.007	-.195	-.023	.005	-.116	-.079	-.003	-.195	-.020	.002	-.186
DA5	.88020396-003	-.021	.017	-.004	-.024	.234	.005	-.019	.016	-.013	.007	.316	-.027	-.018	.024	-.002	-.017
DE5	.51144925-002	.156	.024	.017	.155	.050	-.007	.158	.019	-.006	.135	.067	.031	.158	.017	-.003	.177
DMw6	.27230875-001	-.045	-.020	-.005	-.041	-.114	-.003	-.047	-.018	.011	-.032	-.153	.020	-.047	-.022	.003	-.041
DP6	.19778160-001	-.003	.070	.023	-.003	-.000	.000	.004	.064	-.048	.002	-.000	.001	.005	.080	-.011	.005
DQ6	.19989124-001	-.003	-.028	.043	-.002	.002	-.000	-.002	.020	.052	-.000	.003	-.001	.001	-.007	.055	.001
EDw6	.99018434-002	.008	.002	.001	.008	.004	.000	.008	.002	-.001	.005	.005	-.000	.008	.002	-.000	.008
DA6	.30765173-002	.103	.033	.011	.097	.166	.005	.106	.030	-.017	.070	.222	-.028	.107	.034	-.005	.097
DE6	.10842283-001	-.000	-.000	-.000	-.000	-.000	.000	-.000	-.000	.000	-.000	-.000	.000	-.000	-.000	-.000	-.000
DMw7	.80256468-001	-.020	-.007	-.002	-.019	-.034	-.001	-.021	-.006	.003	-.014	-.046	.006	-.021	-.007	.001	-.019
DP7	.23300299-001	-.000	.016	.026	-.000	.001	.000	.002	.032	.002	.002	.001	.000	.004	.027	.017	.004
DQ7	.19253424-001	-.000	-.040	-.008	-.000	-.001	-.000	-.003	-.032	.030	-.002	-.001	-.001	-.004	-.043	.011	-.004
EDw7	.35253706-001	.002	.000	.000	.002	.003	.000	.002	.000	-.000	.001	.004	-.001	.002	.000	.000	.001
DA7	.28928165-001	.035	.010	.004	.033	.050	.001	.036	.009	-.005	.024	.066	-.008	.036	.010	-.001	.033
DE7	.14419578-001	.005	.001	.001	.005	.009	.000	.005	.001	-.001	.003	.011	-.001	.005	.001	-.000	.005
DMw8	.39976929+000	-.006	-.002	-.001	-.005	-.008	-.000	-.006	-.001	.001	-.004	-.011	.001	-.006	-.002	.000	-.005
DP8	.24731825-001	.003	.098	.030	.003	-.003	.000	.012	.087	-.067	.007	-.003	.003	.014	.110	-.017	.014
DQ8	.23479725-001	-.004	-.051	-.009	-.004	.001	-.000	-.008	-.039	.039	-.005	.001	-.001	-.009	-.054	.016	-.009
EDw8	.17867066+000	.000	-.000	.000	.000	-.000	-.000	.000	-.000	.000	.000	-.000	.000	.000	-.000	.000	.000
DA8	.26803061+000	.008	.002	.001	.007	.011	.000	.008	.002	-.001	.005	.014	-.002	.008	.002	-.000	.007
DE8	.15079304+000	.000	.000	.000	.000	.001	.000	.000	.000	-.000	.000	.001	-.000	.000	.000	-.000	.000
AU	.30555712-001	.406	.014	.072	.417	-.668	-.025	.407	.021	.027	.262	-.927	.156	.408	-.011	.013	.440
RRA1	.39782975+000	-.001	-.002	-.001	-.001	.000	-.000	-.001	-.002	.001	-.001	-.000	-.000	-.002	-.002	-.000	-.001
RDE1	.45770535+000	-.002	.002	.006	-.002	.001	.000	-.001	.007	.003	-.001	.000	-.000	-.001	.005	.006	-.001
RRA2	.26998911-001	-.021	-.017	-.002	-.020	-.001	-.000	-.022	-.011	.014	-.013	-.002	-.003	-.022	-.017	.007	-.021
RDE2	.26763081-001	-.004	.003	.015	-.004	.000	-.000	-.003	.014	.004	-.004	.002	.006	-.002	.010	.013	-.002
ADAY1	.27617463+000	-.040	-.016	-.010	-.039	-.001	-.000	-.041	-.016	.008	-.026	-.002	-.002	-.042	-.017	.001	-.040
ADAY2	.94226642-001	-.002	.007	.005	-.002	.000	-.000	-.001	.008	-.003	-.001	.001	.001	-.001	.009	.002	-.001
ADAY3	.29005544+000	-.003	.001	.001	-.003	-.000	-.000	-.003	.002	-.000	-.002	.000	.000	-.003	.002	.001	-.003
DDAY1	.27341903+000	-.006	.011	.004	-.006	-.000	.000	-.005	.011	-.008	-.003	-.000	.000	-.004	.013	-.001	-.004
