SWISS EPHEMERIS

Computer ephemeris for developers of astrological software

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25-Jan-2011: Dieter: Delta T updated, v. 1.77.
2-Aug-2012: Dieter: New precession, v. 1.78.
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Swiss Ephemeris Release history:
1.00 30-sept-1997

1.01	9-oct-1997	simplified houses() and sidtime() functions, Vertex added.
1.02	16-oct-1997	houses() changed again
1.03	28-oct-1997	minor fixes
1.04	8-Dec-1997	minor fixes
1.10	9-Jan-1998	bug fix, pushed to all licensees
1.11	12-Jan-98	minor fixes
1.20	21-Jan-98	NEW: topocentric planets and house positions
1.21	28-Jan-98	Delphi declarations and sample for Delphi 1.0
1.22	2-Feb-98	Asteroids moved to subdirectory. Swe_calc() finds them there.
1.23	11-Feb-98	two minor bug fixes.
1.24	7-Mar-1998	Documentation for Borland C++ Builder added
1.25	4-June-1998	sample for Borland Delphi-2 added
1.26	29-Nov-1998	source added, Placalc API added
1.30	17-Dec-1998	NEW:Time range extended to 10'800 years
1.31	12-Jan-1999	NEW: Eclipses
1.40	19-Apr-1999	NEW: planetary phenomena
1.50	27-Jul-1999	NEW: sidereal ephemerides
1.52	15-Feb-2000	Several NEW features, minor bug fixes
1.60	15-Feb-2000	Major release with many new features and some minor bug fixes
1.61	11-Sep-2000	Minor release, additions to se_rise_trans(), swe_houses(), ficitious planets
1.62	23-Jul-2001	Minor release, fictitious earth satellites, asteroid numbers > 55535 possible
1.63	5-Jan-2002	Minor release, house calculation added to swetest.c and swetest.exe
1.64	7-Apr-2002	NEW: occultations of planets, minor bug fixes, new Delta T algorithms
1.65	12-Jun-2003	Minor release, small code renovations for 64-bit compilation
1.66	10-Jul-2003	NEW: Morinus houses
1.67	31-Mar-2005	Minor release: Delta-T updated, minor bug fixes
1.70	2-Mar-2006	IAU resolutions up to 2005 implemented; "interpolated" lunar apsides
1.72	28-nov-2007	Delta T calculation according to Morrison/Stephenson 2004
1.74	17-jun-2008	License model changed to dual license, GNU GPL or Professional License
1.76	31-mar-2009	NEW: Heliacal events
1.77	25-jan-2011	Delta T calculation updated acc. to Espenak/Meeus 2006, new fixed stars file
1.78	2-aug-2012	Precession calculation updated acc. to Vondrák et alii 2012
1.79	23-apr-2013	New ayanamshas, improved precision of eclipse functions, minor bug fixes
1.80	3-sep-2013	Security update and bugfixes
2.00	11-feb-2014	Swiss Ephemeris now based on JPL ephemeris DE431

Introduction

Swiss Ephemeris is a function package of astronomical calculations that serves the needs of astrologers, archaeoastronomers, and, depending on purpose, also the needs of astronomers. It includes long-term ephemerides for the Sun, the Moon, the planets, more than 300'000 asteroids, historically relevant fixed stars and several "hypothetical" objects.

The precision of the Swiss Ephemeris is *at least* as good as that of the Astromical Almanac, which follows current standards of ephemeris calculation. **Swiss Ephemeris** will, as we hope, be able to keep abreast to the scientific advances in ephemeris computation for the coming decades.

The **Swiss Ephemeris** package consists of source code in C, a DLL, a collection of ephemeris files and a few sample programs which demonstrate the use of the DLL and the Swiss Ephemeris graphical label. The ephemeris files contain compressed astronomical ephemerides

Full **C source code** is included with the Swiss Ephemeris, so that non-Windows programmers can create a linkable or shared library in their environment and use it with their applications.

1. Licensing

The Swiss Ephemeris is not a product for end users. It is a toolset for programmers to build into their astrological software.

Swiss Ephemeris is made available by its authors under a dual licensing system. The software developer, who uses any part of Swiss Ephemeris in his or her software, must choose between one of the two license models, which are

a) GNU public license version 2 or later

b) Swiss Ephemeris Professional License

The choice must be made before the software developer distributes software containing parts of Swiss Ephemeris to others, and before any public service using the developed software is activated.

If the developer choses the GNU GPL software license, he or she must fulfill the conditions of that license, which includes the obligation to place his or her whole software project under the GNU GPL or a compatible license. See http://www.gnu.org/licenses/old-licenses/gpl-2.0.html

If the developer choses the Swiss Ephemeris Professional license, he must follow the instructions as found in http://www.astro.com/swisseph/ and purchase the Swiss Ephemeris Professional Edition from Astrodienst and sign the corresponding license contract.

The Swiss Ephemeris Professional Edition can be purchased from Astrodienst for a one-time fixed fee for each commercial programming project. The license is just a legal document. All actual software and data are found in the public download area and are to be downloaded from there.

Professional license: The license fee for the first license is Swiss Francs (CHF) 750.- , and CHF 400.- for each additional license by the same licensee. An unlimited license is available for CHF 1550.-.

2. Descripition of the ephemerides

2.1 Planetary and lunar ephemerides

2.1.1 Three ephemerides

The Swiss Ephemeris package allows planetary and lunar computations from any of the following three astronomical ephemerides:

2.1.1.1 The Swiss Ephemeris

The core part of Swiss Ephemeris is a compression of the JPL-Ephemeris DE431, which covers roughly the time range 13’000 BCE to 17’000 CE. Using a sophisticated mechanism, we succeeded in reducing JPL's 2.8 GB storage to only 99 MB. The compressed version agrees with the JPL Ephemeris to 1 milli-arcsecond (0.001”). Since the inherent uncertainty of the JPL ephemeris for most of its time range is a lot greater, the Swiss Ephemeris should be completely satisfying even for computations demanding very high accuracy.

(Before 2014, the Swiss Ephemeris was based on JPL Ephemeris DE406. Its 200 MB were compressed to 18 MB. The time range of the DE406 was 3000 BC to 3000 AD or 6000 years. We had **extended** this time range to 10'800 years, from 2 Jan 5401 BC to 31 Dec 5399. The details of this extension are described below in section 2.1.5. To make sure that you work with current data, please check the date of the ephemeris files. They must be 2014 or later.)

Each Swiss Ephemeris file covers a period of 600 years; there are 50 planetary files, 50 Moon files for the whole time range of almost 30’000 years and 18 main-asteroid files for the time range of 10'800 years.

The file names are as follows:

Planetary file	Moon file	Main asteroid file	Time range
Seplm132.se1	Semom132.se1		11 Aug 13000 BC – 12602 BC
Seplm126.se1	Semom126.se1		12601 BC – 12002 BC
Seplm120.se1	Semom120.se1		12001 BC – 11402 BC
Seplm114.se1	Semom114.se1		11401 BC – 10802 BC
Seplm108.se1	Semom108.se1		10801 BC – 10202 BC
Seplm102.se1	Semom102.se1		10201 BC – 9602 BC
Seplm96.se1	Semom96.se1		9601 BC – 9002 BC
Seplm90.se1	Semom90.se1		9001 BC – 8402 BC

Seplm84.se1	Semom84.se1		8401 BC – 7802 BC
Seplm78.se1	Semom78.se1		7801 BC – 7202 BC
Seplm72.se1	Semom72.se1		7201 BC – 6602 BC
Seplm66.se1	Semom66.se1		6601 BC – 6002 BC
Seplm60.se1	Semom60.se1		6001 BC – 5402 BC
seplm54.se1	semom54.se1	seasm54.se1	5401 BC – 4802 BC
seplm48.se1	semom48.se1	seasm48.se1	4801 BC – 4202 BC
seplm42.se1	semom42.se1	seasm42.se1	4201 BC – 3602 BC
seplm36.se1	semom36.se1	seasm36.se1	3601 BC – 3002 BC
seplm30.se1	semom30.se1	seasm30.se1	3001 BC – 2402 BC
seplm24.se1	semom24.se1	seasm24.se1	2401 BC – 1802 BC
seplm18.se1	semom18.se1	seasm18.se1	1801 BC – 1202 BC
seplm12.se1	semom12.se1	seasm12.se1	1201 BC – 602 BC
seplm06.se1	semom06.se1	seasm06.se1	601 BC – 2 BC
sepl_00.se1	semo_00.se1	seas_00.se1	1 BC – 599 AD
sepl_06.se1	semo_06.se1	seas_06.se1	600 AD – 1199 AD
sepl_12.se1	semo_12.se1	seas_12.se1	1200 AD – 1799 AD
sepl_18.se1	semo_18.se1	seas_18.se1	1800 AD – 2399 AD
sepl_24.se1	semo_24.se1	seas_24.se1	2400 AD – 2999 AD
sepl_30.se1	semo_30.se1	seas_30.se1	3000 AD – 3599 AD
sepl_36.se1	semo_36.se1	seas_36.se1	3600 AD – 4199 AD
sepl_42.se1	semo_42.se1	seas_42.se1	4200 AD – 4799 AD
sepl_48.se1	semo_48.se1	seas_48.se1	4800 AD – 5399 AD
sepl_54.se1	semo_54.se1		5400 AD – 5999 AD
sepl_60.se1	semo_60.se1		6000 AD – 6599 AD
sepl_66.se1	semo_66.se1		6600 AD – 7199 AD
sepl_72.se1	semo_72.se1		7200 AD – 7799 AD
sepl_78.se1	semo_78.se1		7800 AD – 8399 AD
sepl_84.se1	semo_84.se1		8400 AD – 8999 AD
sepl_90.se1	semo_90.se1		9000 AD – 9599 AD
sepl_96.se1	semo_96.se1		9600 AD – 10199 AD
sepl_102.se1	semo_102.se1		10200 AD – 10799 AD
sepl_108.se1	semo_108.se1		10800 AD – 11399 AD
sepl_114.se1	semo_114.se1		11400 AD – 11999 AD
sepl_120.se1	semo_120.se1		12000 AD – 12599 AD
sepl_126.se1	semo_126.se1		12600 AD – 13199 AD
sepl_132.se1	semo_132.se1		13200 AD – 13799 AD
sepl_138.se1	semo_138.se1		13800 AD – 14399 AD
sepl_144.se1	semo_144.se1		14400 AD – 14999 AD
sepl_150.se1	semo_150.se1		15000 AD – 15599 AD

sepl_156.se1	semo_156.se1		15600 AD – 16199 AD
sepl_162.se1	semo_162.se1		16200 AD – 7 Jan 16800 AD

All Swiss Ephemeris files have the file suffix .se1.

A planetary file is about 500 kb, a lunar file 1300 kb.

Swiss Ephemeris files are available for download from Astrodienst's web server.

