VSOP2010 FILES

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INTRODUCTION

The VSOP2010 files contain the series of the elliptic elements for the 8 planets Mercury, Venus, Earth-Moon barycenter, Mars, Jupiter, Saturn, Uranus, Neptune and for the dwarf planet Pluto of the solution VSOP2010.

List of the files:
VSOP2010p1.dat : Mercury
VSOP2010p2.dat : Venus
VSOP2010p3.dat : Earth-Moon Barycenter
VSOP2010p4.dat : Mars
VSOP2010p5.dat : Jupiter
VSOP2010p6.dat : Saturn
VSOP2010p7.dat : Uranus
VSOP2010p8.dat : Neptune
VSOP2010p9.dat : Pluto

The planetary solution VSOP2010 is fitted to the numerical integration DE405 of the Jet Propulsion Laboratory (http://ssd.jpl.nasa.gov).

FILES DESCRIPTION

Each VSOP2010 file corresponds to a planet and contains trigonometric series, functions of time (Periodic series and Poisson series), that represent the 6 elliptic elements of the planet:

Variable 1 : a = semi-major axis (ua)
Variable 2 : λ = mean longitude (radian)
Variable 3 : k = e cos ϖ
Variable 4 : h = e sin ϖ
Variable 5 : q = sin(i/2) cos Ω
Variable 6 : p = sin(i/2) sin Ω

with:
e : eccentricity
ϖ : perihelion longitude
i : inclination
Ω : ascending node longitude

VSOP2010 series are characterized by 3 parameters:
- the planet index 1-9 from Mercury to Pluto,
- the variable index 1-6 for a, λ, k, h, q, p,
- the time power α.

TERMS OF SERIES
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The terms of series are given under the form: T^{α} (S sin Φ + C cos Φ)

T is the time (TDB) from J2000 (JD2451545.0)
expressed in Thousand of Julian Years (tcy = 365250 days)

α is the time power of the series (0 <= α <= 20).

S, C are the coefficients for the variable a (au), the variable λ (radian) and the variables, k, h, q, p (without unit).

Φ is equal to the sum of the products a(i).λl(i) with i=1,17.

a(i) are integers, numerical coefficients of the quantities λl(i).

λl(1,13) : linear part of the mean longitudes of the planets (radian).
λl(14) : argument μ derived from TOP2013 and used for Pluto (radian).
λl(15,17) : linear part of Delaunay lunar arguments D, F, ℓ (radian).

λl(1)	=	4.402608634958	+	26087.90314074786	*	T	Mercury
λl(2)	=	3.176134454599	+	10213.28554727840	*	T	Venus
λl(3)	=	1.753470407365	+	6283.075850238015	*	T	Earth-Moon
λl(4)	=	6.203499866531	+	3340.612433480507	*	T	Mars
λl(5)	=	4.091362210690	+	1731.1705400744020	*	T	Vesta
λl(6)	=	1.713743790353	+	1704.4507840227720	*	T	Iris
λl(7)	=	5.598651923117	+	1428.9490972826291	*	T	Bamberga
λl(8)	=	2.805135511956	+	1364.7564867399469	*	T	Ceres
λl(9)	=	2.326992146758	+	1361.9234964178140	*	T	Pallas
λl(10)	=	0.599546097920	+	529.6909681760810	*	T	Jupiter
λl(11)	=	0.874018344970	+	213.2990860917330	*	T	Saturn
λl(12)	=	5.481224786038	+	74.7816538002780	*	T	Uranus
λl(13)	=	5.311894573453	+	38.1329273732270	*	T	Neptune
λl(14)	=			0.3595362366859080	*	T	μ Pluto
λl(15)	=	5.198466400630	+	77713.7714481804	*	T	D Moon
λl(16)	=	1.627905136020	+	84334.6615717837	*	T	F Moon
λl(17)	=	2.355555638750	+	83286.9142477147	*	T	ℓ Moon

VSOP2010 files contain the numerical values of α, S, C and a(i) (i=1,17).

RECORDS ORGANIZATION
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There are two types of records:

The "HEADER" record for the characteristics of the series (planet, variable, time power).

The "TERMS" records for the quantities a, S and C in each term of the series.

In a VSOP2010 file, series are put in order of the variables <a,λ,k,h,q,p> and, for each variable, in order of the time power (α).

HEADER RECORD
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Fortran Format:
```
      read (ifile,1001) ip,iv,it,nt
1001  format (9x,3i3,i7)
```

Specifications:
ip : planete index (integer)
iv : variable index (integer)
it : time power α (integer)
nt : number of terms in series (integer)

Planet index (ip):
1 : Mercury
2 : Venus
3 : Earth-Moon Barycenter
4 : Mars
5 : Jupiter
6 : Saturn
7 : Uranus
8 : Neptune
9 : Pluto

Variable index (iv):
1 : a = semi-major axis (ua)
2 : λ = mean longitude (radian)
3 : k = e cos ϖ
4 : h = e sin ϖ
5 : q = sin(i/2) cos Ω
6 : p = sin(i/2) sin Ω

Time power α (it):
it=0 : Periodic terms
it>0 : Poisson terms

TERMS RECORDS
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The "TERMS" records are put in the file according to the decreasing values of the sum of absolute values of the coefficients S and C: |S|+|C|.

Each "TERMS" record contains respectively: the rank of the term in the series and the quantities a(i) (i=1,17), S and C.

