REPORT OF HYDROGRAPHIC RESEARCHES No. 15, March, 1980

TRIGONOMETRIC SERIES FOR THE COORDINATES OF THE OBJECTS IN THE SOLAR SYSTEM

Yoshio Kubo*

Received 1979 September 10

Abstract

Trigonometric series for approximate positions of some objects in the solar system are developed. These give geocentric positions of the Sun and the Moon and heliocentric and geocentric positions of the inner planets with a precision of 0.1, which corresponds to the precision in the *Nautical Almanac*.

Key Words : trigonometric series-coordinates of celestial objects

1. Introduction

The spread of electronic calculators has made it quite easy to carry out some astronomical calculations such as obtaining the altitude and azimuth of a celestial object from its right ascension and declination. In that case, the right ascension and declination still have to be obtained from an almanac, interpolated if necessary and put into the calculator as data. Some calculators, however, have an ability of programmed calculation as well as a fairly large number of memories. With such calculators, if a proper formula giving the position of the celestial object is available and programmed, the user will be able to obtain the position by himself. And if it is combined with the program calculating the horizontal coordinates, the altitude or the azimuth will be obtained only by giving the time for which the user desires to calculate them.

In order to provide users of such calculators or mini or personal computers with compact formulas giving approximate coordinates of the objects in the solar system, some trigonometric series have been developed. They consist of the series for geocentric positions of the Sun and the Moon both in ecliptic and equatorial coordinate systems and the heliocentric ecliptic and the geocentric equatorial coordinates of the inner planets.

The formulas are intended to be correct for the years 1970 to 2030, to the precision of 0.1 which is the same as in the *Nautical Almanac* published by the Hydrographic Department of Japan.

As for the outer planets, the present ephemerides are computed by a numerical integration and there exists no analytical formula to represent the result of the integration. This makes the derivation of similar trigonometric series for the outer planets somewhat difficult. However, a new method valid in such a case is being developed and the series will appear in a coming volume of this report.

* Astronomical Division

2. Method of Derivation of the Series

Series for the geocentric longitude, latitude and distance of the Sun and the heliocentric longitudes, latitudes and radius vectors of the inner planets are first derived, based on the respective *Tables* by Newcomb (1895a, 1895b, 1895c, 1898) amended by Ross (1917) for the elements of Mars. Also those for the longitude, latitude and horizontal parallax of the Moon are derived from *Improved Lunar Ephemeris* (Eckert, Jones, Clark, 1954), etc. In deriving the series only the terms of the perturbations greater than 1″ or the equivalent amount for radius vector are taken into consideration. The results are Fourier series with numerical coefficients and arguments consisting of linear combinations of the mean anomalies of planets and so on.

Then, the transformations from heliocentric to geocentric coordinates for the planets and from ecliptic to equatorial coordinates are carried out. Further the effects of nutation and aberration are considered. Throughout these procedures, all the calculations are carried out retaining the form of Fourier series, thus giving apparent geocentric equatorial coordinates also as Fourier series. The operations have been performed using a Fourier series processor for computer developed by the author. At the final stage the arguments are reduced to the form of $aT+b$ by substituting numerical values for the mean anomalies and so on.

3. Structure of the Series

i) General

The formulas give the coordinates of the celestial objects at any time referred to the ecliptic or equator and the equinox *of date*. As for the rectangular coordinates of the Sun, those referred to the equator and equinox of any epoch can be also obtained.

T is the desired time for which the position is to be calculated, measured from J2000.0 in Julian ephemeris centuries, or

$$T=\frac{\mathrm{JED}-2451545.0}{36525},$$

JED being the Julian ephemeris date of the desired time.

In the terms with coefficient multiplied by T, the cosine function is not printed but replaced with double commas (,,) to show it is the cosine function having the same arguments as immediately above.

ii) Sun

The series for geocentric ecliptic coordinates are given in Table 1. They are referred to the mean equinox and do not undergo aberratoin. The latitude is zero with the present precision. In order to get apparent longitude, $-0\overset{\circ}{.}0057+0\overset{\circ}{.}0048\cos(1934^\circ T+145^\circ)$ must be added to the mean longitude.

In Table 2, the series for apparent right ascension and declination are shown. Related to the right ascension of the Sun, Greenwich mean and apparent sidereal times are given by

$$\mathrm{GMST}=12^{\mathrm{h}}+\mathrm{UT}+\alpha_{\mathrm{m}}$$

and

$$\mathrm{GAST}=12^{\mathrm{h}}+\mathrm{UT}+\alpha_{\mathrm{m}}+p$$

respectively, where UT is the universal time,

$$\alpha_m = 18^h.69735 + 2400^h.05130\ T$$

and

$$p = 0^h.00029 \cos\ (1934^\circ\ T + 145^\circ).$$

Table 1. Sun: Mean longitude and geocentric distance (Latitude is zero)

LONGITUDE

$$\begin{aligned}
&280.4659^\circ + 36000.7695^\circ\ T \\
&+ 1.9147 \cos (35999.050^\circ\ T + 267.520^\circ) \\
&- 48'' T \\
&+ 0.0200 \cos (71998.1^\circ\ T + 265.1^\circ) \\
&+ 20 \cos (32964^\circ\ T + 158^\circ) \\
&+ 18 \cos (19^\circ\ T + 159^\circ) \\
&+ 18 \cos (445267^\circ\ T + 208^\circ) \\
&+ 15 \cos (45038^\circ\ T + 254^\circ) \\
&+ 13 \cos (22519^\circ\ T + 352^\circ) \\
&+ 7 \cos (65929^\circ\ T + 45^\circ) \\
&+ 7 \cos (3035^\circ\ T + 110^\circ) \\
&+ 7 \cos (9038^\circ\ T + 64^\circ) \\
&+ 6 \cos (33718^\circ\ T + 316^\circ) \\
&+ 5 \cos (155^\circ\ T + 118^\circ) \\
&+ 0.0005 \cos (2281^\circ\ T + 221^\circ) \\
&+ 4 \cos (29930^\circ\ T + 48^\circ) \\
&+ 4 \cos (31557^\circ\ T + 161^\circ)
\end{aligned}$$

DISTANCE

$$\begin{aligned}
&\text{AU}\ 1.000140 \cos (0^\circ\ T + 0^\circ) \\
&+ 0.016706 \cos (35999.05^\circ\ T + 177.53^\circ) \\
&- 42'' T \\
&+ 139 \cos (71998^\circ\ T + 175^\circ) \\
&+ 31 \cos (445267^\circ\ T + 298^\circ) \\
&+ 16 \cos (32964^\circ\ T + 68^\circ) \\
&+ 16 \cos (45038^\circ\ T + 164^\circ) \\
&+ 5 \cos (22519^\circ\ T + 233^\circ) \\
&+ 5 \cos (33718^\circ\ T + 226^\circ)
\end{aligned}$$

Table 2. Sun: Apparent right ascension and declination

RIGHT ASCENSION

$$\begin{aligned}
&18^h.69735 + 2400^h.05130\ T \\
&+ 0^h.16419 \cos (72001.539^\circ\ T + 290.920^\circ) \\
&- 19'' T \\
&+ 12764 \cos (35999.050^\circ\ T + 267.520^\circ) \\
&- 32'' T \\
&+ 549 \cos (36002.5^\circ\ T + 113.4^\circ) \\
&- 2'' T \\
&+ 549 \cos (108000.6^\circ\ T + 288.5^\circ) \\
&- 2'' T \\
&+ 353 \cos (144003.1^\circ\ T + 311.9^\circ) \\
&+ 133 \cos (71998.1^\circ\ T + 265.1^\circ) \\
&+ 32 \cos (1934^\circ\ T + 145^\circ) \\
&+ 24 \cos (108004^\circ\ T + 134^\circ) \\
&+ 24 \cos (180002^\circ\ T + 309^\circ) \\
&+ 15 \cos (144000^\circ\ T + 286^\circ) \\
&+ 13 \cos (32964^\circ\ T + 158^\circ) \\
&+ 12 \cos (19^\circ\ T + 159^\circ) \\
&+ 12 \cos (445267^\circ\ T + 208^\circ) \\
&+ 10 \cos (45038^\circ\ T + 254^\circ) \\
&+ 10 \cos (216005^\circ\ T + 333^\circ) \\
&+ 9 \cos (22519^\circ\ T + 352^\circ) \\
&+ 5 \cos (65929^\circ\ T + 45^\circ) \\
&+ 5 \cos (3035^\circ\ T + 110^\circ) \\
&+ 5 \cos (9038^\circ\ T + 64^\circ) \\
&+ 4 \cos (33718^\circ\ T + 316^\circ) \\
&+ 3 \cos (155^\circ\ T + 118^\circ) \\
&+ 3 \cos (73936^\circ\ T + 166^\circ) \\
&+ 3 \cos (2281^\circ\ T + 221^\circ) \\
&+ 0.00003 \cos (3^\circ\ T + 296^\circ) \\
&+ 3 \cos (29930^\circ\ T + 48^\circ) \\
&+ 3 \cos (31557^\circ\ T + 161^\circ)
\end{aligned}$$