The time range of the Swiss Ephemeris

Versions until 1.80, which were based on JPL Ephemeris DE406 and some extension created by Astrodienst, work for the following time range:

Start date 2 Jan 5401 BC (-5400) jul. = JD -251291.5

End date 31 Dec 5399 AD (greg. Cal.) = JD 3693368.5

Versions since 2.00, which are based on JPL Ephemeris DE431, work for the following time range:

Start date 11 Aug 13000 BCE (-12999) jul. = JD -3026604.5

End date 7 Jan 16800 CE greg. = JD 7857139.5

Please note that versions prior to 2.00 are **not** able to correctly handle the JPL ephemeris DE431.

A note on year numbering:
There are two numbering systems for years before the year 1 AD. The historical numbering system (indicated with BC) has no year zero. Year 1 BC is followed directly by year 1 AD.
The astronomical year numbering system does have a year zero; years before the common era are indicated by negative year numbers. The sequence is year -1, year 0, year 1 AD.
The historical year 1 BC corresponds to astronomical year 0,
the historical your 2 BC corresponds to astronomical year -1, etc.
In this document and other documents related to the Swiss Ephemeris we use both systems of year numbering.
When we write a negative year number, it is astronomical style; when we write BC, it is historical style.

2.1.1.2 The Moshier Ephemeris

This is a semi-analytical approximation of the JPL planetary and lunar ephemerides DE404, developed by Steve Moshier. Its deviation from JPL is below 1 arc second with the planets and a few arc seconds with the moon. *No data files* are required for this ephemeris, as all data are linked into the program code already.

This may be sufficient accuracy for most purposes, since the moon moves 1 arc second in 2 time seconds and the sun 2.5 arc seconds in one minute.

The advantage of the Moshier mode of the Swiss Ephemeris is that it needs no disk storage. Its disadvantage besides the limited precision is reduced speed: it is about 10 times slower than JPL mode and the compressed JPL mode (described above).

The Moshier Ephemeris covers the interval from 3000 BC to 3000 AD. However, Moshier notes that “the adjustment for the inner planets is strictly valid only from 1350 B.C. to 3000 A.D., but may be used to 3000 B.C. with some loss of precision”. And: “The Moon's position is calculated by a modified version of the lunar theory of Chapront-Touze' and Chapront. This has a precision of 0.5 arc second relative to DE404 for all dates between 1369 B.C. and 3000 A.D. “ (Moshier, http://www.moshier.net/aadoc.html).

2.1.1.3 The full JPL Ephemeris

This is the full precision state-of-the-art ephemeris. It provides the highest precision and is the basis of the Astronomical Almanac. Time range:

Start date 9 Dec 13002 BCE (-13001) jul. = JD -3027215.5

End date 11 Jan 17000 CE greg. = JD 7930192.5

JPL is the Jet Propulsion Laboratory of NASA in Pasadena, CA, USA (see http://www.jpl.nasa.gov). Since many years this institute which is in charge of the planetary missions of NASA has been the source of the highest precision planetary ephemerides. The currently newest version of JPL ephemeris is the DE430/DE431.

There are several versions of the JPL Ephemeris. The version is indicated by the DE-number. A higher number indicates a more recent version. SWISSEPH should be able to read *any* JPL file from DE200 upwards.

Accuracy of JPL ephemerides DE403/404 (1996) and DE405/406 (1998)

According to a paper (see below) by Standish and others on DE403 (of which DE406 is only a slight refinement), the accuracy of this ephemeris can be partly estimated from its difference from DE200:

With the *inner planets*, Standish shows that within the period 1600 – 2160 there is a maximum difference of 0.1 – 0.2” which is mainly due to a mean motion error of DE200. This means that the absolute precision of DE406 is estimated significantly better than 0.1” over that period. However, for the period 1980 – 2000 the deviations between DE200 and DE406 are below 0.01” for *all* planets, and for this period the JPL integration has been fit to measurements by radar and laser interferometry, which are extremely precise.

With the *outer planets*, Standish's diagrams show that there are large differences of several ” around 1600, and he says that these deviations are due to the inherent uncertainty of extrapolating the orbits beyond the period of accurate observational data. The uncertainty of Pluto exceeds 1” before 1910 and after 2010, and increases rapidly in more remote past or future.

With the *moon*, there is an increasing difference of 0.9”/cty^2 between 1750 and 2169. It is mainly caused by errors in LE200 (*L*unar *E*phemeris).

The differences between DE200 and DE403 (DE406) can be summarized as follows:

1980 – 2000	all planets	< 0.01”,
1600 – 1980	Sun – Jupiter	a few 0.1”,
1900 – 1980	Saturn – Neptune	a few 0.1”,
1600 – 1900	Saturn – Neptune	a few ”,
1750 – 2169	Moon	a few ”.

(see: E.M. Standish, X.X. Newhall, J.G. Williams, and W.M. Folkner, *JPL Planetary and Lunar Ephemerides, DE403/LE403*, JPL Interoffice Memorandum IOM 314.10-127, May 22, 1995, pp. 7f.)

Comparison of JPL ephemerides DE406 (1998) with DE431 (2013)

Differences DE431-DE406 for 3000 BCE to 3000 CE :

Moon	< 7" (TT), < 2" (UT)
Sun, Mercury, Venus	< 0.4 "
Mars	< 2"
Jupiter	< 6"
Saturn	< 0.1"
Uranus	< 28"
Neptune	< 53"
Pluto	< 129"

Moon, position(DE431) – position(DE406) in TT and UT
(Delta T adjusted to tidal acceleration of lunar ephemeris)

Year	dL(TT)	dL(UT)	dB(TT)	dB(UT)
-2999	6.33"	-0.30"	-0.01"	0.05"
-2500	5.91"	-0.62"	-0.85"	-0.32"
-2000	3.39"	-1.21"	-0.59"	-0.20"
-1500	1.74"	-1.49"	-0.06"	-0.01"
-1000	1.06"	-1.50"	0.30"	0.12"
-500	0.63"	-1.40"	0.28"	0.09"
0	0.13"	-0.99"	0.11"	0.05"
500	-0.08"	-0.99"	-0.03"	0.05"
1000	-0.12"	-0.38"	-0.08"	-0.06"

1500	-0.08"	-0.15"	-0.03"	-0.02"
2000	0.00"	0.00"	0.00"	0.00"
2500	0.06"	0.06"	-0.02"	-0.02"
3000	0.10"	0.10"	-0.09"	-0.09"

Sun, position(DE431) – position(DE406) in TT and UT

Year	dL(TT)	dL(UT)
-2999	0.21"	-0.34"
-2500	0.11"	-0.33"
-2000	0.09"	-0.26"
-1500	0.04"	-0.22"
-1000	0.06"	-0.14"
-500	0.02"	-0.11"
0	0.02"	-0.06"
500	0.00"	-0.04"
1000	0.00"	-0.01"
1500	-0.00"	-0.01"
2000	-0.00"	-0.00"
2500	-0.00"	-0.00"
3000	-0.01"	-0.01"

Pluto, position(DE431) – position(DE406) in TT

Year	dL(TT)
-2999	66.31"
-2500	82.93"
-2000	100.17"
-1500	115.19"
-1000	126.50"
-500	127.46"
0	115.31"
500	92.43"
1000	63.06"
1500	31.17"
2000	-0.02"
2500	-28.38"
3000	-53.38"

The **Swiss Ephemeris** is based on the latest JPL file, and reproduces the full JPL precision with better than 1/1000 of an arc second, while requiring only a tenth storage. Therefore for most applications it makes little sense to get the full JPL file. Precision comparison can be done at the Astrodienst web server. The Swiss Ephemeris test page http://www.astro.com/swisseph/swetest.htm allows to compute planetary positions for any date using the full JPL ephemerides DE200, DE406, DE421, DE431, or the compressed Swiss Ephemeris or the Moshier ephemeris.

2.1.2.1 Swiss Ephemeris and the Astronomical Almanac

The original JPL ephemeris gives barycentric equatorial Cartesian positions relative to the equinox 2000. Moshier provides heliocentric positions. The conversions to apparent geocentric ecliptical positions were done using the algorithms and constants of the Astronomical Almanac as described in the "Explanatory Supplement to the Astronomical Almanac". Using the DE200 data file, it is possible to reproduce the positions given by the Astronomical Almanac 1995, 1996, and 1997 to the last digit. Editions of other years have not been checked.

Since 2003, the Astronomical Almanac has been using JPL ephemeris DE405, and since Astronomical Almanac 2006 all relevant resolutions of the International Astronomical Union (IAU) have been implemented. Versions 1.70 and higher of the Swiss Ephemeris also follow these resolutions and reproduce the sample calculation given by AA2006 (p. B61-B63), AA2011 and AA2013 (both p. B68-B70) to the last digit, i.e. to better than 0.001 arc second. (To avoid confusion when checking AA2006, it may be useful to know that the JD given on page B62 does not have enough digits in order to produce the correct final result. With later AA2011 and AA2013, there is no such problem.)

2.1.2.2 Swiss Ephemeris and JPL Horizons System of NASA

The Swiss Ephemeris, from version 1.70 on, reproduces *astrometric* planetary positions of the JPL Horizons System precisely. However, there are small differences of about 52 mas (milli-arcseconds) with *apparent* positions. The same deviations also occur if Horizons is compared with the example calculations given in the Astronomical Almanac.

Horizons uses an entirely different approach and a different reference system. It follows IERS Conventions 1996 (p. 22), i. e. it uses the old precession models IAU 1976 (Lieske) and nutation IAU 1980 (Wahr) and corrects the resulting positions by adding daily-measured celestial pole offsets (delta_psi and delta_epsilon) to nutation.

On the other hand, the Astronomical Almanac and the Swiss Ephemeris follow IERS Conventions 2003 and 2010, but do not take into account daily celestial pole offsets.

While Horizons' approach is more accurate in that it takes into account very small and unpredictable motions of the celestial pole (free core nutation), the resulting positions are not relative to the same reference frame as Astronomical Almanac and the Swiss Ephemeris, and they are not in agreement with the recent IERS Conventions 2003 and 2010. Some component of so-called frame bias is lost in Horizons positions. This causes a more or less constant offset of 52 mas in right ascension or 42 mas in ecliptic longitude.

Swiss Ephemeris versions 2.00 and higher contain code to reproduce positions of Horizons with a precision of about 1 mas for 1799 AD – today. Before 1799, the deviations in apparent positions between the Swiss Ephemeris and Horizons slowly increase. This is explained by the fact that Horizons uses the long-term precession model Owen 1990 for the remote past and future, whereas the Swiss Ephemeris uses the long-term precession model Vondrák 2011.

For best agreement with Horizons, current data files with earth orientation parameters (EOP) must be downloaded from the IERS website and put into the ephemeris path. If they are not available, the Swiss Ephemeris uses an approximation which reproduces Horizons still with an accuracy of about 2 mas between 1962 and present.