DDAY2	.96094159-001	-.034	-.040	.269	-.033	-.001	-.001	-.021	.206	.203	-.008	-.002	-.000	-.002	.086	.278	-.000
DDAY3	.28776840+000	.007	-.013	-.004	.006	.000	.000	.005	-.012	.009	.003	.000	-.000	.005	-.016	.002	.005
DELK	.55246045-001	.212	.147	.057	.201	.281	.008	.226	.137	-.084	.149	.375	-.045	.230	.161	-.018	.212
DELN	.47872361-001	.087	-.215	-.082	.082	.138	.003	.067	-.205	.141	.044	.183	-.028	.061	-.251	.021	.053
RAD1	.11297766+000	.002	.206	-.034	.073	-.027	-.399	.003	-.002	.005	.004	-.008	.001	.003	-.004	.003	.004
RAD2	.71473749-001	.029	-.002	.007	.031	-.052	-.009	.028	.078	-.024	-.060	-.130	-.289	.029	-.003	.004	.039
RAD4	.44120139-001	.247	-.000	.066	.252	-.457	-.018	.248	.026	.037	.140	-.633	.069	.250	-.006	.032	.254

Table 9. (contd)

	σ	DAB	DEB	DMW4	DP4	DQ4	EDW4	DA4	DE4	DMW5	DP5	DQ5	EDW5	DA5	DE5	DMW6	DP6
DMW1	.99672865-002	-.415	.240	.994	.070	.016	.991	-.415	-.086	.143	.005	-.009	-.193	-.021	.156	-.045	-.003
DP1	.12414716-001	-.013	.056	.078	-.179	.889	.077	-.021	-.022	.005	.071	.110	-.026	.017	.024	-.020	.070
DQ1	.12185161-001	-.071	.045	.097	-.921	-.184	.099	-.079	-.047	.017	-.083	.057	-.020	-.004	.017	-.005	.023
EDW1	.20968352-002	-.424	.242	.980	.067	.016	.979	-.426	-.110	.143	.005	[illegible]	-.188	-.024	.155	-.041	-.003
DA1	.96878842-005	.677	-.242	-.296	.012	-.009	-.333	.673	.126	-.177	.003	.002	-.059	.234	.050	-.114	-.000
DE1	.30159148-003	.013	.071	-.006	-.001	.004	-.006	.021	.085	-.005	-.001	.000	-.007	.005	-.007	-.003	.000
DMW2	.99846108-002	-.415	.244	.999	.003	.071	.996	-.417	-.089	.144	.006	.003	-.195	-.019	.158	-.047	.004
DP2	.11577049-001	-.019	.050	.057	-.903	.403	.057	-.030	-.033	.003	-.026	.119	-.023	.016	.019	-.018	.064
DQ2	.11424654-001	-.026	-.023	.004	-.419	-.899	.005	-.024	-.012	.005	-.115	-.061	.005	-.013	-.006	.011	-.048
EDW2	.11146406-003	-.241	.056	.615	-.009	.031	.611	-.264	-.304	.074	.004	.004	-.116	.007	.135	-.032	.002
DA2	.17184404-004	.938	-.331	-.397	.018	-.015	-.449	.932	.177	-.238	.004	.003	-.079	.316	.067	-.153	-.000
DE2	.10018625-003	-.152	.162	.092	-.007	.013	.100	-.162	-.190	.015	.000	.003	-.003	-.027	.031	.020	.001
DMWB	.99972998-002	-.416	.245	.999	-.064	.058	.997	-.418	-.091	.143	-.000	.007	-.195	-.018	.158	-.047	.005
DPB	.11360189-001	.012	.050	.023	-.603	.793	.022	.002	-.019	-.005	.032	.135	-.020	.024	.017	-.022	.080
DQB	.11439646-001	-.011	-.009	-.016	-.804	-.596	-.015	-.015	-.023	-.001	-.113	.004	.002	-.002	-.003	.003	-.011
EDWB	.17498452-003	-.434	.229	.982	-.065	.052	.981	-.449	-.258	.135	.000	.008	-.186	-.017	.177	-.041	.005
DAB	.26095554-004	1.000	-.358	-.425	.021	-.016	-.481	.994	.190	-.255	.005	.003	-.084	.338	.071	-.164	-.000
DEB	.15506337-004	-.358	1.000	.248	-.032	.052	.273	-.341	-.060	.002	-.005	.009	-.061	-.038	.065	.037	.005
DMW4	.10029225-001	-.425	.248	1.000	-.028	.048	.998	-.426	-.089	.145	.001	.003	-.194	-.022	.157	-.045	.003
DP4	.11491115-001	.021	-.032	-.028	1.000	.002	-.029	.028	.030	-.004	.071	-.083	.015	-.006	-.004	.010	-.039
DQ4	.11313089-001	-.016	.052	.048	.002	1.000	.048	-.019	.013	.006	.094	.106	-.017	.010	.012	-.015	.071
EDW4	.96633976-003	-.481	.273	.998	-.029	.048	1.000	-.481	-.096	.160	.001	.003	-.180	-.046	.144	-.032	.003