DECLINATION

$$\begin{aligned}
&+ 23.2643^\circ \cos (36000.7696^\circ T + 190.4602^\circ) \\
&- 127'' T \\
&+ 0.3888^\circ \cos (1.72^\circ\ T + 12.94^\circ) \\
&- 12'' T \\
&+ 3886 \cos (71999.82^\circ\ T + 187.99^\circ) \\
&- 12'' T \\
&+ 1646 \cos (108002.3^\circ\ T + 211.4^\circ) \\
&- 3'' T \\
&+ 82 \cos (72003^\circ\ T + 34^\circ) \\
&+ 82 \cos (144001^\circ\ T + 209^\circ) \\
&+ 73 \cos (107999^\circ\ T + 186^\circ) \\
&+ 31 \cos (180004^\circ\ T + 232^\circ) \\
&+ 22 \cos (37935^\circ\ T + 65^\circ) \\
&+ 8 \cos (35997^\circ\ T + 345^\circ) \\
&+ 4 \cos (68965^\circ\ T + 78^\circ) \\
&+ 4 \cos (3036^\circ\ T + 123^\circ) \\
&+ 3 \cos (481268^\circ\ T + 128^\circ) \\
&+ 3 \cos (35982^\circ\ T + 121^\circ) \\
&+ 3 \cos (36020^\circ\ T + 80^\circ) \\
&+ 3 \cos (409266^\circ\ T + 287^\circ) \\
&+ 3 \cos (13482^\circ\ T + 293^\circ) \\
&+ 3 \cos (9037^\circ\ T + 332^\circ) \\
&+ 3 \cos (180000^\circ\ T + 206^\circ)
\end{aligned}$$

In Table 3, the series for equatorial rectangular coordinates are shown. The coordinates are free from aberration and are referred to the mean equator and equinox of date. However, the series give those referred to the equator and equinox of any epoch, if $-1^\circ.3963\,\tau$ is added to the arguments of cosine functions, τ being the time interval from the epoch to the desired time in Julian ephemeris centuries.

Table 3. Sun : Equatorial rectangular coordinates

X

	AU		°		°	
+	0.999860	cos (	36000.7696T	+	280.4659	)
+	25063	cos (	1.720 T	+	102.941	)
-	63T		''			
+	8354	cos (	71999.82 T	+	277.99	)
-	21T		''			
+	105	cos (	107999 T	+	276	)
+	35	cos (	35997 T	+	75	)
+	31	cos (	481268 T	+	218	)
+	26	cos (	3036 T	+	213	)
+	21	cos (	9037 T	+	244	)
+	16	cos (	35982 T	+	211	)
+	16	cos (	36020 T	+	170	)
+	14	cos (	13482 T	+	23	)
+	10	cos (	58520 T	+	9	)
+	9	cos (	68965 T	+	168	)
+	7	cos (	2282 T	+	54	)
+	7	cos (	101930 T	+	56	)
+	7	cos (	29928 T	+	35	)
+	6	cos (	32966 T	+	261	)
+	6	cos (	39035 T	+	120	)
+	6	cos (	26962 T	+	306	)
+	6	cos (	45039 T	+	75	)
+	6	cos (	81038 T	+	265	)
+	5	cos (	36156 T	+	128	)
+	5	cos (	35846 T	+	253	)
+	4	cos (	33720 T	+	149	)
+	4	cos (	38281 T	+	232	)
+	4	cos (	6071 T	+	323	)
+	4	cos (	65931 T	+	58	)
+	4	cos (	67558 T	+	172	)
+	4	cos (	4444 T	+	209	)

Y

	AU		°		°	
+	0.917354	cos (	36000.7696T	+	190.4659	)
+	91T		''			
+	22995	cos (	1.720 T	+	12.941	)
-	56T		''			
+	7664	cos (	71999.82 T	+	187.99	)
-	19T		''			
+	0.000096	cos (	107999 T	+	186	)
+	32	cos (	35997 T	+	165	)
+	28	cos (	481268 T	+	128	)
+	23	cos (	3036 T	+	123	)
+	20	cos (	9037 T	+	334	)
+	14	cos (	35982 T	+	121	)
+	14	cos (	36020 T	+	80	)
+	13	cos (	13482 T	+	293	)
+	9	cos (	58520 T	+	279	)
+	9	cos (	68965 T	+	78	)
+	6	cos (	2282 T	+	324	)
+	6	cos (	29928 T	+	125	)
+	6	cos (	101930 T	+	326	)
+	6	cos (	39035 T	+	30	)
+	6	cos (	32966 T	+	171	)
+	6	cos (	45039 T	+	345	)
+	6	cos (	26962 T	+	216	)
+	5	cos (	81038 T	+	175	)
+	4	cos (	36156 T	+	38	)
+	4	cos (	35846 T	+	163	)
+	4	cos (	33720 T	+	59	)
+	4	cos (	38281 T	+	142	)

Z

	AU		°		°	
+	0.397721	cos (	36000.7696T	+	190.4659	)
-	208T		''			
+	9970	cos (	1.72 T	+	12.94	)
-	30T		''			
+	3323	cos (	71999.82 T	+	187.99	)
-	10T		''			
+	42	cos (	107999 T	+	186	)
+	14	cos (	35997 T	+	165	)
+	12	cos (	481268 T	+	128	)
+	10	cos (	3036 T	+	123	)
+	8	cos (	9037 T	+	334	)
+	6	cos (	35982 T	+	121	)
+	6	cos (	36020 T	+	80	)
+	6	cos (	13482 T	+	293	)
+	4	cos (	58520 T	+	279	)
+	4	cos (	68965 T	+	78	)

iii) Moon

The series for the Moon are given in Tables 4 and 5. Both the ecliptic and equatorial coordinates are referred to the true equinox of date and suffer aberration, though it is very small.

iv) Mercury, Venus and Mars

The series for these planets are listed in Tables 6 through 11. The heliocentric coordinates are referred to the mean equinox of date and do not suffer aberration. Series for apparent right ascension, declination and geocentric distance are not given for these planets because they are too lengthy. Instead, the series giving the geocentric equatorial rectangular coordinates are shown. They are referred to the true equator and equinox of date and suffer aberration. Therefore the apparent right ascension and declination are obtained directly by

$$\text{R.A.} = \tan^{-1}\frac{Y}{X} \quad \text{and} \quad \text{Dec.} = \tan^{-1}\frac{Z}{\sqrt{X^2+Y^2}}.$$

Also,

$$d = \sqrt{X^2+Y^2+Z^2}$$

gives the geocentric distance, though it is not the true distance but suffering aberration.

Table 4. Moon: Apparent longitude, latitude and horizontal parallax

LONGITUDE

$$
\begin{aligned}
&218.3162 + 481267.8809\,T \\
&+ 6.2888 \cos(477198.868\,T + 44.963) \\
&+ 1.2740 \cos(413335.35\,T + 10.74) \\
&+ 0.6583 \cos(890534.22\,T + 145.70) \\
&+ 0.2136 \cos(954397.74\,T + 179.93) \\
&+ 0.1851 \cos(35999.05\,T + 87.53) \\
&+ 0.1144 \cos(966404.0\,T + 276.5) \\
&+ 0.0588 \cos(63863.5\,T + 124.2) \\
&+ 0.0571 \cos(377336.3\,T + 13.2) \\
&+ 0.0533 \cos(1367733.1\,T + 280.7) \\
&+ 0.0458 \cos(854535.2\,T + 148.2) \\
&+ 0.0409 \cos(441199.8\,T + 47.4) \\
&+ 0.0347 \cos(445267.1\,T + 27.9) \\
&+ 0.0304 \cos(513197.9\,T + 222.5) \\
&+ 0.0154 \cos(75870\,T + 41) \\
&+ 0.0125 \cos(1443603\,T + 52) \\
&+ 0.0110 \cos(489205\,T + 142) \\
&+ 0.0107 \cos(1303870\,T + 246) \\
&+ 0.0100 \cos(1431597\,T + 315) \\
&+ 0.0085 \cos(826671\,T + 111) \\
&+ 0.0079 \cos(449334\,T + 188) \\
&+ 0.0068 \cos(926533\,T + 323) \\
&+ 0.0052 \cos(31932\,T + 107) \\
&+ 0.0050 \cos(481266\,T + 205) \\
&+ 0.0040 \cos(1331734\,T + 283) \\
&+ 0.0040 \cos(1844932\,T + 56) \\
&+ 0.0040 \cos(133\,T + 29) \\
&+ 0.0038 \cos(1781068\,T + 21) \\
&+ 0.0037 \cos(541062\,T + 259) \\
&+ 0.0028 \cos(1934\,T + 145) \\
&+ 0.0027 \cos(918399\,T + 182) \\
&+ 0.0026 \cos(1379739\,T + 17) \\
&+ 0.0024 \cos(99863\,T + 122) \\
&+ 0.0023 \cos(922466\,T + 163) \\
&+ 0.0022 \cos(818536\,T + 151) \\
&+ 0.0021 \cos(990397\,T + 357) \\
&+ 0.0021 \cos(71998\,T + 85) \\
&+ 0.0021 \cos(341337\,T + 16) \\
&+ 0.0018 \cos(401329\,T + 274) \\
&+ 0.0016 \cos(1856938\,T + 152) \\
&+ 0.0012 \cos(1267871\,T + 249) \\
&+ 0.0011 \cos(1920802\,T + 186) \\
&+ 0.0009 \cos(858602\,T + 129) \\
&+ 0.0008 \cos(1403732\,T + 98) \\
&+ 0.0007 \cos(790672\,T + 114) \\
&+ 0.0007 \cos(405201\,T + 50) \\
&+ 0.0007 \cos(485333\,T + 186) \\
&+ 0.0007 \cos(27864\,T + 127) \\
&+ 0.0006 \cos(111869\,T + 38) \\
&+ 0.0006 \cos(2258267\,T + 156) \\
&+ 0.0005 \cos(1908795\,T + 90) \\
&+ 0.0005 \cos(1745069\,T + 24) \\
&+ 0.0005 \cos(509131\,T + 242) \\
&+ 0.0004 \cos(39871\,T + 223) \\
&+ 0.0004 \cos(12006\,T + 187) \\
&+ 0.0003 \cos(958465\,T + 340) \\
&+ 0.0003 \cos(381404\,T + 354) \\
&+ 0.0003 \cos(349472\,T + 337) \\
&+ 0.0003 \cos(1808933\,T + 58) \\
&+ 0.0003 \cos(549197\,T + 220) \\
&+ 0.0003 \cos(4067\,T + 70) \\
&+ 0.0003 \cos(2322131\,T + 191)
\end{aligned}
$$