It must be noted that correct values for delta_psi and delta_epsilon are only available between 1962 and present. For all calculations before that, Horizons uses the first values of the EOP data, and for all calculations in the future, it uses the last values of the existing data are used. The resulting positions are not really correct, but the ephemeris is at least continuous.

More information on this and technical details are found in the programmer's documentation and in the source code, file swephlib.h.

IERS Conventions 1996, 2003, and 2010 can be read or downloaded from here:

http://www.iers.org/IERS/EN/DataProducts/Conventions/conventions.html

Many thanks to Jon Giorgini, developer of the Horizons System, for explaining us the methods used at JPL.

2.1.2.3 Differences between Swiss Ephemeris 1.70 and older versions

With version 1.70, the standard algorithms recommended by the IAU resolutions up to 2005 were implemented. The following calculations have been added or changed with Swiss Ephemeris version 1.70:

- "Frame Bias" transformation from ICRS to J2000.

- Nutation IAU 2000B (could be switched to 2000A by the user)

- Precession model P03 (Capitaine/Wallace/Chapront 2003), including improvements in ecliptic obliquity and sidereal time that were achieved by this model

The differences between the old and new *planetary positions* in ecliptic longitude (arc seconds) are:

year	new - old
2000	-0.00108
1995	0.02448
1980	0.05868
1970	0.10224
1950	0.15768
1900	0.30852
1800	0.58428
1799	-0.04644
1700	-0.07524
1500	-0.12636

1000	-0.25344
0	-0.53316
-1000	-0.85824
-2000	-1.40796
-3000	-3.33684
-4000	-10.64808
-5000	-32.68944
-5400	-49.15188

The discontinuity of the curve between 1800 and 1799 is explained by the fact that old versions of the Swiss Ephemeris used different precession models for different time ranges: the model IAU 1976 by Lieske for 1800 - 2200, and the precession model by Williams 1994 outside that time range.

Note: Precession model P03 is said to be accurate to 0.00005 arc second for CE 1000-3000.

The differences between version 1.70 and older versions for the future are as follows:

2000	-0.00108
2010	-0.01620
2050	-0.14004
2100	-0.29448
2200	-0.61452
2201	0.05940
3000	0.27252
4000	0.48708
5000	0.47592
5400	0.40032

The discontinuity in 2200 has the same explanation as the one in 1800.

Jyotish / sidereal ephemerides:

The ephemeris changes by a constant value of about +0.3 arc second. This is because all our ayanamsas have the start epoch 1900, for which epoch precession was corrected by the same amount.

Fictitious planets / Bodies from the orbital elements file seorbel.txt:

There are changes of several 0.1 arcsec, depending on the epoch of the orbital elements and the correction of precession as can be seen in the tables above.

The differences for ecliptic obliquity in arc seconds (new - old) are:

5400	-1.71468
5000	-1.25244
4000	-0.63612
3000	-0.31788
2100	-0.06336
2000	-0.04212
1900	-0.02016
1800	0.01296
1700	0.04032
1600	0.06696
1500	0.09432
1000	0.22716
0	0.51444
-1000	1.07064
-2000	2.62908
-3000	6.68016
-4000	15.73272
-5000	33.54480
-5400	44.22924

The differences for *sidereal time* in seconds (new - old) are:

5400	-2.544
5000	-1.461
4000	-0.122
3000	0.126
2100	0.019
2000	0.001
1900	0.019
1000	0.126
0	-0.122
-500	-0.594
-1000	-1.461
-2000	-5.029
-3000	-12.355
-4000	-25.330
-5000	-46.175
-5400	-57.273

2.1.2.4 Differences between Swiss Ephemeris 1.78 and 1.77

Former versions of the Swiss Ephemeris had used the precession model by Capitaine, Wallace, and Chapront of 2003 for the time range 1800-2200 and the precession model J. G. Williams in Astron. J. 108, 711-724 (1994) for epochs outside this time range.

Version 1.78 calculates precession and ecliptic obliquity according to Vondrák, Capitaine, and Wallace, “New precession expressions, valid for long time intervals”, A&A 534, A22 (2011), which is good for +- 200 millennia.

This change has almost no ramifications for historical epochs. Planetary positions and the obliquity of the ecliptic change by less than an arc minute in 5400 BC. However, for research concerning the prehistoric cave paintings (Lascaux, Altamira, etc, some of which may represent celestial constellations), fixed star positions are required for 15’000 BC or even earlier (the Chauvet cave was painted in 33’000 BC). Such calculations are now possible using the Swiss Ephemeris version 1.78 or higher. However, the Sun, Moon, and the planets remain restricted to the time range 5400 BC to 5400 AD.

Differences in precession (v. 1.78 – v. 1.77, test star was Aldebaran):

Year	Difference in arc sec
-20000	-26715"
-15000	-2690"
-10000	-256"
-5000	-3.95388"
-4000	-9.77904"
-3000	-7.00524"
-2000	-3.40560"
-1000	-1.23732"
0	-0.33948"
1000	-0.05436"
1800	-0.00144"
1900	-0.00036"
2000	0.00000"
2100	-0.00036"
2200	-0.00072"
3000	0.03528"
4000	0.59904"
5000	2.90160"
10000	76"
15001	227"
19000	2839"
20000	5218"

Differences in ecliptic obliquity

Year	Difference in arc sec
-20000	11074.43664"
-15000	3321.50652"
-10000	632.60532"
-5000	-33.42636"
0	0.01008"
1000	0.00972"
2000	0.00000"
3000	-0.01008"
4000	-0.05868"
10000	-72.91980"
15000	-772.91712"
20000	-3521.23488”

2.1.2.5 Differences between Swiss Ephemeris 2.00 and 1.80

These differences are explained by the fact that the Swiss Ephemeris is now based on JPL Ephemeris DE431, whereas before release 2.00 it was based on DE406. The differences are listed above in ch. 2.1.1.3, see paragraph on “*Comparison of JPL ephemerides DE406 (1998) with DE431 (2013)”*.

2.1.3 The details of coordinate transformation

The following conversions are applied to the coordinates after reading the raw positions from the ephemeris files:

Correction for light-time. Since the planet's light needs time to reach the earth, it is never seen where it actually is, but where it was some time before. Light-time amounts to a few minutes with the inner planets and a few hours with distant planets like Uranus, Neptune and Pluto. For the moon, the light-time correction is about one second. With planets, light-time correction may be of the order of 20” in position, with the moon 0.5”

Conversion from the solar system barycenter to the geocenter. Original JPL data are referred to the center of the gravity of the solar system. Apparent planetary positions are referred to an imaginary observer in the center of the earth.

Light deflection by the gravity of the sun. In the gravitational fields of the sun and the planets light rays are bent. However, within the solar system only the sun has enough mass to deflect light significantly. Gravity deflection is greatest for distant planets and stars, but never greater than 1.8”. When a planet disappears behind the sun, the *Explanatory Supplement* recommends to set the deflection = 0. To avoid discontinuities, we chose a different procedure. See Appendix A.

”Annual” aberration of light. The velocity of light is finite, and therefore the apparent direction of a moving body from a moving observer is never the same as it would be if both the planet and the observer stood still. For comparison: if you run through the rain, the rain seems to come from ahead even though it actually comes from above. Aberration may reach 20”.

Frame Bias (ICRS to J2000). JPL ephemeredes since DE403/DE404 are referred to the International Celestial Reference System, a time-independent, non-rotating reference system which was introduced by the IAU in 1997. The planetary positions and speed vectors are rotated to the J2000 system. This transformation makes a difference of only about 0.0068 arc seconds in right ascension. (Implemented from Swiss Ephemeris 1.70 on)

Precession. Precession is the motion of the vernal equinox on the ecliptic. It results from the gravitational pull of the Sun, the Moon, and the planets on the equatorial bulge of the earth. Original JPL data are referred to the mean equinox of the year 2000. Apparent planetary positions are referred to the equinox of *date*. (From Swiss Ephemeris 1.78 on, we use the precession model Vondrák/Capitaine/Wallace 2011.)

*Nutation (*true *equinox of date)*. A short-period oscillation of the vernal equinox. It results from the moon’s gravity which acts on the equatorial bulge of the earth. The period of nutation is identical to the period of a cycle of the lunar node, i.e. 18.6 years. The difference between the true vernal point and the mean one is always below 17”. (From Swiss Ephemeris 2.00, we use the nutation model IAU 2006. Since 1.70, we used nutation model IAU 2000. Older versions used the nutation model IAU 1980 (Wahr).)

Transformation from equatorial to ecliptic coordinates

For *precise speed* of the planets and the moon, we had to make a special effort, because the *Explanatory Supplement* does not give algorithms that apply the above-mentioned transformations to speed. Since this is not a trivial job, the easiest way would have been to compute three positions in a small interval and determine the speed from the derivation of the parabola going through them. However, double float calculation does not guarantee a precision better than 0.1"/day. Depending on the time difference between the positions, speed is either good near station or during fast motion. Derivation from more positions and higher order polynomials would not help either.

Therefore we worked out a way to apply directly all the transformations to the barycentric speeds that can be derived from JPL or Swiss Ephemeris. The precision of daily motion is now better than 0.002" for all planets, and the computation is even a lot faster than it would have been from three positions. A position with speed takes in average only 1.66 times longer than one without speed, if a JPL or a Swiss Ephemeris position is computed. With Moshier, however, a computation with speed takes 2.5 times longer.

2.1.4 The Swiss Ephemeris compression mechanism

The idea behind our mechanism of ephemeris compression was developed by Dr. Peter Kammeyer of the U.S. Naval Observatory in 1987.

This is how it works: The ephemerides of the Moon and the inner planets require by far the greatest part of the storage. A more sophisticated mechanism is required for these than for the outer planets. Instead of the positions we store the differences between JPL and the mean orbits of the analytical theory VSOP87. These differences are a lot smaller than the position values, wherefore they require less storage. They are stored in Chebyshew polynomials covering a period of an anomalistic cycle each. (By the way, this is the reason, why the Swiss Ephemeris does not cover the time range of the full JPL ephemeris. The first ephemeris file begins on the date on which the last of the inner planets (including Mars) passes its first perihelion after the start date of the JPL ephemeris.)

With the outer planets from Jupiter through Pluto we use a simpler mechanism. We rotate the positions provided by the JPL ephemeris to the mean plane of the planet. This has the advantage that only two coordinates have high values, whereas the third one becomes very small. The data are stored in Chebyshew polynomials that cover a period of 4000 days each. (This is the reason, why Swiss Ephemeris stops before the end date of the JPL ephemeris.)

2.1.5 The extension of the time range to 10'800 years

This chapter is only relevant for those who use pre-2014, DE406-based ephemeris files of the Swiss Ephemeris.