DA4	.41780337-004	.994	-.341	-.426	.028	-.019	-.481	1.000	.242	-.249	.005	.001	-.076	.333	.074	-.163	-.001
DE4	.25960616-004	.190	-.060	-.089	.030	.013	-.096	.242	1.000	-.082	.005	-.007	-.116	.073	-.089	-.034	-.002
DMW5	.18051642-001	-.255	.002	.145	-.004	.006	.160	-.249	-.082	1.000	.001	-.005	.762	-.727	-.551	.099	-.000
DP5	.18453470-001	.005	-.005	.001	.071	.094	.001	.005	.005	.001	1.000	.063	-.006	-.001	-.002	-.002	.009
DQ5	.18152235-001	.003	.009	.003	-.083	.106	.003	.001	-.007	-.005	.063	1.000	-.009	.002	.008	-.003	.015
EDW5	.46853976-002	-.084	-.061	-.194	.015	-.017	-.180	-.076	-.116	.762	-.006	-.009	1.000	-.663	-.166	.111	-.002
DA5	.88020396-003	.338	-.038	-.022	-.006	.010	-.046	.333	.073	-.727	-.001	.002	-.663	1.000	.538	-.170	.001
DE5	.51144925-002	.071	.065	.157	-.004	.012	.144	.074	-.089	-.551	-.002	.008	-.166	.538	1.000	-.083	.001
DMW6	.27230875-001	-.164	.037	-.045	.010	-.015	-.032	-.163	-.034	.099	-.002	-.003	.111	-.170	-.083	1.000	-.012
DP6	.19778160-001	-.000	.005	.003	[illegible]	.071	.003	-.001	-.002	-.000	.009	.015	-.002	.001	.001	-.012	1.000
DQ6	.19989124-001	.003	-.002	.000	[illegible]	-.039	-.000	.003	-.000	-.002	-.010	-.004	-.002	.003	.001	-.008	-.066
EDW6	.99018434-002	.006	-.000	.008	-.001	.002	.008	.005	.001	-.004	.000	.000	-.006	.008	.005	.040	-.002
DA6	.30765173-002	.238	-.050	.103	-.016	.024	.083	.236	.049	-.140	.003	.005	-.170	.250	.128	-.847	.007
DE6	.10842283-001	-.000	.000	-.000	.000	-.000	-.000	-.000	.000	.000	-.000	-.000	.000	-.000	-.000	.426	.001
DMW7	.80256468-001	-.049	.010	-.020	.003	-.005	-.016	-.049	-.010	.030	-.001	-.001	.036	-.054	-.027	.037	-.001
DP7	.23300299-001	.001	.001	.003	-.030	.011	.003	.001	-.001	-.001	.003	.007	-.002	.002	.002	-.002	.006
DQ7	.19253424-001	-.001	-.002	-.003	.017	-.041	-.003	-.001	.000	.001	-.006	-.009	.002	-.002	-.002	.002	-.007
EDW7	.35253706-001	.005	-.001	.002	-.000	.000	.001	.005	.001	-.003	-.000	.000	-.003	.005	.002	-.003	-.000
DA7	.28928165-001	.071	-.014	.035	-.005	.007	.029	.071	.015	-.043	.001	.001	-.054	.078	.040	-.054	.001
DE7	.14419578-001	.012	-.003	.005	-.001	.001	.004	.012	.002	-.008	.000	.000	-.009	.013	.007	-.009	.000
DMW8	.39976929+000	-.011	.002	-.006	.001	-.001	-.005	-.011	-.002	.007	-.000	-.000	.009	-.013	-.007	.009	-.000
DP8	.24731825-001	-.004	.008	.011	-.052	.099	.011	-.005	-.003	.001	.030	.035	-.004	.002	.003	-.005	.031
DQ8	.23479725-001	.001	-.004	-.008	.019	-.053	-.008	[illegible]	.001	.001	-.019	-.020	.004	-.003	-.003	.004	-.019
EDW8	.17867066+000	-.000	.000	.000	.000	-.000	.000	-.000	-.000	.000	-.000	-.000	.000	-.000	-.000	.000	-.000
DA8	.26803061+000	.015	-.003	.008	-.001	.002	.007	.015	.003	-.009	.000	.000	-.012	.017	.009	-.012	.000
DE8	.15079304+000	.001	-.000	.000	-.000	.000	.000	.001	.000	-.001	.000	.000	-.001	.001	.000	-.001	.000
AU	.30555712-001	-.988	.290	.417	-.026	.017	.471	-.986	-.281	.233	-.005	-.003	.071	-.320	-.057	.161	.000
RRA1	.39782975+000	-.000	-.000	-.001	.001	-.002	-.001	-.000	.000	-.000	-.000	-.000	.000	.000	-.000	-.000	-.000
RDE1	.45770535+000	.000	-.000	-.001	-.008	.000	-.001	.000	-.000	-.000	-.001	.001	.000	.000	-.000	-.000	.000
RRA2	.26998911-001	-.002	-.003	-.021	.005	-.018	-.021	-.002	.000	.001	-.002	-.003	.008	-.007	-.007	.006	-.002