LATITUDE

$$
\begin{aligned}
&+ 5.1281 \cos(483202.019\,T + 3.273) \\
&+ 0.2806 \cos(960400.89\,T + 138.24) \\
&+ 0.2777 \cos(6003.15\,T + 48.31) \\
&+ 0.1733 \cos(407332.20\,T + 52.43) \\
&+ 0.0554 \cos(896537.4\,T + 104.0) \\
&+ 0.0463 \cos(69866.7\,T + 82.5) \\
&+ 0.0326 \cos(1373736.2\,T + 239.0) \\
&+ 0.0172 \cos(1437599.8\,T + 273.2) \\
&+ 0.0093 \cos(884531\,T + 187) \\
&+ 0.0088 \cos(471196\,T + 87) \\
&+ 0.0082 \cos(371333\,T + 55) \\
&+ 0.0043 \cos(547066\,T + 217) \\
&+ 0.0042 \cos(1850935\,T + 14) \\
&+ 0.0034 \cos(443331\,T + 230) \\
&+ 0.0025 \cos(860538\,T + 106) \\
&+ 0.0022 \cos(481268\,T + 308) \\
&+ 0.0022 \cos(1337737\,T + 241) \\
&+ 0.0021 \cos(105866\,T + 80) \\
&+ 0.0019 \cos(924402\,T + 141) \\
&+ 0.0018 \cos(820668\,T + 153) \\
&+ 0.0018 \cos(519201\,T + 181) \\
&+ 0.0018 \cos(1449606\,T + 10) \\
&+ 0.0015 \cos(42002\,T + 46) \\
&+ 0.0015 \cos(928469\,T + 121) \\
&+ 0.0015 \cos(996400\,T + 316) \\
&+ 0.0014 \cos(29996\,T + 129) \\
&+ 0.0013 \cos(447203\,T + 6) \\
&+ 0.0013 \cos(37935\,T + 65) \\
&+ 0.0011 \cos(1914799\,T + 48) \\
&+ 0.0010 \cos(1297866\,T + 288) \\
&+ 0.0009 \cos(1787072\,T + 340) \\
&+ 0.0008 \cos(972407\,T + 235) \\
&+ 0.0007 \cos(1309873\,T + 205) \\
&+ 0.0006 \cos(559072\,T + 134) \\
&+ 0.0006 \cos(1361730\,T + 322) \\
&+ 0.0005 \cos(848532\,T + 190) \\
&+ 0.0005 \cos(419339\,T + 149) \\
&+ 0.0005 \cos(948395\,T + 222) \\
&+ 0.0004 \cos(2328134\,T + 149) \\
&+ 0.0004 \cos(1024264\,T + 352) \\
&+ 0.0003 \cos(932536\,T + 282) \\
&+ 0.0003 \cos(1409735\,T + 57) \\
&+ 0.0003 \cos(2264270\,T + 115) \\
&+ 0.0003 \cos(1814936\,T + 16) \\
&+ 0.0003 \cos(335334\,T + 57)
\end{aligned}
$$

PARALLAX

$$
\begin{aligned}
&+ 0.950725 \cos(0\,T + 0) \\
&+ 0.051820 \cos(477198.868\,T + 134.963) \\
&+ 0.009530 \cos(413335.35\,T + 100.74) \\
&+ 0.007842 \cos(890534.22\,T + 235.70) \\
&+ 0.002824 \cos(954397.74\,T + 269.93) \\
&+ 0.000858 \cos(1367733.1\,T + 10.7) \\
&+ 0.000531 \cos(854535.2\,T + 238.2) \\
&+ 0.000400 \cos(377336.3\,T + 103.2) \\
&+ 0.000319 \cos(441199.8\,T + 137.4) \\
&+ 0.000271 \cos(445267\,T + 118) \\
&+ 0.000263 \cos(513198\,T + 312) \\
&+ 0.000197 \cos(489205\,T + 232) \\
&+ 0.000173 \cos(1431597\,T + 45) \\
&+ 0.000167 \cos(1303870\,T + 336) \\
&+ 0.000111 \cos(35999\,T + 178) \\
&+ 0.000103 \cos(826671\,T + 201) \\
&+ 0.000084 \cos(63864\,T + 214) \\
&+ 0.000083 \cos(926533\,T + 53) \\
&+ 0.000078 \cos(1844932\,T + 146) \\
&+ 0.000073 \cos(1781068\,T + 111) \\
&+ 0.000064 \cos(1331734\,T + 13) \\
&+ 0.000063 \cos(449334\,T + 278) \\
&+ 0.000041 \cos(481266\,T + 295) \\
&+ 0.000034 \cos(918399\,T + 272) \\
&+ 0.000033 \cos(541062\,T + 349) \\
&+ 0.000031 \cos(922466\,T + 253) \\
&+ 0.000030 \cos(75870\,T + 131) \\
&+ 0.000029 \cos(990397\,T + 87) \\
&+ 0.000026 \cos(818536\,T + 241) \\
&+ 0.000023 \cos(553069\,T + 266) \\
&+ 0.000019 \cos(1267871\,T + 339) \\
&+ 0.000013 \cos(1403732\,T + 188) \\
&+ 0.000013 \cos(341337\,T + 106) \\
&+ 0.000013 \cos(401329\,T + 4) \\
&+ 0.000012 \cos(2258267\,T + 246) \\
&+ 0.000011 \cos(1908795\,T + 180) \\
&+ 0.000011 \cos(858602\,T + 219) \\
&+ 0.000010 \cos(1745069\,T + 114) \\
&+ 0.000009 \cos(790672\,T + 204) \\
&+ 0.000007 \cos(2322131\,T + 281) \\
&+ 0.000007 \cos(1808933\,T + 148) \\
&+ 0.000006 \cos(485333\,T + 276) \\
&+ 0.000006 \cos(99863\,T + 212) \\
&+ 0.000005 \cos(405201\,T + 140)
\end{aligned}
$$