The JPL ephemeris DE406 covers the time range from 3000 BC to 3000 AD. While this is an excellent range covering all precisely known historical events, there are some types of ancient astrology and archaeoastronomical research which would require a longer time range.

In December 1998 we have made an effort to extend the time range using our own numerical integration. The exact physical model used by Standish et. al. for the numerical integration of the DE406 ephemeris is not fully documented (at least we do not understand some details), so that we cannot use the same integration program as had been used at JPL for the creation of the original ephemeris.

The previous JPL ephemeris DE200, however, has been reproduced by Steve Moshier over a very long time range with his numerical integrator, which was available to us. We used this software with start vectors taken at the end points of the DE406 time range. To test our numerical integrator, we ran it upwards from 3000 BC to 600 BC for a period of 2400 years and compared its results with the DE406 ephemeris itself. The agreement is excellent for all planets except the Moon (see table below). The lunar orbit creates a problem because the physical model for the Moon's libration and the effect of the tides on lunar motion is quite different in the DE406 from the model in the DE200. We varied the tidal coupling parameter (love number) and the longitudinal libration phase at the start epoch until we found the best agreement over the 2400 year test range between our integration and the JPL data. We could reproduce the Moon's motion over a the 2400 time range with a maximum error of 12 arcseconds. For most of this time range the agreement is better than 5 arcsec.

With these modified parameters we ran the integration backward in time from 3000 BC to 5400 BC. It is reasonable to assume that the integration errors in the backward integration are not significantly different from the integration errors in the upward integration.

Planet	max. Error arcsec	avg. error arcec
Mercury	1.67	0.61
Venus	0.14	0.03
Earth	1.00	0.42
Mars	0.21	0.06
Jupiter	0.85	0.38
Saturn	0.59	0.24
Uranus	0.20	0.09
Neptune	0.12	0.06
Pluto	0.12	0.04
Moon	12.2	2.53
Sun bary.	6.3	0.39

The same procedure was applied at the upper end of the DE406 range, to cover an extension period from 3000 AD to 5400 AD. The maximum integration errors as determined in the test run 3000 AD down to 600 AD are given in the table below.

Planet	max. error arcsec	avg. error arcsec
Mercury	2.01	0.69
Venus	0.06	0.02
Earth	0.33	0.14
Mars	1.69	0.82
Jupiter	0.09	0.05
Saturn	0.05	0.02
Uranus	0.16	0.07
Neptune	0.06	0.03
Pluto	0.11	0.04
Moon	8.89	3.43
Sun bary.	0.61	0.05

Deviations in heliocentric longitude from new JPL ephemeris DE431 (2013), time range 5400 BC to 3000 BC:

Moon (geocentric)	< 40”
Earth, Mercury, Venus	< 1.4”
Mars	< 4”
Jupiter	< 9”
Saturn	< 1.2”
Uranus	< 36”
Neptune	< 76”
Pluto	< 120”

2.2 Lunar and Planetary Nodes and Apsides

2.2.1 Mean Lunar Node and Mean Lunar Apogee ('Lilith', 'Black Moon' in astrology)

JPL ephemerides do not include a mean lunar node or mean lunar apsis (perigee/apogee). We therefore have to derive them from different sources.

Our mean node and mean apogee are computed from Moshier's lunar routine, which is an adjustment of the ELP2000-85 lunar theory to the JPL ephemeris on the interval from 3000 BC to 3000 AD. Its deviation from the mean node of ELP2000-85 is 0 for J2000 and remains below 20 arc seconds for the whole period. With the apogee, the deviation reaches 3 arc minutes at 3000 BC.

In order to cover the whole time range of DE431, we had to add some corrections to Moshier's mean node and apsis, which we derived from the true node and apsis that result from the DE431 lunar ephemeris. Estimated precision is 1 arcsec, relative to DE431.

Notes for Astrologers:

Astrological *Lilith* or the *Dark Moon* is either the apogee (”aphelion”) of the lunar orbital ellipse or, according to some, its empty focal point. As seen from the geocenter, this makes no difference. Both of them are located in exactly the same direction. But the definition makes a difference for topocentric ephemerides.

The opposite point, the lunar perigee or orbital point closest to the Earth, is also known as *Priapus*. However, if Lilith is understood as the second focal point, an opposite point makes no sense, of course.

Originally, the term ”Dark Moon” stood for a hypothetical second body that was believed to move around the earth. There are still ephemerides circulating for such a body, but modern celestial mechanics clearly exclude the possibility of such an object. Later the term ”Dark Moon” was used for the lunar apogee.

The Swiss Ephemeris apogee differs from the ephemeris given by Joëlle de Gravelaine in her book ”Lilith, der schwarze Mond” (Astrodata 1990). The difference reaches several arc minutes. The mean apogee (or perigee) moves along the mean lunar orbit which has an inclination of 5 degrees. Therefore it has to be projected on the ecliptic. With de Gravelaine's ephemeris, this was not taken into account. As a result of this projection, we also provide an ecliptic latitude of the apogee, which will be of importance if declinations are used.

There may be still another problem. The 'first' focal point does not coincide with the geocenter but with the barycenter of the earth-moon-system. The difference is about 4700 km. If one took this into account, it would result in a monthly oscillation of the Black Moon. If one defines the Black Moon as the apogee, this oscillation would be about +/- 40 arc minutes. If one defines it as the second focus, the effect is a lot greater: +/- 6 degrees. However, we have neglected this effect.

[added by Alois 7-feb-2005, arising out of a discussion with Juan Revilla] The concept of 'mean lunar orbit' means that short term. e.g. monthly, fluctuations must not be taken into account. In the temporal average, the EMB coincides with the geocenter. Therefore, when mean elements are computed, it is correct only to consider the geocenter, not the Earth-Moon Barycenter.

Computing topocentric positions of mean elements is also meaningless and should not be done.

2.2.2 The 'True' Node

The 'true' lunar node is usually considered the osculating node element of the momentary lunar orbit. I.e., the axis of the lunar nodes is the intersection line of the momentary orbital plane of the moon and the plane of the ecliptic. Or in other words, the nodes are the intersections of the two great circles representing the momentary apparent orbit of the moon and the ecliptic.

The nodes are considered important because they are connected with eclipses. They are the meeting points of the sun and the moon. From this point of view, a more correct definition might be: The axis of the lunar nodes is the intersection line of the momentary orbital plane of the moon and *the momentary orbital plane of the sun.*

This makes a difference, although a small one. Because of the monthly motion of the earth around the earth-moon barycenter, the sun is not exactly on the ecliptic but has a latitude, which, however, is always below an arc second. Therefore the momentary plane of the sun's motion is not identical with the ecliptic. For the true node, this would result in a difference in longitude of several arc seconds. However, Swiss Ephemeris computes the traditional version.

The advantage of the 'true' nodes against the mean ones is that when the moon is in exact conjunction with them, it has indeed a zero latitude. This is not so with the mean nodes.

In the strict sense of the word, even the ”true” nodes are true only twice a month, viz. at the times when the moon crosses the ecliptic. Positions given for the times in between those two points are based on the idea that celestial orbits can be approximated by elliptical elements or great circles. The monthly oscillation of the node is explained by the strong perturbation of the lunar orbit by the sun. A different approach for the “true” node that would make sense, would be to interpolate between the true node passages. The monthly oscillation of the node would be suppressed, and the maximum deviation from the conventional ”true” node would be about 20 arc minutes.

Precision of the true node:

The true node can be computed from all of our three ephemerides. If you want a precision of the order of at least one arc second, you have to choose either the JPL or the Swiss Ephemeris.

Maximum differences:

JPL-derived node – Swiss-Ephemeris-derived node	~ 0.1 arc second
JPL-derived node – Moshier-derived node	~ 70 arc seconds

(PLACALC was not better either. Its error was often > 1 arc minute.)

Distance of the true lunar node:

The distance of the true node is calculated on the basis of the osculating ellipse of date.

2.2.3 The Osculating Apogee (astrological 'True Lilith' or 'True Dark Moon')

The position of 'True Lilith' is given in the 'New International Ephemerides' (NIE, Editions St. Michel) and in Francis Santoni 'Ephemerides de la lune noire vraie 1910-2010' (Editions St. Michel, 1993). Both Ephemerides coincide precisely.

The relation of this point to the mean apogee is not exactly of the same kind as the relation between the true node and the mean node. Like the 'true' node, it can be considered as an osculating orbital element of the lunar motion. But there is an important difference: The apogee contains the concept of the ellipse, whereas the node can be defined without thinking of an ellipse. As has been shown above, the node can be derived from orbital planes or great circles, which is not possible with the apogee. Now ellipses are good as a description of planetary orbits because planetary orbits are close to a two-body problem. But they are not good for the lunar orbit which is strongly perturbed by the gravity of the Sun (three-body problem). *The lunar orbit is far from being an ellipse!*

The osculating apogee is 'true' twice a month: when it is in exact conjunction with the Moon, the Moon is most distant from the earth; and when it is in exact opposition to the moon, the moon is closest to the earth. The motion in between those two points, is an oscillation with the period of a month. This oscillation is largely an artifact caused by the reduction of the Moon's orbit to a two-body problem. The amplitude of the oscillation of the *osculating* apogee around the mean apogee is +/- 30 degrees, while the *true* apogee's deviation from the mean one never exceeds 5 degrees.

There is a small difference between the NIE's 'true Lilith' and our osculating apogee, which results from an inaccuracy in NIE. The error reaches 20 arc minutes. According to Santoni, the point was calculated using 'les 58 premiers termes correctifs au perigée moyen' published by Chapront and Chapront-Touzé. And he adds: "Nous constatons que même en utilisant ces 58 termes *correctifs*, l'erreur peut atteindre 0,5d!" (p. 13) We avoid this error, computing the orbital elements from the position and the speed vectors of the moon. (By the way, there is also an error of +/- 1 arc minute in NIE's true node. The reason is probably the same.)

Precision:

The osculating apogee can be computed from any one of the three ephemerides. If a precision of at least one arc second is required, one has to choose either the JPL or the Swiss Ephemeris.

Maximum differences:

JPL-derived apogee – Swiss-Ephemeris-derived apogee	~ 0.9 arc second	
JPL-derived apogee – Moshier-derived apogee	~ 360 arc seconds	= 6 arc minutes!

There have been several other attempts to solve the problem of a 'true' apogee. They are not included in the SWISSEPH package. All of them work with a correction table.

They are listed in Santoni's 'Ephemerides de la lune noire vraie' mentioned above. With all of them, a value is added to the mean apogee depending on the angular distance of the sun from the mean apogee. There is something to this idea. The actual apogees that take place once a month differ from the mean apogee by never more than 5 degrees and seem to move along a regular curve that is a function of the elongation of the mean apogee.