RDE2	.26763081-001	.000	-.000	-.003	-.017	.000	-.003	.000	-.001	.000	-.001	.002	.001	-.001	-.001	.000	.001
ADAY1	.27617463+000	-.002	-.006	-.041	.011	-.014	-.040	-.002	-.000	.005	-.001	-.003	.018	-.016	-.014	.013	-.002
ADAY2	.94226642-001	.000	.000	-.001	-.007	.006	-.001	.000	.001	-.000	.000	.002	.300	.000	-.000	-.000	.001
ADAY3	.29005544+000	-.000	-.000	-.003	-.002	.001	-.003	-.000	-.000	.000	.000	.000	.001	-.001	-.001	.001	.000
DDAY1	.27341903+000	-.000	.000	-.005	-.007	.011	-.004	-.000	-.000	.001	.001	.002	.002	-.002	-.002	.001	.002
DDAY2	.96094159-001	-.002	.001	-.010	-.272	-.100	-.010	-.004	-.008	.000	-.028	.013	.003	-.002	-.002	.001	.004
DDAY3	.28776840+000	.000	-.000	.005	.008	-.013	.005	.000	.000	-.001	-.002	-.003	-.002	.002	.002	-.002	-.002
DELK	.55246045-001	.403	-.072	.220	-.082	.129	.185	.398	.082	-.253	.035	.043	-.321	.460	.241	-.320	.035
DELN	.47872361-001	.196	-.057	.065	.132	-.220	.049	.198	.046	-.118	-.078	-.091	-.134	.204	.100	-.132	-.082
RAD1	.11297766+000	-.008	-.010	.003	-.000	-.004	.003	-.008	-.012	-.001	-.000	-.001	-.002	-.001	.001	.001	-.000
RAD2	.71473749-001	-.077	-.015	.030	-.003	-.003	.034	-.080	-.064	.014	-.001	-.001	.004	-.021	.000	.012	-.000
RAD4	.44120139-001	-.674	.060	.256	-.043	.015	.293	-.663	-.113	.269	-.007	.003	.173	-.301	-.076	.121	.000

Table 9. (contd)

	σ	DQ6	EDW6	DA6	DE6	DMW7	DP7	DQ7	EDW7	DA7	DE7	DMW8	DP8	DQ8	EDW8	DA8	DE8
DMW1	.99672865-002	-.003	.008	.103	-.000	-.020	-.000	-.000	.002	.035	.005	-.006	.003	-.004	.000	.008	.000
DP1	.12414716-001	-.028	.002	.033	-.000	-.007	.016	-.040	.000	.010	.001	-.002	.098	-.051	-.000	.002	.000
DQ1	.12185161-001	.043	.001	.011	-.000	-.002	.026	-.008	.000	.004	.001	-.001	.030	-.009	.000	.001	.000
EDW1	.20968352-002	-.002	.008	.097	-.000	-.019	-.000	-.000	.002	.033	.005	-.005	.003	-.004	.000	.007	.000
DA1	.96878842-005	.002	.004	.166	-.000	-.034	.001	-.001	.003	.050	.009	-.008	-.003	.001	-.000	.011	.001
DE1	.30159148-003	-.000	.000	.005	.000	-.001	.000	-.000	.000	.001	.000	-.000	.000	-.000	-.000	.000	.000
DMW2	.99846108-002	-.002	.008	.106	-.000	-.021	.002	-.003	.002	.036	.005	-.006	.012	-.008	.000	.008	.000
DP2	.11577049-001	.020	.002	.030	-.000	-.006	.032	-.032	.000	.009	.001	-.001	.087	-.039	-.000	.002	.000
DQ2	.11424654-001	.052	-.001	-.017	.000	.003	.002	.030	-.000	-.005	-.001	.001	-.067	.039	.000	-.001	-.000
EDW2	.11146406-003	-.000	.005	.070	-.000	-.014	.002	-.002	.001	.024	.003	-.004	.007	-.005	.000	.005	.000
DA2	.17184404-004	.003	.005	.222	-.000	-.046	.001	-.001	.004	.066	.011	-.011	-.003	.001	-.000	.014	.001
DE2	.10018625-003	-.001	-.000	-.028	.000	.006	.000	-.001	-.001	-.008	-.001	.001	.003	-.001	.000	-.002	-.000
DMW3	.99972998-002	.001	.008	.107	-.000	-.021	.004	-.004	.002	.036	.005	-.006	.014	-.009	.000	.008	.000
DP3	.11360189-001	-.007	.002	.034	-.000	-.007	.027	-.043	.000	.010	.001	-.002	.110	-.054	-.000	.002	.000
DQ3	.11439646-001	.055	-.000	-.005	-.000	.001	.017	.011	.000	-.001	-.000	.000	-.017	.016	.000	-.000	-.000
EDW3	.17498452-003	.001	.008	.097	-.030	-.019	.004	-.004	.001	.033	.005	-.005	.014	-.009	.000	.007	.000