Table 5. Moon: Apparent right ascension and declination

RIGHT ASCENSION

H H
14.55441 + 32084.52539 T

	H	° °
+	0.41925	COS (477198.868 T + 44.963)
+	16358	COS (962535.762 T + 166.633)
-	19T	''
+	8494	COS (413335.35 T + 10.74)
+	7104	COS (1934.14 T + 324.96)
-	4T	''
+	7048	COS (964469.90 T + 41.59)
-	4T	''
+	4389	COS (890534.22 T + 145.70)
+	1818	COS (485336.89 T + 211.67)
-	2T	''
+	1795	COS (1439734.63 T + 301.60)
-	2T	''
+	1424	COS (954397.74 T + 179.93)
+	1235	COS (35999.05 T + 87.53)
+	778	COS (487271.0 T + 86.6)
+	773	COS (1441668.8 T + 176.6)
+	763	COS (966404.0 T + 276.5)
+	392	COS (63863.5 T + 124.2)
+	383	COS (549200.4 T + 245.9)
+	381	COS (377336.3 T + 13.2)
+	355	COS (1367733.1 T + 280.7)
+	348	COS (1925071.5 T + 63.3)
+	345	COS (1375871.1 T + 267.4)
+	306	COS (960601.6 T + 291.7)
+	305	COS (854535.2 T + 148.2)
+	295	COS (1927005.7 T + 298.2)
+	273	COS (441199.8 T + 47.4)
+	268	COS (73935.7 T + 345.9)
+	232	COS (445267.1 T + 27.9)
+	223	COS (1853070.0 T + 42.3)
+	203	COS (888600.1 T + 90.7)
+	203	COS (513197.9 T + 222.5)
+	160	COS (1916933.5 T + 76.6)
+	159	COS (551134.5 T + 120.9)
+	154	COS (72001.5 T + 110.9)
+	149	COS (1377805.3 T + 142.3)
+	102	COS (75870 T + 41)
+	97	COS (1855004 T + 277)
+	96	COS (1928940 T + 173)
+	83	COS (1443603 T + 52)
+	79	COS (1447873 T + 108)
+	78	COS (2402270 T + 198)
+	73	COS (489205 T + 142)
+	71	COS (1303870 T + 246)
+	69	COS (1918868 T + 312)
+	68	COS (1431597 T + 315)
+	67	COS (1449807 T + 343)
+	66	COS (2404205 T + 73)
+	59	COS (1026399 T + 21)
+	57	COS (826671 T + 111)
+	53	COS (449334 T + 188)
+	53	COS (998535 T + 344)
+	52	COS (926537 T + 169)
+	45	COS (926533 T + 323)
+	40	COS (2330269 T + 177)
+	38	COS (8138 T + 257)
+	34	COS (31932 T + 107)
+	34	COS (483403 T + 337)
+	34	COS (1437800 T + 67)
+	34	COS (3868 T + 200)
+	33	COS (481266 T + 205)
+	28	COS (411401 T + 136)
+	27	COS (1331734 T + 283)
+	27	COS (1844932 T + 56)
+	26	COS (133 T + 29)
+	26	COS (1781068 T + 21)
+	25	COS (541062 T + 259)
+	24	COS (898672 T + 312)
+	23	COS (1028333 T + 256)
+	23	COS (1365799 T + 226)
+	22	COS (2406139 T + 308)
+	18	COS (918399 T + 182)
+	18	COS (1403736 T + 304)
+	17	COS (2332203 T + 52)
+	17	COS (1511736 T + 143)
+	16	COS (585199 T + 243)
+	16	COS (99863 T + 122)
+	16	COS (1339872 T + 270)
+	16	COS (1379739 T + 17)
+	16	COS (922466 T + 163)
+	15	COS (1513670 T + 17)
+	15	COS (1817071 T + 45)
+	15	COS (818536 T + 151)
+	15	COS (1451741 T + 218)
+	15	COS (1475734 T + 119)
+	14	COS (2338407 T + 164)
+	14	COS (990397 T + 357)
+	14	COS (1930874 T + 48)
	H	° °
+	0.00014	COS (71998 T + 85)
+	14	COS (341337 T + 16)
+	14	COS (1000469 T + 219)
+	13	COS (1036471 T + 243)
+	13	COS (2394132 T + 212)
+	13	COS (1923137 T + 188)
+	13	COS (109935 T + 343)
+	13	COS (928471 T + 44)
+	12	COS (2889541 T + 195)
+	12	COS (2340341 T + 39)
+	11	COS (401329 T + 274)
+	11	COS (2815606 T + 299)
+	11	COS (2879469 T + 333)
+	11	COS (108001 T + 108)
+	11	COS (1856938 T + 152)
+	10	COS (2887607 T + 320)
+	10	COS (517269 T + 229)
+	10	COS (1407803 T + 284)
+	10	COS (2881403 T + 208)
+	10	COS (900606 T + 187)
+	10	COS (952464 T + 125)
+	10	COS (2817540 T + 174)
+	10	COS (34065 T + 213)
+	9	COS (37933 T + 322)
+	8	COS (852601 T + 93)
+	8	COS (886666 T + 216)
+	8	COS (475265 T + 170)
+	8	COS (1373937 T + 32)
+	8	COS (1267871 T + 249)
+	8	COS (1920802 T + 186)
+	7	COS (2266405 T + 143)
+	7	COS (587134 T + 118)
+	7	COS (2891476 T + 70)
+	7	COS (547266 T + 11)
+	7	COS (10072 T + 132)
+	7	COS (473331 T + 115)
+	7	COS (1341806 T + 145)
+	6	COS (1405670 T + 179)
+	6	COS (1503598 T + 156)
+	6	COS (1819005 T + 280)
+	6	COS (970674 T + 153)
+	6	COS (1789206 T + 8)
+	6	COS (858602 T + 129)
+	6	COS (521336 T + 209)
+	6	COS (2396067 T + 86)
+	5	COS (1477668 T + 354)
+	5	COS (1403732 T + 98)
+	5	COS (405197 T + 204)
+	5	COS (2807468 T + 312)
+	5	COS (405201 T + 50)
+	5	COS (485333 T + 186)
+	5	COS (37937 T + 168)
+	5	COS (1301935 T + 191)
+	5	COS (27864 T + 127)
+	5	COS (972608 T + 28)
+	5	COS (1034537 T + 8)
+	5	COS (790672 T + 114)
+	4	COS (958667 T + 57)
+	4	COS (1409737 T + 159)
+	4	COS (924599 T + 268)
+	4	COS (2342275 T + 274)
+	4	COS (2412343 T + 240)
+	4	COS (3366740 T + 330)
+	4	COS (1988935 T + 277)
+	4	COS (519203 T + 104)
+	4	COS (1851136 T + 347)
+	4	COS (1411870 T + 85)
+	4	COS (1515604 T + 252)
+	4	COS (2408073 T + 183)
+	3	COS (2268339 T + 18)
+	3	COS (2410408 T + 5)
+	3	COS (3364806 T + 95)
+	3	COS (1908795 T + 90)
+	3	COS (111869 T + 38)
+	3	COS (1445939 T + 233)
+	3	COS (523270 T + 84)
+	3	COS (2400336 T + 323)
+	3	COS (2743604 T + 278)
+	3	COS (1791141 T + 243)
+	3	COS (1914999 T + 202)
+	3	COS (2258267 T + 156)
+	3	COS (994468 T + 4)
+	3	COS (449338 T + 34)
+	3	COS (1745069 T + 24)
+	3	COS (1861208 T + 209)
+	3	COS (2294270 T + 180)
+	3	COS (349472 T + 337)
+	3	COS (1779134 T + 326)
+	3	COS (1990869 T + 152)
+	3	COS (1961071 T + 241)
+	3	COS (1889072 T + 66)
+	3	COS (1842998 T + 1)

Table 5. Moon: Apparent right ascension and declination (Continued)

	H		°		°	
+	0.00002	COS (	12006	T +	187	)
+	2	COS (	451272	T +	269	)
+	2	COS (	509131	T +	242	)
+	2	COS (	70067	T +	236	)
+	2	COS (	1880934	T +	79	)
+	2	COS (	3368674	T +	205	)
+	2	COS (	2893410	T +	305	)
+	2	COS (	2883338	T +	83	)
+	2	COS (	381404	T +	354	)
+	2	COS (	39871	T +	223	)
+	2	COS (	1889069	T +	220	)
+	2	COS (	2819474	T +	49	)
+	2	COS (	2414277	T +	115	)
+	2	COS (	549197	T +	220	)
+	2	COS (	958465	T +	340	)
+	2	COS (	135865	T +	325	)
+	2	COS (	4067	T +	70	)

DECLINATION

	°		°		°	
+	23.1925	COS (	481267.8808	T +	128.3163	)
−	127T		″			
+	4.9107	COS (	483202.019	T +	3.273	)
+	1.2789	COS (	4069.01	T +	173.35	)
−	7T		″			
+	1.2707	COS (	958466.75	T +	263.28	)
−	7T		″			
+	0.2686	COS (	960400.89	T +	138.24	)
+	2659	COS (	6003.15	T +	48.31	)
+	2646	COS (	67932.53	T +	207.58	)
+	2510	COS (	894603.23	T +	229.05	)
+	1657	COS (	407332.2	T +	52.4	)
+	1621	COS (	1443803.6	T +	24.9	)
−	3T		″			
+	1470	COS (	1371802.1	T +	4.0	)
+	1195	COS (	409266.3	T +	287.4	)
+	1060	COS (	479333.7	T +	253.4	)
+	1033	COS (	1445737.8	T +	259.9	)
+	778	COS (	1435665.6	T +	38.2	)
+	531	COS (	896537.4	T +	104.0	)
+	443	COS (	69866.7	T +	82.5	)
+	377	COS (	517266.9	T +	305.8	)
+	371	COS (	445268.8	T +	130.8	)
+	312	COS (	1373736.2	T +	239.0	)
+	272	COS (	966604.8	T +	70.0	)
+	268	COS (	1921002.5	T +	159.9	)
+	264	COS (	545131.4	T +	342.5	)
+	244	COS (	485136.2	T +	58.2	)
+	220	COS (	1447671.9	T +	134.9	)
+	190	COS (	1849001.0	T +	139.0	)
+	172	COS (	968538.9	T +	304.9	)
+	170	COS (	1922936.6	T +	34.9	)
+	164	COS (	1437600	T +	273	)
+	116	COS (	103932	T +	205	)
+	115	COS (	858604	T +	232	)
+	102	COS (	1335803	T +	6	)
+	102	COS (	922468	T +	266	)
+	88	COS (	884531	T +	187	)
+	85	COS (	473130	T +	322	)
+	84	COS (	471196	T +	87	)
+	84	COS (	373267	T +	290	)
+	83	COS (	994466	T +	81	)
+	78	COS (	371333	T +	55	)
+	70	COS (	926535	T +	246	)
+	70	COS (	36001	T +	190	)
+	64	COS (	40068	T +	171	)
+	58	COS (	956533	T +	28	)
+	58	COS (	2135	T +	298	)
+	57	COS (	1030468	T +	104	)
+	50	COS (	1912864	T +	173	)
+	49	COS (	1857139	T +	126	)
+	41	COS (	547066	T +	217	)
+	41	COS (	555204	T +	204	)
+	41	COS (	31930	T +	4	)
+	40	COS (	1850935	T +	14	)
+	38	COS (	1785137	T +	105	)
+	37	COS (	1032402	T +	339	)
+	36	COS (	2334338	T +	261	)
+	35	COS (	1924871	T +	270	)
+	34	COS (	886465	T +	62	)
+	33	COS (	7937	T +	283	)
+	32	COS (	1441870	T +	150	)
+	32	COS (	443331	T +	230	)
+	32	COS (	1859073	T +	1	)
+	32	COS (	557138	T +	259	)
+	31	COS (	2408274	T +	157	)
+	31	COS (	2398201	T +	295	)
+	30	COS (	405398	T +	177	)
+	30	COS (	1307939	T +	330	)
+	29	COS (	2406339	T +	282	)
+	23	COS (	860538	T +	106	)