However, this curve does not have exactly the shape of a sine, as is assumed by all of those correction tables. And most of them have an amplitude of more than 10 degrees, which is a lot too high. The most realistic solution so far was the one proposed by Henry Gouchon in "Dictionnaire Astrologique", Paris 1992, which is based on an amplitude of 5 degrees.

In "Meridian" 1/95, Dieter Koch has published another table that pays regard to the fact that the motion does not precisely have the shape of a sine. (Unfortunately, "Meridian" confused the labels of the columns of the apogee and the perigee.)

2.2.4 The Interpolated or Natural Apogee and Perigee (astrological Lilith and Priapus)

As has been said above, the osculating lunar apogee (so-called "true Lilith") is a mathematical construct which assumes that the motion of the moon is a two-body problem. This solution is obviously too simplistic. Although Kepler ellipses are a good means to describe planetary orbits, they fail with the orbit of the moon, which is strongly perturbed by the gravitational pull of the sun. This solar perturbation results in gigantic monthly oscillations in the ephemeris of the osculating apsides (the amplitude is 30 degrees). These oscillations have to be considered an *artifact* of the insufficient model, they do not really show a motion of the apsides.

A more sensible solution seems to be an interpolation between the real passages of the moon through its apogees and perigees. It turns out that the motions of the lunar perigee and apogee form curves of different quality and the two points are usually not in opposition to each other. They are more or less opposite points only at times when the sun is in conjunction with one of them or at an angle of 90° from them. The amplitude of their oscillation about the mean position is 5 degrees for the apogee and 25 degrees for the perigee.

This solution has been called the *"interpolated"* or "realistic" apogee and perigee by Dieter Koch in his publications. Juan Revilla prefers to call them the *"natural"* apogee and perigee. Today, Dieter Koch would prefer the designation "natural". The designation "interpolated" is a bit misleading, because it associates something that astrologers used to do everyday in old days, when they still used to work with printed ephemerides and house tables.

Note on implementation (from Swiss Ephemeris Version 1.70 on):

Conventional interpolation algorithms do not work well in the case of the lunar apsides. The supporting points are too far away from each other in order to provide a good interpolation, the error estimation is greater than 1 degree for the perigee. Therefore, Dieter chose a different solution. He derived an "interpolation method" from the analytical lunar theory which we have in the form of moshier's lunar ephemeris. This "interpolation method" has not only the advantage that it probably makes more sense, but also that the curve and its derivation are both continuous.

Literature (in German):

- Dieter Koch, "Was ist Lilith und welche Ephemeride ist richtig", in: Meridian 1/95

- Dieter Koch and Bernhard Rindgen, "Lilith und Priapus", Frankfurt/Main, 2000. (http://www.vdhb.de/Lilith_und_Priapus/lilith_und_priapus.html)

- Juan Revilla, "The Astronomical Variants of the Lunar Apogee - Black Moon", http://www.expreso.co.cr/centaurs/blackmoon/barycentric.html

2.2.5 Planetary Nodes and Apsides

Differences between the Swiss Ephemeris and other ephemerides of the osculation nodes and apsides are probably due to different planetary ephemerides being used for their calculation. Small differences in the planetary ephemerides lead to greater differences in nodes and apsides.

Definitions of the nodes

Methods described in small font are not supported by the Swiss Ephemeris software.

The lunar nodes are defined by the intersection axis of the lunar orbital plane with the plane of the ecliptic. At the lunar nodes, the moon crosses the plane of the ecliptic and its ecliptic latitude changes sign. There are similar nodes for the planets, but their definition is more complicated. Planetary nodes can be defined in the following ways:

1) They can be understood as an *axis* defined by the intersection line of two orbital planes. E.g., the nodes of Mars are defined by the intersection line of the orbital plane of Mars with the plane of the ecliptic (or the orbital plane of the Earth).

   Note: However, as Michael Erlewine points out in his elaborate web page on this topic (http://thenewage.com/resources/articles/interface.html), planetary nodes could be defined for any couple of planets. E.g. there is also an intersection line for the two orbital planes of Mars and Saturn. Such non-ecliptic nodes have not been implemented in the Swiss Ephemeris.

   Because such lines are, in principle, infinite, the heliocentric and the geocentric positions of the planetary nodes will be the same. There are astrologers that use such heliocentric planetary nodes in geocentric charts.

   The ascending and the descending node will, in this case, be in precise opposition.

2) There is a second definition that leads to different geocentric ephemerides. The planetary nodes can be understood, not as an infinite axis, but as the two *points* at which a planetary orbit intersects with the ecliptic plane.

For the lunar nodes and heliocentric planetary nodes, this definition makes no difference from the definition 1). However, it does make a difference for *geocentric* planetary nodes, where, the nodal points on the planets orbit are transformed to the geocenter. The two points will not be in opposition anymore, or they will roughly be so with the outer planets. The advantage of these nodes is that when a planet is in conjunction with its node, then its ecliptic latitude will be zero. This is not true when a planet is in geocentric conjunction with its heliocentric node. (And neither is it always true for inner the planets, for Mercury and Venus.)

Note: There is another possibility, not implemented in the Swiss ephemeris: E.g., instead of considering the points of the Mars orbit that are located in the ecliptic plane, one might consider the points of the *earth's* orbit that are located in the orbital plane of Mars. If one takes these points geocentrically, the ascending and the descending node will always form an approximate square. This possibility has not been implemented in the Swiss Ephemeris.

3) Third, the planetary nodes could be defined as the intersection points of the plane defined by their momentary geocentric position and motion with the plane of the ecliptic. Here again, the ecliptic latitude would change sign at the moment when the planet were in conjunction with one of its nodes. This possibility has not been implemented in the Swiss Ephemeris.

Possible definitions for apsides and focal points

The lunar apsides - the lunar apogee and lunar perigee - have already been discussed further above. Similar points exist for the planets, as well, and they have been considered by astrologers. Also, as with the lunar apsides, there is a similar disagreement:

One may consider either the planetary *apsides*, i.e. the two points on a planetary orbit that are closest to the sun and most distant from the sun, resp. The former point is called the *"perihelion"* and the latter one the *"aphelion"*. For a geocentric chart, these points could be transformed from the heliocenter to the geocenter.

However, Bernard Fitzwalter and Raymond Henry prefer to use the second focal points of the planetary orbits. And they call them the "black stars" or the "black suns of the planets". The heliocentric positions of these points are identical to the heliocentric positions of the aphelia, but geocentric positions are not identical, because the focal points are much closer to the sun than the aphelia. Most of them are even inside the Earth orbit.

The Swiss Ephemeris supports both points of view.

Special case: the Earth

The Earth is a special case. Instead of the motion of the Earth herself, the heliocentric motion of the Earth-Moon-Barycenter (EMB) is used to determine the osculating perihelion.

There is no node of the earth orbit itself.

There is an axis around which the earth's orbital plane slowly rotates due to planetary precession. The position points of this axis are not calculated by the Swiss Ephemeris.

Special case: the Sun

In addition to the Earth (EMB) apsides, our software computes so-to-say "apsides" of the solar orbit around the Earth, i.e. points on the orbit of the Sun where it is closest to and where it is farthest from the Earth. These points form an opposition and are used by some astrologers, e.g. by the Dutch astrologer George Bode or the Swiss astrologer Liduina Schmed. The "perigee", located at about 13 Capricorn, is called the "Black Sun", the other one, in Cancer, is called the "Diamond".

So, for a complete set of apsides, one might want to calculate them for the Sun *and* the Earth and all other planets.

Mean and osculating positions

There are serious problems about the ephemerides of planetary nodes and apsides. There are mean ones and osculating ones. Both are well-defined points in astronomy, but this does not necessarily mean that these definitions make sense for astrology. Mean points, on the one hand, are not true, i.e. if a planet is in precise conjunction with its mean node, this does not mean it be crossing the ecliptic plane exactly that moment. Osculating points, on the other hand, are based on the idealization of the planetary motions as two-body problems, where the gravity of the sun and a single planet is considered and all other influences neglected. There are no planetary nodes or apsides, at least today, that really deserve the label ”true”.

Mean positions

Mean nodes and apsides can be computed for the Moon, the Earth and the planets Mercury – Neptune. They are taken from the planetary theory VSOP87. Mean points can *not* be calculated for Pluto and the asteroids, because there is no planetary theory for them.

Although the Nasa has published mean elements for the planets Mercury – Pluto based on the JPL ephemeris DE200, we do not use them (so far), because their validity is limited to a 250 year period, because only linear rates are given, and because they are not based on a planetary theory. (http://ssd.jpl.nasa.gov/elem_planets.html, ”mean orbit solutions from a 250 yr. least squares fit of the DE 200 planetary ephemeris to a Keplerian orbit where each element is allowed to vary linearly with time”)

The differences between the DE200 and the VSOP87 mean elements are considerable, though:

	Node	Perihelion
Mercury	3”	4”
Venus	3”	107”
Earth	-	35”
Mars	74”	4”
Jupiter	330”	1850”
Saturn	178”	1530”
Uranus	806”	6540”
Neptune	225”	11600” (>3 deg!)

Osculating nodes and apsides

Nodes and apsides can also be derived from the osculating orbital elements of a body, the parameters that define an ideal unperturbed elliptic (two-body) orbit for a given time. Celestial bodies would follow such orbits *if perturbations were to cease suddenly or if there were only two bodies (the sun and the planet) involved in the motion and the motion were an ideal ellipse*. This ideal assumption makes it obvious that it would be misleading to call such nodes or apsides "true". It is more appropriate to call them "osculating". Osculating nodes and apsides are "true" only at the precise moments, when the body passes through them, but for the times in between, they are a mere mathematical construct, nothing to do with the nature of an orbit.

We tried to solve the problem by *interpolating* between actual passages of the planets through their nodes and apsides. However, this method works only well with Mercury. With all other planets, the supporting points are too far apart as to allow a sensible interpolation.

There is another problem about heliocentric ellipses. E.g. Neptune's orbit has often two perihelia and two aphelia (i. e. minima and maxima in heliocentric distance) within one revolution. As a result, there is a wild oscillation of the osculating or "true" perihelion (and aphelion), which is not due to a transformation of the orbital ellipse but rather due to the deviation of the heliocentric orbit from an elliptic shape. Neptune’s orbit cannot be adequately represented by a heliocentric ellipse.

In actuality, Neptune’s orbit is not heliocentric at all. The double perihelia and aphelia are an effect of the motion of the sun about the solar system barycenter. This motion is a lot faster than the motion of Neptune, and Neptune cannot react to such fast displacements of the Sun. As a result, Neptune seems to move around the barycenter (or a mean sun) rather than around the real sun. In fact, Neptune's orbit around the barycenter is therefore closer to an ellipse than his orbit around the sun. The same is also true, though less obvious, for Saturn, Uranus and Pluto, but not for Jupiter and the inner planets.