DA3	.26095554-004	.003	.006	.238	-.000	-.049	.001	-.001	.005	.071	.012	-.011	-.004	.001	-.000	.015	.001
DE3	.15506337-004	-.002	-.000	-.050	.000	.010	.001	-.002	-.001	-.014	-.003	.002	.008	-.004	.000	-.003	-.000
DMW4	.10029225-001	.000	.008	.103	-.000	-.020	.003	-.003	.002	.035	.005	-.006	.011	-.008	.000	.008	.000
DP4	.11491115-001	-.039	-.001	-.016	.000	.003	-.030	.017	-.000	-.005	-.001	.001	-.052	.019	.000	-.001	-.000
DQ4	.11313089-001	-.039	.002	.024	-.000	-.005	.011	-.041	.000	.007	.001	-.001	.099	-.053	-.000	.002	.000
EDW4	.96633976-003	-.000	.008	.083	-.000	-.016	.003	-.003	.001	.029	.004	-.005	.011	-.008	.000	.007	.000
DA4	.41780337-004	.003	.005	.236	-.000	-.049	.001	-.001	.005	.071	.012	-.011	-.005	.001	-.000	.015	.001
DE4	.25960616-004	-.000	.001	.049	.000	-.010	-.001	.000	.001	.015	.002	-.002	-.003	.001	-.000	.003	.000
DMW5	.18051642-001	-.002	-.004	-.140	.000	.030	-.001	.001	-.003	-.043	-.008	.007	.001	.001	.000	-.009	-.001
DP5	.18453470-001	-.010	.000	.003	-.000	-.001	.003	-.006	-.000	.001	.000	-.000	.030	-.019	-.000	.000	.000
DQ5	.18152235-001	-.004	.000	.005	-.000	-.001	.007	-.009	.000	.001	.000	-.000	.035	-.020	-.000	.000	.000
EDW5	.46853976-002	-.002	-.006	-.170	.000	.036	-.002	.002	-.003	-.054	-.009	.009	-.004	.004	.000	-.012	-.001
DA5	.88020396-003	.003	.004	.250	-.000	-.054	.002	-.002	.005	.078	.013	-.013	.002	-.003	-.000	.017	.001
DE5	.51144925-002	.001	.005	.128	-.000	-.027	.002	-.002	.002	.040	.007	-.007	.003	-.003	-.000	.009	.000
DMW6	.27230875-001	-.008	.040	-.847	.426	.037	-.002	.002	-.003	-.054	-.009	.009	-.005	.004	.000	-.012	-.001
DP6	.19778160-001	-.066	-.002	.007	.001	-.001	.006	-.007	-.000	.001	.000	-.000	.031	-.019	-.000	.000	.000
DQ6	.19989124-001	1.000	.005	.006	-.004	-.001	-.002	.003	.000	.001	.000	-.000	-.017	.011	.000	.000	-.000
EDW6	.99018434-002	.005	1.000	.095	-.074	-.002	.000	-.000	.000	.003	.000	-.000	.001	-.001	-.000	.001	.000
DA6	.30765173-002	.006	.095	1.000	-.357	-.055	.003	-.003	.005	.080	.014	-.013	.007	-.006	-.000	.017	.001
DE6	.10842283-001	-.004	-.074	-.357	1.000	.000	-.000	.000	-.000	-.000	-.000	.000	-.000	.000	.000	-.000	-.000
DMW7	.80256468-001	-.001	-.002	-.055	.000	1.000	-.001	.003	.945	-.972	.135	.003	-.001	.001	.000	-.004	-.000
DP7	.23300299-001	-.002	.000	.003	-.000	-.001	1.000	-.013	-.000	.001	.003	-.000	.019	-.012	-.000	.000	.000
DQ7	.19253424-001	.003	-.000	-.003	.000	.003	-.013	1.000	.002	-.003	.002	.000	-.020	.012	.000	-.000	-.000
EDW7	.35253706-001	.000	.000	.005	-.000	.945	-.000	.002	1.000	-.948	.031	-.000	-.000	.000	-.000	.000	.000
DA7	.28928165-001	.001	.003	.080	-.006	-.972	.001	-.003	-.948	1.000	.006	-.004	.001	-.001	-.000	.005	.000
DE7	.14419578-001	.000	.000	.014	-.000	.135	.003	.002	.031	.006	1.000	-.001	-.000	.000	-.000	.001	.000
DMW8	.39976929+000	-.000	-.000	-.013	.000	.003	-.000	.000	-.000	-.004	-.001	1.000	.002	-.006	-.997	-.985	.925
DP8	.24731825-001	-.017	.001	.007	-.000	-.001	.019	-.020	-.000	.001	-.000	.002	1.000	-.411	-.002	-.001	.000
DQ8	.23479725-001	.011	-.001	-.006	.000	.001	-.012	.012	.000	-.001	.000	-.006	-.411	1.000	.006	.006	-.005
EDW8	.17867066+000	.000	-.000	-.000	.000	.000	-.000	.000	-.000	-.000	-.000	-.997	-.002	.006	1.000	.985	-.932