	°		°		°	
+	0.0023	COS (	1369868	T +	309	)
+	22	COS (	417404	T +	274	)
+	22	COS (	2336272	T +	136	)
+	22	COS (	1022330	T +	118	)
+	21	COS (	1337737	T +	241	)
+	19	COS (	105866	T +	80	)
+	19	COS (	930602	T +	47	)
+	19	COS (	553269	T +	329	)
+	19	COS (	2400136	T +	170	)
+	18	COS (	2326200	T +	274	)
+	18	COS (	924402	T +	141	)
+	18	COS (	1407801	T +	182	)
+	17	COS (	519201	T +	181	)
+	17	COS (	892669	T +	354	)
+	17	COS (	820668	T +	153	)
+	15	COS (	513200	T +	325	)
+	14	COS (	2262336	T +	240	)
+	14	COS (	42002	T +	46	)
+	14	COS (	1813002	T +	141	)
+	14	COS (	962335	T +	193	)
+	14	COS (	928469	T +	121	)
+	14	COS (	996400	T +	316	)
+	13	COS (	1449606	T +	10	)
+	13	COS (	970473	T +	360	)
+	13	COS (	29996	T +	129	)
+	13	COS (	2410208	T +	31	)
+	13	COS (	447203	T +	6	)
+	12	COS (	37935	T +	65	)
+	12	COS (	489406	T +	115	)
+	12	COS (	31933	T +	30	)
+	11	COS (	65998	T +	333	)
+	11	COS (	1399667	T +	41	)
+	11	COS (	1507667	T +	239	)
+	10	COS (	581130	T +	340	)
+	10	COS (	1914799	T +	48	)
+	10	COS (	962534	T +	64	)
+	10	COS (	2	T +	13	)
+	10	COS (	445265	T +	105	)
+	9	COS (	1297866	T +	288	)
+	9	COS (	1471665	T +	216	)
+	9	COS (	1403734	T +	21	)
+	9	COS (	972407	T +	235	)
+	8	COS (	1929141	T +	327	)
+	8	COS (	2883538	T +	57	)
+	8	COS (	481401	T +	248	)
+	8	COS (	481135	T +	189	)
+	7	COS (	1787072	T +	340	)
+	7	COS (	1931075	T +	202	)
+	7	COS (	2885472	T +	292	)
+	7	COS (	2811537	T +	36	)
+	7	COS (	1479803	T +	202	)
+	7	COS (	1407805	T +	27	)
+	6	COS (	1509601	T +	114	)
+	6	COS (	822602	T +	28	)
+	6	COS (	559072	T +	134	)
+	6	COS (	1309873	T +	205	)
+	6	COS (	491340	T +	350	)
+	6	COS (	1861007	T +	236	)
+	6	COS (	449336	T +	111	)
+	6	COS (	1379940	T +	171	)
+	6	COS (	1361730	T +	322	)
+	5	COS (	79939	T +	304	)
+	5	COS (	1299804	T +	9	)
+	5	COS (	411200	T +	162	)
+	5	COS (	848532	T +	190	)
+	5	COS (	964671	T +	195	)
+	5	COS (	1919068	T +	285	)
+	5	COS (	409270	T +	133	)
+	4	COS (	2813471	T +	271	)
+	4	COS (	419339	T +	149	)
+	4	COS (	2338206	T +	11	)
+	4	COS (	1749138	T +	107	)
+	4	COS (	337268	T +	292	)
+	4	COS (	139931	T +	203	)
+	4	COS (	822605	T +	234	)
+	4	COS (	948395	T +	222	)
+	4	COS (	2328134	T +	149	)
+	4	COS (	1024264	T +	352	)
+	4	COS (	553266	T +	303	)
+	3	COS (	2402070	T +	45	)
+	3	COS (	1847067	T +	84	)
+	3	COS (	477400	T +	18	)
+	3	COS (	1381874	T +	46	)
+	3	COS (	932536	T +	282	)
+	3	COS (	1481737	T +	77	)
+	3	COS (	1409735	T +	57	)
+	3	COS (	2390063	T +	308	)
+	3	COS (	1409739	T +	262	)
+	3	COS (	2264270	T +	115	)
+	3	COS (	1885000	T +	317	)
+	3	COS (	898472	T +	159	)
+	3	COS (	1814936	T +	16	)

Table 6. Mercury: Heliocentric longitude, latitude and radius vector

LONGITUDE

	°		°			
	252.2502	+	149474.0714	T		
	°		°		°	
+	23.4405	COS (	149472.5153	T +	84.7947	)
+	23T			''		
+	2.9818	COS (	298945.031	T +	259.589	)
+	6T			''		
+	0.5258	COS (	448417.55	T +	74.38	)
+	1796	COS (	298945.77	T +	137.84	)
+	1061	COS (	597890.1	T +	249.2	)
+	850	COS (	149473.3	T +	143.0	)
+	760	COS (	448418.3	T +	312.6	)
+	256	COS (	597890.8	T +	127.4	)
+	230	COS (	747362.6	T +	64.0	)
+	81	COS (	747363	T +	302	)
+	69	COS (	1	T +	148	)
+	52	COS (	896835	T +	239	)
+	23	COS (	896836	T +	117	)
+	19	COS (	6356	T +	85	)
+	11	COS (	1046308	T +	54	)
+	10	COS (	32437	T +	234	)
+	9	COS (	143403	T +	171	)
+	6	COS (	155828	T +	268	)
+	5	COS (	1046308	T +	292	)
+	4	COS (	143117	T +	84	)
+	3	COS (	181909	T +	63	)
+	3	COS (	123392	T +	288	)
+	3	COS (	448419	T +	11	)

LATITUDE

	°		°		°	
+	6.7057	COS (	149472.886	T +	113.919	)
+	17T			''		
+	1.4396	COS (	0.37	T +	119.12	)
+	5T			''		
+	1.3643	COS (	298945.40	T +	288.71	)
+	5T			''		
+	0.3123	COS (	448417.92	T +	103.51	)
+	753	COS (	597890.4	T +	278.3	)
+	367	COS (	149472.1	T +	55.7	)
+	187	COS (	747362.9	T +	93.1	)
+	50	COS (	298945	T +	230	)
+	47	COS (	896835	T +	268	)
+	28	COS (	448419	T +	342	)
+	23	COS (	298946	T +	347	)
+	20	COS (	597891	T +	157	)
+	12	COS (	1046308	T +	83	)
+	9	COS (	747364	T +	331	)
+	9	COS (	448417	T +	45	)
+	5	COS (	149474	T +	352	)
+	3	COS (	896836	T +	146	)

RADIUS VECTOR

	AU		°		°	
+	0.395283	COS (	0	T +	0	)
+	2T			''		
+	78341	COS (	149472.515	T +	354.795	)
+	8T			''		
+	7955	COS (	298945.03	T +	169.59	)
+	2T			''		
+	1214	COS (	448417.55	T +	344.38	)
+	218	COS (	597890.1	T +	159.2	)
+	42	COS (	747363	T +	334	)
+	6	COS (	896835	T +	149	)

Table 7. Mercury: Apparent geocentric equatorial rectangular coordinates

X

	AU		°		°	
+	0.999860	COS (	36000.7696	T +	280.4583	)
+	377489	COS (	149474.0714	T +	252.2228	)
+	118956	COS (	1.5561	T +	257.4522	)
+	12T			''		
+	38402	COS (	298946.587	T +	66.995	)
+	25063	COS (	1.720	T +	102.941	)
-	63T			''		
+	8354	COS (	71999.82	T +	277.99	)
-	21T			''		
+	5860	COS (	448419.10	T +	241.77	)
+	2068	COS (	149470.96	T +	97.34	)
+	1414	COS (	149471.70	T +	155.59	)
+	1060	COS (	597891.6	T +	56.6	)
+	446	COS (	0.8	T +	199.2	)
+	211	COS (	747364.1	T +	231.4	)
+	144	COS (	298944.2	T +	330.4	)
+	141	COS (	298943.5	T +	272.1	)
+	105	COS (	107999	T +	276	)
+	45	COS (	896837	T +	46	)
+	42	COS (	34067	T +	226	)
+	42	COS (	37935	T +	155	)
+	35	COS (	35997	T +	75	)
+	31	COS (	481268	T +	218	)
+	26	COS (	3036	T +	213	)
+	25	COS (	262947	T +	134	)
+	22	COS (	448417	T +	145	)
+	21	COS (	9037	T +	244	)
+	16	COS (	448416	T +	87	)
+	16	COS (	77473	T +	141	)
+	16	COS (	147540	T +	197	)
+	16	COS (	151408	T +	127	)
+	16	COS (	35982	T +	211	)
+	16	COS (	36020	T +	170	)
+	14	COS (	13482	T +	23	)
+	10	COS (	1046309	T +	221	)
+	10	COS (	58520	T +	9	)
+	9	COS (	68965	T +	168	)
+	9	COS (	412420	T +	309	)
+	8	COS (	113475	T +	139	)
+	8	COS (	149473	T +	194	)
	AU		°		°	
+	0.000007	COS (	2282	T +	54	)
+	7	COS (	101930	T +	56	)
+	7	COS (	29928	T +	35	)
+	7	COS (	143118	T +	245	)
+	7	COS (	155830	T +	80	)
+	6	COS (	32966	T +	261	)
+	6	COS (	39035	T +	120	)
+	6	COS (	26962	T +	306	)
+	6	COS (	45039	T +	75	)
+	6	COS (	81038	T +	265	)
+	5	COS (	1936	T +	132	)
+	5	COS (	1933	T +	158	)
+	5	COS (	36156	T +	128	)
+	5	COS (	35846	T +	253	)
+	4	COS (	72000	T +	213	)
+	4	COS (	33720	T +	149	)
+	4	COS (	38281	T +	232	)
+	4	COS (	597889	T +	320	)
+	4	COS (	65931	T +	58	)
+	4	COS (	6071	T +	323	)
+	4	COS (	67558	T +	172	)
+	4	COS (	4444	T +	209	)