This fundamental problem about osculating ellipses of planetary orbits does of course not only affect the apsides but also the nodes.

As a solution, it seems reasonable to compute the osculating elements of *slow* planets from their barycentric motions rather than from their heliocentric motions. This procedure makes sense especially for Neptune, but also for all planets beyond Jupiter. It comes closer to the mean apsides and nodes for planets that have such points defined. For Pluto and all trans-Saturnian asteroids, this solution may be used as a substitute for "mean" nodes and apsides. Note, however, that there are considerable differences between barycentric osculating and mean nodes and apsides for Saturn, Uranus, and Neptune. (A few degrees! But heliocentric ones are worse.)

Anyway, neither the heliocentric nor the barycentric ellipse is a perfect representation of the nature of a planetary orbit. So, astrologers should not expect anything very reliable here either!

The best choice of method will probably be:

For Mercury – Neptune: mean nodes and apsides.

For asteroids that belong to the inner asteroid belt: osculating nodes/apsides from a heliocentric ellipse.

For Pluto and transjovian asteroids: osculating nodes/apsides from a barycentric ellipse.

The modes of the Swiss Ephemeris function swe_nod_aps()

The function *swe_nod_aps()* can be run in the following modes:

1) Mean positions are given for nodes and apsides of Sun, Moon, Earth, and the planets up to Neptune. Osculating positions are given with Pluto and all asteroids. This is the default mode.

2) Osculating positions are returned for nodes and apsides of all planets.

3) Same as 2), but for planets and asteroids beyond Jupiter, a barycentric ellipse is used.

4) Same as 1), but for Pluto and asteroids beyond Jupiter, a barycentric ellipse is used.

For the reasons given above, method 4) seems to make best sense.

In all of these modes, the second focal point of the ellipse can be computed instead of the aphelion.

2.3. Asteroids

Asteroid ephemeris files

The standard distribution of SWISSEPH includes the *main* asteroids Ceres, Pallas, Juno, Vesta, as well as 2060 Chiron, and 5145 Pholus. To compute them, one must have the main-asteroid ephemeris files in the ephemeris directory.

The names of these files are of the following form:

`seas_18.se1` main asteroids for 600 years from 1800 - 2400

The size of such a file is about 200 kb.

All other asteroids are available in separate files. The names of additional asteroid files look like:

`se00433.se1` the file of asteroid No. 433 (= Eros)

These files cover the period 3000 BC - 3000 AD.
A short version for the years 1500 – 2100 AD has the file name with an 's' imbedded, `se00433s.se1`.

The numerical integration of the all numbered asteroids is an ongoing effort. In December 1998, 8000 asteroids were numbered, and their orbits computed by the devlopers of Swiss Ephemeris. In January 2001, the list of numbered asteroids reached 20957, in January 2014 more than 380’000, and it is still growing very fast.

Any asteroid can be called either with the JPL, the Swiss, or the Moshier ephemeris flag, and the results will be slightly different. The reason is that the solar position (which is needed for geocentric positions) will be taken from the ephemeris that has been specified.

Availability of asteroid files:

- all short files (over 200000) are available for free download at our ftp server ftp.astro.ch/pub/swisseph. The purpose of providing this large number of files for download is that the user can pick those few asteroids he/she is interested in.
- for all named asteroids also a long (6000 years) file is available in the download area.

How the asteroids were computed

To generate our asteroid ephemerides, we have modified the numerical integrator of Steve Moshier, which was capable to rebuild the DE200 JPL ephemeris.

Orbital elements, with a few exceptions, were taken from the asteroid database computed by E. Bowell, Lowell Observatory, Flagstaff, Arizona (astorb.dat). After the introduction of the JPL database mpcorb.dat, we still keep working with the Lowell data because Lowell elements are given with one more digit, which can be relevant for long-term integrations.

For a few close-Sun-approaching asteroids like 1566 Icarus, we use the elements of JPL's DASTCOM database. Here, the Bowell elements are not good for long term integration because they do not account for relativity.

Our asteroid ephemerides take into account the gravitational perturbations of all planets, including the major asteroids Ceres, Pallas, and Vesta and also the Moon.

The mutual perturbations of Ceres, Pallas, and Vesta were included by iterative integration. The first run was done without mutual perturbations, the second one with the perturbing forces from the positions computed in the first run.

The precision of our integrator is very high. A test integration of the orbit of Mars with start date 2000 has shown a difference of only 0.0007 arc second from DE200 for the year 1600. We also compared our asteroid ephemerides with data from JPL's on-line ephemeris system "Horizons" which provides asteroid positions from 1600 on. Taking into account that Horizons does not consider the mutual perturbations of the major asteroids Ceres, Pallas and Vesta, the difference is never greater than a few 0.1 arcsec.

(However, the Swisseph asteroid ephemerides *do* consider those perturbations, which makes a difference of 10 arcsec for Ceres and 80 arcsec for Pallas. This means that our asteroid ephemerides are even better than the ones that JPL offers on the web.)

The accuracy limits are therefore not set by the algorithms of our program but by the inherent uncertainties in the orbital elements of the asteroids from which our integrator has to start.

Sources of errors are:

- Only some of the minor planets are known to better than an arc second for recent decades. (See also informations below on Ceres, Chiron, and Pholus.)
- Bowells elements do not consider relativistic effects, which leads to significant errors with long-term integrations of a few close-Sun-approaching orbits (except 1566, 2212, 3200, 5786, and 16960, for which we use JPL elements that do take into account relativity).

The orbits of some asteroids are extremely sensitive to perturbations by major planets. E.g. 1862 Apollo becomes chaotic before the year 1870 AD when he passes Venus within a distance which is only one and a half the distance from the Moon to the Earth. In this moment, the small uncertainty of the initial elements provided by the Bowell database grows, so to speak, "into infinity", so that it is impossible to determine the precise orbit prior to that date. Our integrator is able to detect such happenings and end the ephemeris generation to prevent our users working with meaningless data.

Ceres, Pallas, Juno, Vesta

The orbital elements of the four main asteroids Ceres, Pallas, Juno, and Vesta are known very precisely, because these planets have been discovered almost 200 years ago and observed very often since. On the other hand, their orbits are not as well-determined as the ones of the main planets. We estimate that the precision of the main asteroid ephemerides is better than 1 arc second for the whole 20th century. The deviations from the Astronomical Almanac positions can reach 0.5" (AA 1985 – 1997). But the tables in AA are based on older computations, whereas we used recent orbital elements. (s. AA 1997, page L14)

MPC elements have a precision of five digits with mean anomaly, perihelion, node, and inclination and seven digits with eccentricity and semi-axis. For the four main asteroids, this implies an uncertainty of a few arc seconds in 1600 AD and a few arc minutes in 3000 BC.

Chiron

Positions of Chiron can be well computed for the time between 700 AD and 4650 AD. As a result of close encounters with Saturn in Sept. 720 AD and in 4606 AD we cannot trace its orbit beyond this time range. Small uncertainties in today's orbital elements have *chaotic* effects before the year 700.

Do not rely on earlier Chiron ephemerides supplying a Chiron for Cesar's, Jesus', or Buddha's birth chart. They are completely meaningless.

Pholus

Pholus is a minor planet with orbital characteristics that are similar to Chiron's. It was discovered in 1992. Pholus' orbital elements are not yet as well-established as Chiron's. Our ephemeris is reliable from 1500 AD through now. Outside the 20th century it will probably have to be corrected by several arc minutes during the coming years.

"Ceres" - an application program for asteroid astrology

Dieter Koch has written the application program *Ceres* which allows to compute all kinds of lists for asteroid astrology. E.g. you can generate a list of all your natal asteroids ordered by position in the zodiac. But the program does much more:

- natal positions, synastries/transits, composite charts, progressions, primary directions etc.

- geocentric, heliocentric, topocentric, house horoscopes

- lists sorted by position in zodiac, by asteroid name, by declination etc.

The program is on the asteroid short files CD-ROM and the standard Swiss Ephemeris CD-ROM.

2.4 Comets

The Swiss Ephemeris does not provide ephemerides of comets yet.

2.5 Fixed stars and Galactic Center

A database of fixed stars is included with Swiss Ephemeris. It contains about 800 stars, which can be computed with the swe_fixstar() function. The precision is about 0.001".

Our data are based on the star catalogue of Steve Moshier. It can be easily extended if more stars are required.

The database was improved by Valentin Abramov, Tartu, Estonia. He reordered the stars by constellation, added some stars, many names and alternative spellings of names.

In Feb. 2006 (Version 1.70) the fixed stars file was updated with data from the SIMBAD database (http://simbad.u-strasbg.fr/Simbad).

In Jan. 2011 (Version 1.77) a new fixed stars file sefstars.txt was created from the SIMBAD database.

2.6 ‚Hypothetical' bodies

We include some astrological factors in the ephemeris which have no astronomical basis – they have never been observed physically. As the purpose of the Swiss Ephemeris is astrology, we decided to drop our scientific view in this area and to be of service to those astrologers who use these 'hypothetical' planets and factors. Of course neither of our scientific sources, JPL or Steve Moshier, have anything to do with this part of the Swiss Ephemeris.

Uranian Planets (Hamburg Planets: Cupido, Hades, Zeus, Kronos, Apollon, Admetos, Vulkanus, Poseidon)

There have been discussions whether these factors are to be called 'planets' or 'Transneptunian points'. However, their inventors, the German astrologers Witte and Sieggrün, considered them to be planets. And moreover they behave like planets in as far as they circle around the sun and obey its gravity.

On the other hand, if one looks at their orbital elements, it is obvious that these orbits are highly unrealistic. Some of them are perfect circles – something that does not exist in physical reality. The inclination of the orbits is zero, which is very improbable as well. The revised elements published by James Neely in Matrix Journal VII (1980) show small eccentricities for the four Witte planets, but they are still smaller than the eccentricity of Venus which has an almost circular orbit. This is again very improbable.

There are even more problems. An ephemeris computed with such elements describes an unperturbed motion, i.e. it takes into account only the Sun's gravity, not the gravitational influences of the other planets. This may result in an error of a degree within the 20th century, and greater errors for earlier centuries.

Also, note that none of the real transneptunian objects that have been discovered since 1992 can be identified with any of the Uranian planets.

SWISSEPH uses James Neely's revised orbital elements, because they agree better with the original position tables of Witte and Sieggrün.

The hypothetical planets can again be called with any of the three ephemeris flags. The solar position needed for geocentric positions will then be taken from the ephemeris specified.

Transpluto (Isis)

This hypothetical planet was postulated 1946 by the French astronomer M.E. Sevin because of otherwise unexplainable gravitational perturbations in the orbits of Uranus and Neptune.

However, this theory has been superseded by other attempts during the following decades, which proceeded from better observational data. They resulted in bodies and orbits completely different from what astrologers know as 'Isis-Transpluto'. More recent studies have shown that the perturbation residuals in the orbits of Uranus and Neptune are too small to allow postulation of a new planet. They can, to a great extent, be explained by observational errors or by systematic errors in sky maps.