DA8	.26803061+000	.000	.001	.017	-.000	-.004	.000	-.000	.000	.005	.001	-.985	-.001	.006	.985	1.000	-.975
DE8	.15079304+000	-.000	.000	.001	-.000	-.000	.000	-.000	.000	.000	.000	.925	.000	-.005	-.932	-.975	1.000
AU	.30555712-001	-.003	-.005	-.234	.000	.048	-.001	.001	-.005	-.070	-.012	.011	.004	-.001	.000	-.015	-.001
RRA1	.39782975+000	.000	-.000	.000	.000	-.000	-.000	.000	.000	.000	.000	-.000	-.000	.000	-.000	.000	.000
RDE1	.45770535+000	.000	-.000	-.000	-.000	.000	.000	-.000	-.000	-.000	-.000	.000	.000	-.000	-.000	-.000	.000
RRA2	.26998911-001	.001	-.000	-.010	.000	.002	-.001	.001	-.000	-.003	-.000	.000	-.004	.003	.000	-.001	-.000
RDE2	.26763081-001	.000	-.000	-.001	-.000	.000	.001	-.000	-.000	-.000	-.000	.000	.002	-.001	-.000	-.000	.000
ADAY1	.27617463+000	.000	-.001	-.021	.000	.004	-.001	.001	-.000	-.007	-.001	.001	-.005	.003	.000	-.001	-.000
ADAY2	.94226642-001	-.000	.000	.000	-.000	-.000	.001	-.001	-.000	.000	.000	-.000	.002	-.001	-.000	.000	.000
ADAY3	.29005544+000	-.000	-.000	-.002	-.000	.000	.000	-.000	-.000	-.001	-.000	.000	.001	-.000	-.000	-.000	-.000
DDAY1	.27341903+000	-.001	-.000	-.002	-.000	.000	.001	-.001	-.000	-.001	-.000	.000	.004	-.003	-.000	-.000	-.000
DDAY2	.96094159-001	.014	-.000	-.003	-.000	.001	.008	-.001	-.000	-.001	-.000	.000	.008	-.003	.000	-.000	.000
DDAY3	.28776840+000	.001	.000	.003	.000	-.001	-.001	.001	.000	.001	.000	-.000	-.005	.003	.000	.000	.000
DELK	.55246045-001	-.013	.017	.478	-.000	-.102	.025	-.025	.008	.149	.025	-.024	.119	-.078	-.000	.032	.002
DELN	.47872361-001	.049	.005	.198	.000	-.044	-.051	.052	.004	.065	.012	-.011	-.298	.187	.000	.014	.000
RAD1	.11297766+000	.000	-.000	-.002	-.000	.000	.000	.000	-.000	-.001	-.000	.000	.000	-.000	.000	-.000	-.000
RAD2	.71473749-001	.000	-.000	-.018	.000	.004	-.000	.000	-.000	-.005	-.001	.001	-.001	.000	.000	-.001	-.000
RAD4	.44120139-001	-.001	-.004	-.178	.000	.037	-.000	.001	-.003	-.053	-.009	.009	.002	.000	.000	-.011	-.001

Table 9. (contd)

	σ	AU	RRA1	RDE1	RRA2	RDE2	ADAY1	ADAY2	ADAY3	DDAY1	DDAY2	DDAY3	DELK	DELN	RAD1	RAD2	RAD4
DMW1	.99672865-002	.406	-.001	-.002	-.021	-.004	-.040	-.002	-.003	-.006	-.034	.007	.212	.087	.002	.029	.247
DP1	.12414716-001	.014	-.002	.002	-.017	.003	-.016	.007	.001	.011	-.040	-.013	.147	-.215	.206	-.002	-.000
DQ1	.12185161-001	.072	-.001	.006	-.002	.015	-.010	.005	.001	.004	.269	-.004	.057	-.082	-.034	.007	.066
EDW1	.20968352-002	.417	-.001	-.002	-.020	-.004	-.039	-.002	-.003	-.006	-.033	.006	.201	.082	.073	.031	.252
DA1	.96878842-005	-.668	.000	.001	-.001	.000	-.001	.000	-.000	-.000	-.001	.000	.281	.138	-.027	-.052	-.457
DE1	.30159148-003	-.025	-.000	.000	-.000	-.000	-.000	-.000	-.000	.000	-.001	.000	.008	.003	-.399	-.009	-.018
DMW2	.99846108-002	.407	-.001	-.001	-.022	-.003	-.041	-.001	-.003	-.005	-.021	.005	.226	.067	.003	.028	.248
DP2	.11577049-001	.021	-.002	.007	-.011	.014	-.016	.008	.002	.011	.206	-.012	.137	-.205	-.002	.078	.026
DQ2	.11424654-001	.027	.001	.003	.014	.004	.008	-.003	-.000	-.008	.203	.009	-.084	.141	.005	-.024	.037
EDW2	.11146406-003	.262	-.001	-.001	-.013	-.004	-.026	-.001	-.002	-.003	-.008	.003	.149	.044	.004	-.060	.140
DA2	.17184904-004	-.927	-.000	.000	-.002	.002	-.002	.001	.000	-.000	-.002	.000	.375	.183	-.008	-.130	-.633