Y

	AU		°		°	
+	0.917354	COS (	36000.7696	T +	190.4583	)
+	91T			''		
+	346339	COS (	149474.0714	T +	162.2228	)
+	32T			''		
+	109140	COS (	1.556	T +	167.452	)
+	21T			''		
+	35233	COS (	298946.587	T +	336.995	)
+	7T			''		
+	22995	COS (	1.720	T +	12.941	)
-	56T			''		
+	18380	COS (	149472.886	T +	293.894	)
-	5T			''		
+	7664	COS (	71999.82	T +	187.99	)
-	19T			''		
+	5792	COS (	0.37	T +	299.12	)
+	5376	COS (	448419.10	T +	151.77	)

Table 7. Mercury: Apparent geocentric equatorial rectangular coordinates (Continued)

	AU		°		°	
+	0.001897	cos (	149470.96	T +	187.34	)
+	1870	cos (	298945.40	T +	108.71	)
+	1297	cos (	149471.70	T +	245.59	)
+	973	cos (	597891.6	T +	326.6	)
+	409	cos (	0.8	T +	109.2	)
+	285	cos (	448417.9	T +	283.5	)
+	193	cos (	747364.1	T +	141.4	)
+	132	cos (	298944.2	T +	60.4	)
+	129	cos (	298943.5	T +	2.1	)
+	101	cos (	149472	T +	56	)
+	96	cos (	107999	T +	186	)
+	52	cos (	597890	T +	98	)
+	47	cos (	34067	T +	136	)
+	41	cos (	896837	T +	316	)
+	32	cos (	35997	T +	165	)
+	29	cos (	37935	T +	65	)
+	28	cos (	481268	T +	128	)
+	23	cos (	3036	T +	123	)
+	23	cos (	262947	T +	44	)
+	20	cos (	448417	T +	235	)
+	20	cos (	9037	T +	334	)
+	18	cos (	147540	T +	107	)
+	15	cos (	448416	T +	177	)
+	15	cos (	77473	T +	231	)
+	14	cos (	35982	T +	121	)
+	14	cos (	36020	T +	80	)
+	13	cos (	13482	T +	293	)
+	11	cos (	151408	T +	37	)
+	10	cos (	747363	T +	273	)
+	9	cos (	1046309	T +	131	)
+	9	cos (	58520	T +	279	)
+	9	cos (	68965	T +	78	)
+	8	cos (	113475	T +	49	)
+	8	cos (	412420	T +	219	)
+	7	cos (	149473	T +	104	)
+	7	cos (	298945	T +	230	)
+	6	cos (	2282	T +	324	)
+	6	cos (	29928	T +	125	)
+	6	cos (	101930	T +	326	)
+	6	cos (	143118	T +	155	)
+	6	cos (	155830	T +	350	)
+	6	cos (	39035	T +	30	)
+	6	cos (	32966	T +	171	)
+	6	cos (	1933	T +	248	)
+	6	cos (	45039	T +	345	)
+	6	cos (	26962	T +	216	)
+	5	cos (	81038	T +	175	)
+	4	cos (	36156	T +	38	)
+	4	cos (	35846	T +	163	)
+	4	cos (	72000	T +	123	)
+	4	cos (	33720	T +	59	)
+	4	cos (	38281	T +	142	)
+	4	cos (	597889	T +	50	)
+	4	cos (	1936	T +	42	)

Z

	AU		°		°	
+	0.397721	cos (	36000.7696	T +	190.4583	)
-	208T		″			
+	150156	cos (	149474.0714	T +	162.2228	)
-	80T		″			
+	47318	cos (	1.556	T +	167.453	)
-	20T		″			
+	42395	cos (	149472.886	T +	113.894	)
+	15T		″			
+	15275	cos (	298946.587	T +	336.996	)
-	7T		″			
+	13360	cos (	0.371	T +	119.124	)
+	6T		″			
+	9970	cos (	1.72	T +	12.94	)
-	30T		″			
+	4313	cos (	298945.40	T +	288.66	)
+	3323	cos (	71999.82	T +	187.99	)
-	10T		″			
+	2331	cos (	448419.10	T +	151.77	)
+	823	cos (	149471.0	T +	187.3	)
+	658	cos (	448417.9	T +	103.5	)
+	562	cos (	149471.7	T +	245.6	)
+	422	cos (	597891.6	T +	326.6	)
+	232	cos (	149472.1	T +	235.7	)
+	177	cos (	0.8	T +	109.2	)
+	119	cos (	597890.4	T +	278.3	)
+	84	cos (	747364	T +	141	)
+	57	cos (	298944	T +	60	)
+	56	cos (	298943	T +	2	)
+	42	cos (	107999	T +	186	)
+	37	cos (	37935	T +	65	)
+	24	cos (	747363	T +	93	)
+	18	cos (	896837	T +	316	)
+	16	cos (	298945	T +	50	)
+	14	cos (	151408	T +	37	)
+	14	cos (	35997	T +	165	)
+	12	cos (	481268	T +	128	)
+	11	cos (	262947	T +	44	)
+	10	cos (	3036	T +	123	)
+	9	cos (	448417	T +	235	)
+	8	cos (	9037	T +	334	)
+	7	cos (	77473	T +	231	)
+	6	cos (	448416	T +	177	)
+	6	cos (	35982	T +	121	)
+	6	cos (	36020	T +	80	)
+	6	cos (	13482	T +	293	)
+	5	cos (	896835	T +	268	)
+	4	cos (	1046309	T +	131	)
+	4	cos (	58520	T +	279	)
+	4	cos (	34067	T +	316	)
+	4	cos (	68965	T +	78	)
+	4	cos (	113475	T +	49	)
+	4	cos (	412420	T +	219	)

Table 8. Venus: Heliocentric longitude, latitude and radius vector

LONGITUDE

181.9793° + 58519.2125° T

	°		°		°	
+	0.7761	cos (	58517.81	T +	320.41	)
-	54T		″			
+	503	cos (	117036.6	T +	300.6	)
+	33	cos (	117036	T +	11	)
+	32	cos (	45038	T +	254	)
+	20	cos (	67556	T +	159	)
+	14	cos (	22519	T +	172	)
+	10	cos (	9038	T +	244	)
+	8	cos (	55483	T +	239	)
+	8	cos (	155	T +	303	)
+	7	cos (	58519	T +	70	)
+	7	cos (	175554	T +	351	)
+	5	cos (	3035	T +	110	)
+	4	cos (	54076	T +	34	)

LATITUDE

	°		°		°	
+	3.3939	cos (	58518.312	T +	15.299	)
+	10T		″			
+	0.0230	cos (	0.5	T +	144.9	)
+	230	cos (	117036.1	T +	65.7	)
+	5	cos (	175555	T +	46	)

RADIUS VECTOR

	AU		°		°	
+	0.723348	cos (	0	T +	0	)
+	4899	cos (	58517.81	T +	230.41	)
-	34T		″			
+	17	cos (	117036	T +	281	)
+	16	cos (	45038	T +	164	)
+	14	cos (	67556	T +	69	)
+	4	cos (	55483	T +	121	)

Table 9. Venus: Apparent geocentric equatorial rectangular coordinates

X

AU °

+ 0.999860 cos (36000.7696T + 280.4572)
+ 722680 cos (58519.2126T + 181.9661)
+ 25063 cos (1.720 T + 102.941)
- 63T ″
+ 8354 cos (71999.82 T + 277.99)
- 21T ″
+ 7342 cos (1.41 T + 311.57)
- 52T ″
+ 2447 cos (117037.02 T + 232.39)
- 17T ″
+ 635 cos (58517.4 T + 28.6)
+ 105 cos (107999 T + 276)
+ 42 cos (34067 T + 226)
+ 42 cos (37935 T + 155)
+ 40 cos (9037 T + 245)
+ 39 cos (13482 T + 335)
+ 35 cos (35997 T + 75)
+ 34 cos (81038 T + 353)
+ 31 cos (481268 T + 218)
+ 30 cos (56585 T + 127)
+ 30 cos (60453 T + 57)
+ 26 cos (3036 T + 213)
+ 16 cos (35982 T + 211)
+ 16 cos (36020 T + 170)
+ 14 cos (13482 T + 23)
+ 12 cos (175555 T + 283)
+ 12 cos (103557 T + 166)
+ 10 cos (58520 T + 9)
+ 9 cos (68965 T + 168)
+ 9 cos (81038 T + 84)
+ 9 cos (36000 T + 100)
+ 7 cos (3036 T + 42)
+ 7 cos (2282 T + 54)
+ 7 cos (101930 T + 56)
+ 7 cos (29928 T + 35)
+ 6 cos (0 T + 202)
+ 6 cos (32966 T + 261)
+ 6 cos (39035 T + 120)
+ 6 cos (26962 T + 306)
+ 6 cos (45039 T + 75)
+ 6 cos (67558 T + 156)
+ 6 cos (49481 T + 28)
+ 6 cos (126075 T + 71)
+ 6 cos (81038 T + 265)
+ 5 cos (58364 T + 329)
+ 5 cos (58674 T + 215)
+ 5 cos (103556 T + 75)
+ 5 cos (36156 T + 128)
+ 5 cos (35846 T + 253)
+ 4 cos (58516 T + 279)
+ 4 cos (33720 T + 149)
+ 4 cos (38281 T + 232)
+ 4 cos (6071 T + 323)
+ 4 cos (65931 T + 58)
+ 4 cos (67558 T + 172)
+ 4 cos (4444 T + 209)