In telescope observations, no hint could be discovered that this planet actually existed. Rumors that claim the opposite are wrong. Moreover, all of the transneptunian bodies that have been discovered since 1992 are very different from Isis-Transpluto.

Even if Sevin's computation were correct, it could only provide a rough position. To rely on arc minutes would be illusory. Neptune was more than a degree away from its theoretical position predicted by Leverrier and Adams.

Moreover, Transpluto's position is computed from a simple Kepler ellipse, disregarding the perturbations by other planets' gravities. Moreover, Sevin gives no orbital inclination.

Though Sevin gives no inclination for his Transpluto, you will realize that there is a small ecliptic latitude in positions computed by SWISSEPH. This mainly results from the fact that its orbital elements are referred to epoch 5.10.1772 whereas the ecliptic changes position with time.

The elements used by SWISSEPH are taken from ”Die Sterne” 3/1952, p. 70. The article does not say which equinox they are referred to. Therefore, we fitted it to the Astron ephemeris which apparently uses the equinox of 1945 (which, however, is rather unusual!).

Harrington

This is another attempt to predict Planet X's orbit and position from perturbations in the orbits of Uranus and Neptune. It was published in The Astronomical Journal 96(4), October 1988, p. 1476ff. Its precision is meant to be of the order of +/- 30 degrees. According to Harrington there is also the possibility that it is actually located in the opposite constellation, i.e. Taurus instead of Scorpio. The planet has a mean solar distance of about 100 AU and a period of about 1000 years.

Nibiru

A highly speculative planet derived from the theory of Zecharia Sitchin, who is an expert in ancient Mesopotamian history and a ”paleoastronomer”. The elements have been supplied by Christian Woeltge, Hannover. This planet is interesting because of its bizarre orbit. It moves in clockwise direction and has a period of 3600 years. Its orbit is extremely eccentric. It has its perihelion within the asteroid belt, whereas its aphelion lies at about 12 times the mean distance of Pluto. In spite of its retrograde motion, it *seems* to move counterclockwise in recent centuries. The reason is that it is so slow that it does not even compensate the precession of the equinoxes.

Vulcan

This is a ‘hypothetical’ planet inside the orbit of Mercury (not identical to the “Uranian” planet Vulkanus). Orbital elements according to L.H. Weston. Note that the speed of this “planet” does not agree with the Kepler laws. It is too fast by 10 degrees per year.

Selena/White Moon

This is a ‘hypothetical’ second moon of the earth (or a third one, after the “Black Moon”) of obscure provenance. Many Russian astrologers use it. Its distance from the earth is more than 20 times the distance of the moon and it moves about the earth in 7 years. Its orbit is a perfect, unperturbed circle. Of course, the physical existence of such a body is not possible. The gravities of Sun, Earth, and Moon would strongly influence its orbit.

Dr. Waldemath’s Black Moon

This is another hypothetical second moon of the earth, postulated by a Dr. Waldemath in the *Monthly Wheather Review* 1/1898. Its distance from the earth is 2.67 times the distance of the moon, its daily motion about 3 degrees. The orbital elements have been derived from Waldemath’s original data. There are significant differences from elements used in earlier versions of Solar Fire, due to different interpretations of the values given by Waldemath. After a discussion between Graham Dawson and Dieter Koch it has been agreed that the new solution is more likely to be correct. The new ephemeris does not agree with Delphine Jay’s ephemeris either, which is obviously inconsistent with Waldemath’s data.

This body has never been confirmed. With its 700-km diameter and an apparent diameter of 2.5 arc min, this should have been possible very soon after Waldemath’s publication.

The Planets X of Leverrier, Adams, Lowell and Pickering

These are the hypothetical planets that have lead to the discovery of Neptune and Pluto or at least have been brought into connection with them. Their enormous deviations from true Neptune and Pluto may be interesting for astrologers who work with hypothetical bodies. E.g. Leverrier and Adams are good only around the 1840ies, the discovery epoch of Neptune. To check this, call the program *swetest* as follows:

$ swetest -p8 -dU -b1.1.1770 -n8 -s7305 -hel -fPTLBR -head

(i.e.: compute planet 8 (Neptune) - planet 'U' (Leverrier), from 1.1.1770, 8 times, in 7305-day-steps, heliocentrically. You can do this from the Internet web page swetest.htm. The output will be:)

```
Nep-Lev 01.01.1770  -18° 0'52.3811    0°55' 0.0332   -6.610753489
Nep-Lev 01.01.1790   -8°42' 9.1113    1°42'55.7192   -4.257690148
Nep-Lev 02.01.1810   -3°49'45.2014    1°35'12.0858   -2.488363869
Nep-Lev 02.01.1830   -1°38' 2.8076    0°35'57.0580   -2.112570665
Nep-Lev 02.01.1850    1°44'23.0943   -0°43'38.5357   -3.340858070
Nep-Lev 02.01.1870    9°17'34.4981   -1°39'24.1004   -5.513270186
Nep-Lev 02.01.1890   21°20'56.6250   -1°38'43.1479   -7.720578177
Nep-Lev 03.01.1910   36°27'56.1314   -0°41'59.4866   -9.265417529

   (difference in     (difference in    (difference in
   longitude)         latitude)         solar distance)
```

One can see that the error is in the range of 2 degrees between 1830 and 1850 and grows very fast beyond that period.

2.7 Sidereal Ephemerides

Sidereal Calculations

Sidereal astrology has a complicated history, and we (the developers of Swiss Ephemeris) are actually tropicalists. Any suggestions how we could improve our sidereal calculations are welcome!

For deeper studies of the problem, read:
Raymond Mercier, ”Studies in the Medieval Conception of Precession”,
in 'Archives Internationales d'Histoire des Sciences', (1976) 26:197-220 (part I), and (1977) 27:33-71 (part II)

Thanks to Juan Ant. Revilla, San Jose, Costa Rica, who gave us this precious bibliographic hint.

The problem of defining the zodiac

One of the main differences between the western and the eastern tradition of astrology is the definition of the zodiac. Western astrology uses the so-called *tropical zodiac* in which 0 Aries is defined by the vernal point (the celestial point where the sun stands at the beginning of spring). The *tropical zodiac* is a division of the ecliptic into 12 *zodiac signs* that are all of equal size, i. e. 30°. Astrologers call these signs after some constellations that are found along the ecliptic, but they are actually independent of these constellations. Because the vernal point slowly moves through the constellations and completes a full cycle once in 26000 years, tropical Aries moves through all constellations along the ecliptic, staying in each one for roughly 2160 years. Currently, the vernal point, and the beginning of tropical Aries, is located in the constellation of Pisces. In a few hundred years, it will enter Aquarius, which is the reason why the more impatient ones among us are already preparing for the "Age of Aquarius".

The so-called *sidereal zodiac* also consists of 12 equal-sized zodiac signs, but it is tied to the fixed stars. These sidereal signs, which are used in Hindu astrology and by some western Neo-Babylonian and Neo-Hellenistic astrologers, only roughly coincide with the sidereal constellations, which are of variable size.

While the definition of the tropical zodiac is clear and never questioned, sidereal astrology has quite some problems in defining its zodiac. There are many different definitions of the sidereal zodiac, and they differ by several degrees. At a first glance, all of them look arbitrary, and there is no striking evidence – from a mere astronomical point of view – for anyone of them. However, a historical study shows at least that all of them stem from only one sidereal zodiac. On the other hand, this does not mean that it be simple to give a precise definition of it.

Sidereal planetary positions are usually computed from an equation similar to:

sidereal_position = tropical_position – ayanamsha(t) ,

where *ayanamsha* is the difference between the two zodiacs and changes with time. (Sanskrit *ayanâmsha* means "part of a path"; the Hindi form of the word is *ayanamsa* with an *s* instead of *sh*.) "
The value of the *ayanamsha* of date is computed from the *ayanamsha* value at a particular start date (e.g. 1 Jan 1900) and the speed of the vernal point, the so-called *precession rate* in ecliptic longitude.

The zero point of the sidereal zodiac is therefore traditionally defined by the equation:

sidereal_Aries = tropical Aries + ayanamsha(t) .

And planetary .

The Swiss Ephemeris allows for about thirty different *ayanamshas*, but the user can also define his or her own *ayanamsha*.

The Babylonian tradition and the Fagan/Bradley ayanamsha

There have been several attempts to calculate the zero point of the Babylonian ecliptic from cuneiform lunar and planetary tablets. Positions were given relative to some sidereally fixed reference point. The main problem in fixing the zero point is the inaccuracy of ancient observations. Around 1900 *F.X. Kugler* found that the Babylonian star positions fell into three groups:

9) *ayanamsha* = -3°22´, t0 = -100
10) *ayanamsha* = -4°46´, t0 = -100   Spica at 29 vi 26
11) *ayanamsha* = -5°37´, t0 = -100

(9 – 11 = Swiss Ephemeris *ayanamsha* numbers)

In 1958, *Peter Huber* reviewed the topic in the light of new material and found:

12) *ayanamsha* = -4°34´ +/- 20´, t0 = –100   Spica at 29 vi 14
The standard deviation was 1°08'

In 1977 *Raymond Mercier* noted that the zero point might have been defined as the ecliptic point that culminated simultaneously with the star *eta Piscium* (Al Pherg). For this possibility, we compute:

13) *ayanamsha* = -5°04'46", t0 = –129 Spica at 29 vi 21

Around 1950, *Cyril Fagan*, the founder of the modern western sidereal astrology, reintroduced the old Babylonian zodiac into astrology, placing the fixed star Spica near 29°00 Virgo. As a result of "rigorous statistical investigation" (astrological!) of solar and lunar ingress charts, *Donald Bradley* decided that the sidereal longitude of the vernal point must be computed from Spica at 29 vi 06'05" *disregarding its proper motion*. Fagan and Bradley defined their "synetic vernal point" as:

0) *ayanamsha* = 24°02'31.36" for 1 Jan. 1950 with Spica at 29 vi 06'05" (without aberration)
(For the year –100, this *ayanamsha* places Spica at 29 vi 07'32".)

Fagan and Bradley said that the difference between P. Huber's zodiac and theirs was only 1'. But actually (if Mercier's value for the Huber *ayanamsha* is correct) it was 7'.

According to a text by Fagan (found on the internet), Bradley "once opined in print prior to "New Tool" that it made more sense to consider Aldebaran and Antares, at 15 degrees of their respective signs, as prime fiducials than it did to use Spica at 29 Virgo". Such statements raise the question if the sidereal zodiac ought to be tied up to one of those stars. Today, we know that the fixed stars have a proper motion, wherefore such definitions are not a good idea, if an absolute coordinate system independent on moving bodies is intended. But the Babylonians considered them to be fixed.