DE2	.10018625-003	.156	-.000	-.000	-.003	.006	-.002	.001	.000	.000	-.000	-.000	-.045	-.028	.001	-.289	.069
DMW3	.99972998-002	.408	-.002	-.001	-.022	-.002	-.042	-.001	-.003	-.004	-.002	.005	.230	.061	.003	.029	.250
DP3	.11360189-001	-.011	-.002	.005	-.017	.010	-.017	.009	.002	.013	.086	-.016	.161	-.251	-.004	-.003	-.006
DQ3	.11439646-001	.013	-.000	.006	.007	.013	.001	.002	.001	-.001	.278	.002	-.018	.021	.003	.004	.032
EDW3	.17498452-003	.440	-.001	-.001	-.021	-.002	-.040	-.001	-.003	-.004	-.000	.005	.212	.053	.004	.039	.254
DA3	.26095554-004	-.988	-.000	.000	-.002	.000	-.002	.000	-.000	-.000	-.002	.000	.403	.196	-.008	-.077	-.674
DE3	.15506337-004	.290	-.000	-.000	-.003	-.000	-.006	.000	-.000	.000	.001	-.000	-.072	-.057	-.010	-.015	.060
DMW4	.10029225-001	.417	-.001	-.001	-.021	-.003	-.041	-.001	-.003	-.005	-.010	.005	.220	.065	.003	.030	.256
DP4	.11491115-001	-.026	.001	-.008	.005	-.017	.011	-.007	-.002	-.007	-.272	.008	-.082	.132	-.000	-.003	-.043
DQ4	.11313089-001	.017	-.002	.000	-.018	.000	-.014	.006	.001	.011	-.100	-.013	.129	-.220	-.004	-.003	.015
EDW4	.96633976-003	.471	-.001	-.001	-.021	-.003	-.040	-.001	-.003	-.004	-.010	.005	.185	.049	.003	.034	.293
DA4	.41780337-004	-.986	-.000	.000	-.002	.000	-.002	.000	-.000	-.000	-.004	.000	.398	.198	-.008	-.080	-.663
DE4	.25960616-004	-.281	.000	-.000	.000	-.001	-.000	.001	-.000	-.000	-.008	.000	.082	.046	-.012	-.064	-.113
DMW5	.18051642-001	.233	-.000	-.000	.001	.000	.005	-.000	.000	.001	.000	-.001	-.253	-.118	-.001	.014	.269
DP5	.18453470-001	-.005	-.000	-.001	-.002	-.001	-.001	.000	.000	.001	-.028	-.002	.035	-.078	-.000	-.001	-.007
DQ5	.18152235-001	-.003	-.000	.001	-.003	.002	-.003	.002	.000	.002	.013	-.003	.043	-.091	-.001	-.001	.003
EDW5	.46853976-002	.071	.000	.000	.008	.001	.018	.000	.001	.002	.003	-.002	-.321	-.134	-.002	.004	.173
DA5	.86020396-003	-.320	.000	.000	-.007	-.001	-.016	.000	-.001	-.002	-.002	.002	.460	.204	-.001	-.021	-.301
DE5	.51144925-002	-.057	-.000	-.000	-.007	-.001	-.014	-.000	-.001	-.002	-.002	.002	.241	.100	.001	.000	-.076
DMW6	.27230875-001	.161	-.000	-.000	.006	.000	.013	-.000	.001	.001	.001	-.002	-.320	-.132	.001	.012	.121
DP6	.19778160-001	.000	-.000	.000	-.002	.001	-.002	.001	.000	.002	.004	-.002	.035	-.082	-.000	-.000	.000
DQ6	.19989124-001	-.003	.000	.000	.001	.000	.000	-.000	-.000	-.001	.014	.001	-.013	.049	.000	.000	-.001
EDW6	.99018434-002	-.005	-.000	-.000	-.000	-.000	-.001	.000	-.000	-.000	-.000	.000	.017	.005	-.000	-.000	-.004
DA6	.30765173-002	-.234	.000	-.000	-.010	-.001	-.021	.000	-.002	-.002	-.003	.003	.478	.198	-.002	-.018	-.178
DE6	.10842283-001	.000	.000	-.000	.000	-.000	.000	-.000	-.000	-.000	-.000	.000	-.000	.000	-.000	.000	.000
DMW7	.80256468-001	.048	-.000	.000	.002	.000	.004	-.000	.000	.000	.001	-.001	-.102	-.044	.000	.004	.037
DP7	.23300299-001	-.001	-.000	.000	-.001	.001	-.001	.001	.000	.001	.008	-.001	.025	-.051	.000	-.000	-.000
DQ7	.19253424-001	.001	.000	-.000	.001	-.000	.001	-.001	-.000	-.001	-.001	.001	-.025	.052	.000	.000	.001
EDW7	.35253706-001	-.005	.000	-.000	-.000	-.000	-.000	-.000	-.000	-.000	-.000	.000	.008	.004	-.000	-.000	-.003