Y

AU °

+ 0.917354 cos (36000.7696T + 190.4572)
- 91T ″
+ 663046 cos (58519.2126T + 91.9661)
- 65T ″
+ 22995 cos (1.720 T + 12.941)
- 56T ″
+ 17037 cos (58518.312 T + 195.289)
- 4T ″
+ 7664 cos (71999.82 T + 187.99)
- 19T ″
+ 6736 cos (1.41 T + 221.57)
- 47T ″
+ 2245 cos (117037.02 T + 142.39)
- 16T ″
+ 582 cos (58517.4 T + 118.6)
+ 173 cos (0.5 T + 324.9)
+ 96 cos (107999 T + 186)

AU °

+ 0.000058 cos (117036 T + 246)
+ 47 cos (34067 T + 136)
+ 38 cos (9037 T + 335)
+ 36 cos (13482 T + 245)
+ 34 cos (56585 T + 37)
+ 32 cos (35997 T + 165)
+ 31 cos (81038 T + 263)
+ 29 cos (37935 T + 65)
+ 28 cos (481268 T + 128)
+ 23 cos (3036 T + 123)
+ 21 cos (60453 T + 327)
+ 14 cos (36020 T + 80)
+ 14 cos (35982 T + 121)
+ 13 cos (13482 T + 293)
+ 11 cos (175555 T + 193)
+ 11 cos (103557 T + 76)
+ 9 cos (58520 T + 279)
+ 9 cos (68965 T + 78)
+ 8 cos (81038 T + 354)
+ 8 cos (36000 T + 10)
+ 7 cos (3036 T + 312)
+ 6 cos (2282 T + 324)
+ 6 cos (29928 T + 125)
+ 6 cos (101930 T + 326)
+ 6 cos (0 T + 112)
+ 6 cos (39035 T + 30)
+ 6 cos (32966 T + 171)
+ 6 cos (45039 T + 345)
+ 6 cos (26962 T + 216)
+ 6 cos (67558 T + 66)
+ 6 cos (49481 T + 298)
+ 5 cos (126075 T + 341)
+ 5 cos (81038 T + 175)
+ 4 cos (58674 T + 125)
+ 4 cos (58364 T + 239)
+ 4 cos (103556 T + 345)
+ 4 cos (36156 T + 38)
+ 4 cos (35846 T + 163)
+ 4 cos (58516 T + 9)
+ 4 cos (38281 T + 142)
+ 4 cos (33720 T + 59)

Z

AU °

+ 0.397721 cos (36000.7696T + 190.4572)
- 208T ″
+ 287466 cos (58519.2126T + 91.9661)
- 151T ″
+ 39295 cos (58518.312 T + 15.289)
+ 15T ″
+ 9970 cos (1.72 T + 12.94)
- 30T ″
+ 3323 cos (71999.82 T + 187.99)
- 10T ″
+ 2921 cos (1.41 T + 221.57)
- 22T ″
+ 974 cos (117037.0 T + 142.4)
- 7T ″
+ 399 cos (0.5 T + 144.9)
+ 252 cos (58517.4 T + 118.6)
+ 133 cos (117036.1 T + 65.7)
+ 42 cos (107999 T + 186)
+ 37 cos (37935 T + 65)
+ 27 cos (60453 T + 327)
+ 16 cos (9037 T + 335)
+ 16 cos (13482 T + 245)
+ 14 cos (35997 T + 165)
+ 13 cos (81038 T + 263)
+ 12 cos (481268 T + 128)
+ 10 cos (3036 T + 123)
+ 6 cos (35982 T + 121)
+ 6 cos (36020 T + 80)
+ 6 cos (13482 T + 293)
+ 5 cos (175555 T + 193)
+ 5 cos (103557 T + 76)
+ 4 cos (58520 T + 279)
+ 4 cos (34067 T + 316)
+ 4 cos (68965 T + 78)

Table 10. Mars: Heliocentric longitude, latitude and radius vector

```
LONGITUDE

   °               °
355.4472 +  19141.6999 T
   °                  °              °
+ 10.6919 COS (  19139.859 T + 289.388  )
+     105T                ''
+  0.6227 COS (  38279.71  T + 308.78   )
+      12T                ''
+     504 COS (  57419.6   T + 328.2    )
+     147 COS (     19     T + 336      )
+     144 COS (  38282     T + 342      )
+     140 COS (      0     T + 180      )
+      37T                ''
+      70 COS (  16105     T +  48      )
+      60 COS (  13071     T + 168      )
+      47 COS (  76559     T + 348      )
+      45 COS (  32211     T + 191      )
+      38 COS (   2281     T +  21      )
+      28 COS (  19142     T + 142      )
+      28 COS (  57422     T +   1      )
+      23 COS (  16859     T +  13      )
+      19 COS (  14579     T +  95      )
+      18 COS (   1098     T +  50      )
+      13 COS (   4561     T + 290      )
+      10 COS (   3035     T +  39      )
+       9 COS (  35245     T +  67      )
+       9 COS (  10036     T + 167      )
+       7 COS (  29176     T + 208      )
+       7 COS (  12298     T + 166      )
+       6 COS (  51350     T + 205      )
+       5 COS (  16696     T + 137      )
+       5 COS (  21421     T +  53      )
+       4 COS (    895     T + 229      )
+       4 COS (   6069     T + 220      )
+       4 COS (  17918     T +  28      )
+       3 COS (  10017     T + 256      )
+  0.0003 COS (  76562     T +  21      )
+       3 COS (  48316     T + 179      )
+       3 COS (   6842     T + 214      )

LATITUDE

   °                  °              °
+  1.8334 COS (  19140.925 T + 215.876  )
-       7T                ''
+  0.1727 COS (      1.07  T +  16.50   )
+    1709 COS (  38280.79  T + 235.28   )
+     179 COS (  57420.6   T + 254.7    )
+      21 COS (  19139     T +   3      )
+      20 COS (  76561     T + 274      )

RADIUS VECTOR

 AU                   °              °
+ 1.530339 COS (      0     T +   0      )
+      13T                ''
+ 0.141850 COS (  19139.859 T + 199.388  )
+     139T                ''
+     6606 COS (  38279.72  T + 218.78   )
+      13T                ''
+      455 COS (  57419.6   T + 238.2    )
+       80 COS (  16105     T + 317      )
+       72 COS (  32211     T + 103      )
+       55 COS (  13071     T +  77      )
+       35 COS (  76559     T + 258      )
+       24 COS (  16859     T + 284      )
+       23 COS (  14579     T +   3      )
+       13 COS (  29176     T + 118      )
+       10 COS (  35245     T + 338      )
+        9 COS (  48316     T +  89      )
+        8 COS (   2281     T + 311      )
```

Table 11. Mars: Apparent geocentric equatorial rectangular coordinates

```
X

 AU                   °              °
+ 1.516648 COS (  19141.6961T + 355.4263 )
-      13T                ''
+ 0.999860 COS (  36000.7696T + 280.4541 )
+   213424 COS (      1.8372T + 156.0424 )
+     210T                ''
+    70678 COS (  38281.555 T +  14.812  )
+      69T                ''
+    25063 COS (      1.720 T + 102.941  )
-      63T                ''
+     8354 COS (  71999.82  T + 277.97   )
-      21T                ''
+     4940 COS (  57421.42  T +  34.22   )
+      10T                ''
+     1666 COS (  19138.02  T +  43.33   )
+      410 COS (  76561.3   T +  53.6    )
+      395 COS (  19140.2   T + 256.3    )
+      194 COS (  19122.8   T + 109.5    )
+      194 COS (  19160.6   T +  61.4    )
+      134 COS (   3036.4   T +  37.0    )
+      114 COS (   6071.0   T + 277.8    )
+      105 COS ( 107999     T + 276      )
+       83 COS (  13069     T + 108      )
+       63 COS (  17208     T + 300      )
+       63 COS (  21076     T + 230      )
+       56 COS (      0     T +  57      )
+       53 COS (  35247     T + 134      )
+       53 COS (  16861     T +  61      )
+       52 COS (  38278     T +  63      )
+       49 COS (  32212     T + 255      )
+       48 COS (   2283     T +  31      )
+       47 COS (  21422     T + 104      )
+       42 COS (  34067     T + 226      )
+       42 COS (  37935     T + 155      )
 AU                   °              °
+ 0.000041 COS (  52860     T + 115      )
+       37 COS (  95701     T +  73      )
+       36 COS (   4563     T + 351      )
+       35 COS (  35997     T +  75      )
+       31 COS ( 481268     T + 218      )
+       27 COS (     21     T + 222      )
+       27 COS (     17     T +  90      )
+       26 COS (   3036     T + 213      )
+       23 COS (  20240     T + 135      )
+       23 COS (  18043     T +  36      )
+       23 COS (  51352     T + 275      )
+       21 COS (   9037     T + 244      )
+       21 COS (  36001     T +  96      )
+       18 COS (  38280     T + 276      )
+       18 COS (  23703     T +  14      )
+       16 COS (  14580     T + 154      )
+       16 COS (  22176     T + 105      )
+       16 COS (  33720     T + 181      )
+       16 COS (  10034     T + 123      )
+       16 COS (  35982     T + 211      )
+       16 COS (  36020     T + 170      )
+       14 COS (  13482     T +  23      )
+       13 COS (   6844     T + 280      )
+       13 COS (  16107     T +  16      )
+       12 COS (  29178     T + 252      )
+       12 COS (   9106     T + 278      )
+       10 COS (  58520     T +   9      )
+        9 COS (  68965     T + 168      )
+        9 COS (  38263     T + 129      )
+        9 COS (  38300     T +  81      )
+        9 COS (  25211     T + 305      )
+        9 COS (   1936     T +  31      )
+        9 COS (   1932     T + 259      )
+        8 COS (  29174     T +  93      )
+        8 COS (  40562     T + 130      )
```