Fortran format:
```
      read  (ifile,1002) num,(iphi(i),i=1,17),c1,ie1,c2,ie2
1002  format (i5,1x,4i3,1x,5i3,1x,4i4,1x,i6,1x,3i3,2(f20.16,1x,i3))
```

Specifications:
num : rank of the terms in the series (integer)
iphi : 17 numerical coefficients a(i) (i=1,17)) (integer)
c1, ie1 : coefficient S, mantissa and exponent (real*8 and integer)
c2, ie2 : coefficient C, mantissa and exponent (real*8 and integer)
Units of the coefficients: au for a, radian for λ, without unit for the other variables k, h, q, p.

TIME SCALE AND REFERENCE SYSTEM

The time used in VSOP2010 series is TDB (Barycentrc Dynamical Time).
This time can be considered equal to TAI + 32.184 s with an approximation less than 0.002s (TAI: International Atomic Time).

The solution VSOP2010 is fitted to the numerical integration DE405 over the time interval [1890-2000].
The VSOP2010 coordinates are referred to the inertial frame defined by the dynamical equinox and ecliptic J2000 (JD 2451545.0).
The planetary coordinates of DE405 are referred in a frame close by ICRF.

If X_E, Y_E, Z_E are the rectangular coordinates of a planet computed from VSOP2010, the rectangular coordinates of the planet in equatorial frame of the ICRF, X_Q, Y_Q, Z_Q, may be obtained by the following rotation:

$$\begin{bmatrix} X_Q \\ Y_Q \\ Z_Q \end{bmatrix} = \begin{bmatrix} \cos\varphi & -\sin\varphi\cos\varepsilon & \sin\varphi\sin\varepsilon \\ \sin\varphi & \cos\varphi\cos\varepsilon & -\cos\varphi\sin\varepsilon \\ 0 & \sin\varepsilon & \cos\varepsilon \end{bmatrix} \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix}$$

with: $\varepsilon = 23^\circ\ 26'\ 21.40960''$ et $\varphi = -0.05028''$

PRECISION OF THE SERIES VOP2010

An estimation of the precision of the series VSOP2010 is given by the largest differences between VSOP2010 and DE405

TIME INTERVAL [1890; 2000]

Planet	a	λ	k	h	q	p	L	B	R
Mercury	0.006	0.07	3.1	1.0	0.5	0.9	0.22	0.05	0.019
Venus	0.003	0.08	1.0	1.4	0.8	0.7	0.13	0.04	0.015
EMB	0.003	0.06	0.8	0.6	0.1	2.0	0.08	0.08	0.011
Mars	0.073	2.01	7.0	6.4	0.7	1.6	2.13	0.09	0.206
Jupiter	0.683	0.72	13.3	13.6	0.6	0.4	0.74	0.03	0.689
Saturn	0.816	0.19	5.5	5.8	1.0	0.9	0.22	0.06	0.851
Uranus	24.467	0.88	60.6	68.5	2.8	2.2	2.29	0.13	8.873
Neptune	7.747	0.27	10.6	7.8	1.5	1.1	0.52	0.05	4.526
Pluto	130.489	3.42	161.6	149.7	26.5	23.9	7.50	2.63	141.707

Unîts:
Elliptic elements: a (km), λ (mas), k, h, q, p (10^{-10}).
Heliocentric longitude L and latitude B (mas).
Distance Sun-Planet R (km).

TIME INTERVAL [-3000; 3000]

Planet	λ	L	B	R
Mercury	0.32	0.51	0.06	22
Venus	0.62	0.62	0.03	2
EMB	0.25	0.24	0.02	4
Mars	0.49	0.63	0.08	83
Jupiter	0.87	0.96	0.03	743
Saturn	5.09	6.63	0.03	6859
Uranus	2.42	2.42	0.02	2223
Neptune	0.58	0.93	0.05	3859

Unîts:
mean longitude λ (arcsecond).
Heliocentric longitude L and latitude B (arcsecond).
Distance Sun-Planet R (km).

COMPUTATION
==========

The program VSOP2010.f (Fortran) computes the planetary elliptic elements between 1890 and 2000 using the files VSOP2010.
This program computes also the planetary rectangular coordinates referred to the dynamical ecliptic frame of J2000 and referred to the equatorial frame of ICRS.

Starting date : 1890 June 6 (DJ 2411544.5)
Number of dates : 11
Step : 4000 days.

The results of this computation are given in the file: VSOP2010.out
The file VSOP2010.ctl is given for checking these results.

The mean elements of the elliptic variables of the series VSOP2010 are given in the file: VSOP2010-secular.dat.

The astronomical constants consistent with the solution VSOP2010 are the constants used in the numerical integration DE405, especially:

AU	0.1495978706910000D+09	km
CLIGHT	0.2997924580000000D+06	m/s
GM_Mer	0.4912547451450812D-10	au^3/day^2
GM_Ven	0.7243452486162703D-09	au^3/day^2
GM_EMB	0.8997011346712499D-09	au^3/day^2
GM_Mar	0.9549535105779258D-10	au^3/day^2
GM_Jup	0.2825345909524226D-06	au^3/day^2
GM_Sat	0.8459715185680659D-07	au^3/day^2
GM_Ura	0.1292024916781969D-07	au^3/day^2
GM_Nep	0.1524358900784276D-07	au^3/day^2
GM_Plu	0.2188699765425970D-11	au^3/day^2
GM_Sun	0.2959122082855911D-03	au^3/day^2
EMRAT	0.8130056000000000D+02	
RSUN	0.6960000000000000D+06	km
RMOON	0.1738000000000000D+04	km
REARTH	0.6378137000000000D+04	km
J2SUN	0.2000000000000000D-06	