DA7	.28928165-001	-.070	.000	-.000	-.003	-.000	-.007	.000	-.001	-.001	-.001	.001	.149	.065	-.001	-.005	-.053
DE7	.14419578-001	-.012	.000	-.000	-.000	-.000	-.001	.000	-.000	-.000	-.000	.000	.025	.012	-.000	-.001	-.009
DMW8	.39976929+000	.011	-.000	.000	.000	.000	.001	-.000	.000	.000	.000	-.000	-.024	-.011	.000	.001	.009
DP8	.24731825-001	.004	-.000	.000	-.004	.002	-.005	.002	.001	.004	.008	-.005	.119	-.298	.000	-.001	.002
DQ8	.23479725-001	-.001	.000	-.000	.003	-.001	.003	-.001	-.000	-.003	-.003	.003	-.078	.187	-.000	.000	.000
EDW8	.17867066+000	.000	-.000	-.000	.000	-.000	.000	-.000	-.000	-.000	.000	.000	-.000	.000	.000	.000	.000
DA8	.26803061+000	-.015	.000	-.000	-.001	-.000	-.001	.000	-.000	-.000	-.000	.000	.032	.014	-.000	-.001	-.011
DE8	.15079304+000	-.001	.000	.000	-.000	.000	-.000	.000	-.000	-.000	.000	.000	.002	.000	-.000	-.000	-.001
AU	.30555712-001	1.000	.000	-.000	.002	-.000	.002	-.000	.000	.000	.003	-.000	-.396	-.193	.013	.087	.708
RRA1	.39782975+000	.000	1.000	-.000	.000	-.000	.000	-.000	-.000	-.000	-.000	.000	-.000	.000	-.000	.000	.000
RDE1	.45770535+000	-.000	-.000	1.000	-.000	.000	-.000	.000	.000	.000	.002	-.000	.000	-.001	.001	-.000	-.000
RRA2	.26998911-001	.002	.000	-.000	1.000	-.000	-.060	-.014	.059	-.000	.001	.000	-.022	.003	.000	.001	.002
RDE2	.26763081-001	-.000	-.000	.000	-.000	1.000	-.000	.000	.000	-.040	.025	.037	.000	-.006	-.000	.002	.000
ADAY1	.27617463+000	.002	.000	-.000	-.060	-.000	1.000	-.033	-.994	.000	-.001	-.000	-.044	-.006	.000	.000	.004
ADAY2	.94226642-001	-.000	-.000	.000	-.014	.000	-.033	1.000	.026	.000	.001	-.000	.003	-.007	.000	-.000	.000
ADAY3	.29005544+000	.000	-.000	.000	.059	.000	-.994	.026	1.000	.000	.001	-.000	-.003	-.003	-.000	.000	.000
DDAY1	.27341903+000	.000	-.000	.000	-.000	-.040	.000	.000	.000	1.000	-.030	-.996	.000	-.014	-.000	.000	.000
DDAY2	.96094159-001	.003	-.000	.002	.001	.025	-.001	.001	.001	-.030	1.000	.022	.005	-.030	-.000	-.000	.009
DDAY3	.28776840+000	-.000	.000	-.000	.000	.037	-.000	-.000	-.000	-.996	.022	1.000	-.000	.016	.000	-.000	-.000
DELK	.55246045-001	-.396	-.000	.000	-.022	.000	-.044	.003	-.003	.000	.005	-.000	1.000	.074	-.003	-.031	-.304
DELN	.47872361-001	-.193	.000	-.001	.003	-.006	-.006	-.007	-.003	-.014	-.030	.016	.074	1.000	-.002	-.013	-.147
RAD1	.11297766+000	.013	-.000	.001	.000	-.000	.000	.000	-.000	-.000	-.000	.000	-.003	-.002	1.000	.003	.016
RAD2	.71473749-001	.087	.000	-.000	.001	.002	.000	-.000	.000	.000	-.000	-.000	-.031	-.013	.003	1.000	.069
RAD4	.44120139-001	.708	.000	-.000	.002	.000	.004	.000	.000	.000	.009	-.000	-.304	-.147	.016	.069	1.000

Table 10. The masses and Keplerian elements of the asteroids used in the force model[a]

Asteroid	m $[m_{\odot}^{-1}]$	a	e	i, °	Ω, °	ω, °	M, ° (2440000.5)	n, ″/day
Ceres	5.9×10^{-10}	2.7663	.078796	10.604	80.420	69.762	58.455	771.167
Pallas	1.3×10^{-10}	2.7687	.241216	34.848	172.802	310.110	46.750	770.201
Vesta	1.2×10^{-10}	2.3619	.088744	7.137	103.631	149.932	85.095	977.467

[a]The masses of Ceres and Pallas are from Schubart (Ref. 12), the mass of Vesta is from Hertz (Ref. 13), and the elements are from the Astronomical Papers (Ref. 14).

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