Table 11. Mars: Apparent geocentric equatorial rectangular coordinates (Continued)

Y

AU °

+ 1.391497 COS (19141.6961T + 265.4263)
+ 125T ″
+ 0.917354 COS (36000.7696T + 190.4541)
+ 91T ″
+ 195813 COS (1.8372T + 66.0424)
+ 212T ″
+ 64845 COS (38281.555 T + 284.812)
+ 69T ″
+ 22995 COS (1.720 T + 12.941)
- 56T ″
+ 19478 COS (19140.925 T + 35.876)
- 17T ″
+ 7664 COS (71999.82 T + 187.97)
- 19T ″
+ 4533 COS (57421.42 T + 304.22)
+ 9T ″
+ 2741 COS (1.07 T + 196.50)
+ 1529 COS (19138.02 T + 133.33)
+ 908 COS (38280.8 T + 55.3)
+ 376 COS (76561.3 T + 323.6)
+ 363 COS (19140.2 T + 346.3)
+ 178 COS (19122.8 T + 19.5)
+ 178 COS (19160.6 T + 331.4)
+ 123 COS (3036.4 T + 307.0)
+ 104 COS (6071 T + 188)
+ 96 COS (107999 T + 186)
+ 76 COS (13069 T + 198)
+ 72 COS (17208 T + 210)
+ 63 COS (57421 T + 75)
+ 51 COS (0 T + 147)
+ 49 COS (35247 T + 44)
+ 48 COS (16861 T + 331)
+ 48 COS (38278 T + 153)
+ 47 COS (34067 T + 136)
+ 45 COS (32212 T + 165)
+ 45 COS (21076 T + 140)
+ 44 COS (2283 T + 301)
+ 43 COS (21422 T + 14)
+ 37 COS (52860 T + 25)
+ 34 COS (95701 T + 343)
+ 33 COS (4563 T + 261)
+ 32 COS (35997 T + 165)
+ 29 COS (37935 T + 65)
+ 28 COS (481268 T + 128)
+ 25 COS (21 T + 132)
+ 25 COS (17 T + 180)
+ 23 COS (3036 T + 123)
+ 21 COS (20240 T + 45)
+ 21 COS (18043 T + 306)
+ 21 COS (19139 T + 3)
+ 21 COS (51352 T + 185)
+ 20 COS (9037 T + 334)
+ 19 COS (36001 T + 6)
+ 17 COS (38280 T + 6)
+ 17 COS (23703 T + 284)
+ 15 COS (14580 T + 64)
+ 15 COS (22176 T + 15)
+ 15 COS (33720 T + 91)
+ 14 COS (10034 T + 213)
+ 14 COS (36020 T + 80)
+ 14 COS (35982 T + 121)
+ 13 COS (13482 T + 293)
+ 12 COS (6844 T + 190)
+ 12 COS (16107 T + 286)

AU ° °

+ 0.000011 COS (29178 T + 162)
+ 11 COS (9106 T + 188)
+ 10 COS (1932 T + 349)
+ 9 COS (58520 T + 279)
+ 9 COS (68965 T + 78)
+ 8 COS (38263 T + 39)
+ 8 COS (38300 T + 351)
+ 8 COS (25211 T + 215)
+ 8 COS (29174 T + 183)

Z

AU ° °

+ 0.603288 COS (19141.6961T + 265.4263)
- 321T ″
+ 397721 COS (36000.7696T + 190.4541)
- 208T ″
+ 84895 COS (1.837 T + 66.042)
+ 39T ″
+ 44925 COS (19140.925 T + 215.871)
- 12T ″
+ 28114 COS (38281.555 T + 284.812)
+ 13T ″
+ 9970 COS (1.72 T + 12.94)
- 30T ″
+ 6322 COS (1.07 T + 16.50)
+ 3323 COS (71999.82 T + 187.99)
- 10T ″
+ 2094 COS (38280.79 T + 235.28)
+ 1965 COS (57421.42 T + 304.22)
+ 663 COS (19138.0 T + 133.3)
+ 163 COS (76561.3 T + 323.6)
+ 157 COS (19140.2 T + 346.3)
+ 146 COS (57420.6 T + 254.7)
+ 77 COS (19123 T + 19)
+ 77 COS (19161 T + 331)
+ 56 COS (21076 T + 140)
+ 53 COS (3036 T + 307)
+ 49 COS (19139 T + 183)
+ 45 COS (6071 T + 188)
+ 42 COS (107999 T + 186)
+ 37 COS (37935 T + 65)
+ 33 COS (13069 T + 198)
+ 22 COS (0 T + 147)
+ 21 COS (35247 T + 44)
+ 21 COS (16861 T + 331)
+ 21 COS (38278 T + 153)
+ 19 COS (32212 T + 165)
+ 19 COS (21422 T + 14)
+ 19 COS (2283 T + 301)
+ 16 COS (52860 T + 25)
+ 15 COS (95701 T + 343)
+ 14 COS (4563 T + 261)
+ 14 COS (35997 T + 165)
+ 12 COS (481268 T + 128)
+ 12 COS (76561 T + 274)
+ 11 COS (21 T + 132)
+ 11 COS (17 T + 180)
+ 10 COS (3036 T + 123)
+ 9 COS (20240 T + 45)
+ 9 COS (18043 T + 306)
+ 9 COS (51352 T + 175)
+ 8 COS (9037 T + 334)
+ 8 COS (36001 T + 6)
+ 8 COS (1936 T + 301)
+ 7 COS (38280 T + 6)

Table 12. Distributions of the differences between the values by the series and the rigorous ones

Coordinates	Unit	series − rigorous												
		less	−10	−8	−6	−4	−2	0	+2	+4	+6	+8	+10	more
Sun														
longitude	1″				141	453	1298	1247	398	116				
distance	10^{-5} AU					46	1796	1788	23					
right ascension	0^{s}.1				75	276	1540	1395	362	5				
declination	1″				91	477	1163	1357	464	90	11			
X 1950.0	10^{-5} AU					18	1748	1887						
Y 1950.0	10^{-5} AU					80	1757	1654	162					
Z 1950.0	10^{-5} AU						1788	1795	70					
Moon														
longitude	1″	11	42	92	295	617	880	917	553	191	47	6	2	
latitude	1″		7	32	141	427	910	1165	710	228	29	3	1	
parallax	0″.1						1817	1836						
right ascension	0^{s}.1	27	55	145	351	544	806	742	538	279	118	29	19	
declination	1″	71	67	158	336	477	617	600	500	365	236	126	100	
Mercury														
longitude	1″	6	17	50	144	547	1102	1067	456	178	65	21		
latitude	1″				7	178	1631	1523	301	13				
radius vector	10^{-5} AU						1760	1893						
right ascension	0^{s}.1				42	491	1391	1306	380	43				
declination	1″		6	34	69	423	1444	1135	416	90	32	4		
Venus														
longitude	1″				66	593	1578	1207	209					
latitude	1″						1516	2137						
radius vector	10^{-5} AU						1693	1960						
right ascension	0^{s}.1	46	63	92	95	390	1502	1086	287	24	15	15	38	
declination	1″				65	355	1204	1134	452	206	83	55	99	
Mars														
longitude	1″			36	75	495	997	1180	619	228	23			
latitude	1″				14	286	1746	1485	122					
radius vector	10^{-5} AU					417	1583	1190	387	76				
right ascension	0^{s}.1		43	103	276	502	801	1371	447	74	12	24		
declination	1″	75	61	92	148	448	1414	837	361	98	99	20		

4. Precision

In order to evaluate the precision of the series presented above, the differences between the values calculated by them and the rigorous values tabulated in the *Japanese Ephemeris* are examined. The comparison is made for every 0^h ET from 1972 January 1 to 1981 December 31 (3653 points in total), and the distributions of the differences are shown in Table 12. Since the series are constructed so as to fit best at J 2000.0, the precision reprsesnted by the distributions is considered to be retained throughout the 60 years centering at 2000.

References

Eckert, W. J., Jones, R., Clark, H. K. 1954: *Improved Lunar Ephemeris 1952-1959*, U. S. Gov. Printing Office, Washington, D. C.

Newcomb, S. 1895a: *Astr. Pap. Amer. Eph.* Vol. VI, Pt. I.

Newcomb, S. 1895b: *Astr. Pap. Amer. Eph.* Vol. VI, Pt. II.

Newcomb, S. 1895c: *Astr. Pap. Amer. Eph.* Vol. VI, Pt. III.

Newcomb, S. 1898: *Astr. Pap. Amer. Eph.* Vol. VI, Pt. IV.

Ross, F. E. 1917: *Astr. Pap. Amer. Eph.* Vol. IX, Pt. II.