For this possibility, Swiss Ephemeris gives an Aldebaran *ayanamsha*:

14) *ayanamsha* with Aldebaran at 15ta00'00" and Antares at 15sc00'17" around the year –100.

The difference between this *ayanamsha* and the Fagan/Bradley one is 1'06".

The Hipparchan tradition

Raymond Mercier has shown that all of the ancient Greek and the medieval Arabic astronomical works located the zero point of the ecliptic somewhere *between 10 and 22 arc minutes east of the star zeta Piscium*. This definition goes back to the great Greek astronomer *Hipparchus*. How did he choose that point? Hipparchus said that the beginning of Aries rises when Spica sets. This statement was meant for a geographical latitude of 36°, the latitude of the island of Rhodos, which Hipparchus' descriptions of rises and settings are referred to.

However, there seems to be more behind it. Mercier points out that according to Hipparchus' star catalogue the stars *alpha Arietis, beta Arietis, zeta Piscium,* and *Spica* are located in a very precise alignment on a great circle which goes through that zero point near *zeta Piscium*. Moreover, this great circle was identical with the horizon once a day at Hipparchus' geographical latitude of 36°. In other words, the zero point rose at the same time when the three mentioned stars in Aries and Pisces rose and when Spica set.

This would of course be a nice definition for the zero point, but unfortunately the stars were not really in such precise alignment. They were only *assumed* to be so.

Mercier gives the following *ayanamsha*s for *Hipparchus* and *Ptolemy* (who used the same star catalogue as Hipparchus):

16) *ayanamsha* = -9°20' 27 June –128 (jd 1674484) zePsc 29pi33'49" Hipparchos

(According to Mercier's calculations, the Hipparchan zero point should have been between 12 and 22 arc min east of zePsc, but the Hipparchan *ayanamsha*, as given by Mercier, has actually the zero point 26' east of zePsc. This comes from the fact that Mercier refers to the *Hipparchan* position of zeta Piscium, which was at least rounded to 10' – if otherwise correct.)

If we used the explicit statement of Hipparchus that *Aries rose when Spica set* at a geographical latitude of 36 degrees, the precise *ayanamsha* would be -8°58'13" for 27 June –128 (jd 1674484) and zePsc would be found at 29pi12', which is too far from the place where it ought to be.

Mercier also discusses the old Indian precession models and zodiac point definitions. He notes that, in the *Sûrya Siddânta*, the star *zeta Piscium* (in Sanskrit *Revatî*) has almost the same position as in the Greek sidereal zodiac, i.e. 29°50' in Pisces. On the other hand, however, Spica (in Sanskrit *Citra*) is given the longitude 30° Virgo. This is a contradiction, either Spica or Revatî must be considered wrong.

Moreover, if the precession model of the *Sûrya Siddânta* is used to compute an *ayanamsha* for the date of Hipparchus, it will turn out to be –9°14'01", which is very close to the Hipparchan value. The same calculation can be done with the *Ârya Siddânta*, and the *ayanamsha* for Hipparchos' date will be –9°14'55". For the *Siddânta Shiromani* the zero point turns out to be Revatî itself. By the way, this is also the zero point chosen by *Copernicus*! So, there is an astonishing agreement between Indian and Western traditions!

The same zero point near the star Revatî is also used by the so-called *Ushâshashî ayanamsha* which is still in use. It differs from the Hipparchan one by only 11 arc minutes.

4) *ayanamsha* = 18°39'39.46 1 Jan. 1900 Ushâshashî
zePsc (Revatî) 29pi50' (today), 29pi45' (Hipparchus' epoch)

The Greek-Arabic-Hindu *ayanamsha* was zero around 560 AD. The tropical and the sidereal zero points were at exactly the same place. Did astronomers or astrologers react to that event? They did! Under the Sassanian ruler Khusrau Anûshirwân, in the year 556, the astronomers of Persia met to correct their astronomical tables, the so-called *Zîj al-Shâh*. These tables are no longer extant, but they were the basis of later Arabic tables, the ones of al-Khwârizmî and the Toledan tables.

One of the most important cycles in Persian astronomy/astrology was the one of Jupiter, which started and ended with the conjunctions of Jupiter with the sun. This cycle happened to end *in the year 564*, and the conjunction of Jupiter with the Sun took place only one day after the spring equinox. And *the spring equinox took place precisely 10 arcmin east of zePsc*. This may be a mere coincidence from a present-day astronomical point of view, but for scientists of those days this was obviously the moment to redefine all astronomical data.

Mercier also shows that in the precession model used in that epoch and in other models used later by Arabic Astronomers, precession was considered to be a phenomenon connected with "the movement of Jupiter, the calendar marker of the night sky, in its relation to the Sun, the time keeper of the daily sky". Such theories were of course wrong, from the point of view of today's knowledge, but they show how important that date was considered to be.

After the Sassanian reform of astronomical tables, we have a new definition of the Greek-Arabic-Hindu sidereal zodiac (this is not explicitly stated by Mercier, however):

16) *ayanamsha* = 0 18 Mar 564, 7:53:23 UT (jd /ET 1927135.8747793) Sassanian
zePsc 29pi49'59"

The same zero point then reappears with a precision of 1' in the Toledan tables, the Khwârizmian tables, the Sûrya Siddhânta, and the Ushâshashî *ayanamsha*.

(Besides the synchronicity of the Sun-Jupiter conjunction and the coincidence of the two zodiacs, it is funny to note that the cosmos helped the inaccuracy of ancient astronomy by "rounding" the position of the star zePsc to precisely 10 arc minutes east of the zero point! All Ptolemean star positions were rounded to 10 arc minutes.)

Suryasiddhanta and Aryabhata

The explanations above are mainly derived from the article by Mercier. However, it is possible to derive ayanamshas from ancient Indian works themselves.

The planetary theory of the main work of ancient Indian astronomy, the Suryasiddhanta, uses the so-called Kaliyuga era as its zero point, i. e. the 18th February 3102 BC, 0:00 local time at Ujjain, which is at geographic longitude of 75.7684565 east (Mahakala temple). This era is henceforth called “K0s”. This is also the zero date for the planetary theory of the ancient Indian astronomer Aryabhata, with the only difference that he reckons from sunrise of the same date instead of midnight. We call this Aryabhatan era “K0a”.

Now, Aryabhata mentioned that he was 23 years old when exactly 3600 years had passed since the beginning of the Kaliyuga era. If 3600 years with a year length as defined by the Aryabhata are counted from K0a, we arrive at the 21st March, 499 AD, 6:56:55.57 UT. At this point of time the mean Sun is assumed to have returned to the beginning of the sidereal zodiac, and we can derive an ayanamsha from this information. There are two possible solutions, though:

1. We can find the place of the mean Sun at that time using modern astronomical algorithms and define this point as the beginning of the sidereal zodiac.
2. As Aryabhata believed that the zodiac began at the vernal point, we can take the vernal point of this date as the zero point.

The same calculations can be done based on K0s and the year length of the Suryasiddhanta. The resulting date of Kali 3600 is the same day but about half an hour later: 7:30:31.57 UT.

Algorithms for the mean Sun were taken from: Simon et alii, “Numerical expressions for precession formulae and mean elements for the Moon and the planets”, in: Astron. Astrophys. 282,663-683 (1994).

21) *ayanamsha* = 0	21 Mar 499, 7:30:31.57 UT = noon at Ujjain, 75.7684565 E. Based on Suryasiddhant: ingress of mean Sun into Aries at point of mean equinox of date.
22) *ayanamsha* = -0.21463395	Based on Suryasiddhanta again, but assuming ingress of mean Sun into Aries at true position of mean Sun at the same epoch
23) *ayanamsha* = 0	21 Mar 499, 6:56:55.57 UT = noon at Ujjain, 75.7684565 E. Based on Aryabhata, ingress of mean Sun into Aries at point of mean equinox of date.
24) *ayanamsha* = -0.23763238	Based on Aryabhata again, but assuming ingress of mean Sun into Aries at true position of mean Sun at the same epoch

The Spica/Citra tradition and the Lahiri ayanamsha

There is another ayanamsha tradition that assumes the star Spica (in Sanskrit Citra) at 0° Libra. This ayanamsha definition is the most common one in modern Hindu astrology. It was first proposed by the astronomy historian S. B. Dixit (also written Dikshit), who in 1896 published his important work *History of Indian Astronomy* (= *Bharatiya Jyotih Shastra*; bibliographical details further below). Dixit came to the conclusion that, given the prominence that Vedic religion gave to the cardinal points of the tropical year, the Indian calendar, which is based on the zodiac, should be reformed and no longer be calculated relative to the sidereal, but to the tropical zodiac. However, if such a reform could not be brought about due to the rigid conservatism of contemporary Vedic culture, then the ayanamsha should be chosen in such a way that the sidereal zero point would be in opposition to Spica. In this way, it would be in accordance with *Grahalaghava*, a work by the 16th century astronomer *Ganeśa Daivajña* that was still used in the 20th century by Indian calendar makers. (op. cit., Part II, p. 323ff.). This view was taken over by the *Indian Calendar Reform Committee* on the occasion of the Indian calendar reform in 1956, when the ayanamsha based on the star Spica/Citra was declared the Indian standard. This standard is mandatory not only for astrology but also for astronomical ephemerides and almanacs and calendars published in India. The ayanamsha based on the star Spica/Citra became known as “Lahiri ayanamsha”. It was named after the Calcuttan astronomer and astrologer Nirmala Chandra Lahiri, who was a member of the Reform Committee.

However, as has been said, it was Dixit who first propagated this solution to the ayanamsha problem. Besides, the Suryasiddhanta, the most important work of ancient Hindu astronomy, which was written in the first centuries AD, but reworked several times, already assumes Spica/Citra at 180° (although this statement has caused a lot of controversy because it is in contradiction with the positions of other stars, and in particular with zeta Piscium/Revati at 359°50‘). And last but not least, the same ayanamsha definition seems to have been used in Babylon and Greece, as well. While the information given above in the chapters about the Babylonian and the Hipparchan traditions are based on analyses of old star catalogues and planetary theories, a study by Nick

Kollerstrom of 22 ancient Greek and 5 Babylonian birth charts has lead to a different conclusion: they fit better with Spica at 0 Libra (= Lahiri), than with Aldebaran at 15 Taurus and Spica at 29 Virgo (= Fagan/Bradley).

The standard definition of the Indian ayanamsha ("Lahiri" ayanamsha) was originally introduced in 1955 by the Indian *Calendar Reform Committee* (23°15' 00" on the 21 March 1956, 0:00 Ephemeris Time). The definition was corrected in *Indian Astronomical Ephemeris* 1989, page 556, footnote:
"According to new determination of the location of equinox this initial value has been revised to and used in computing the mean ayanamsha with effect from 1985'."
The mention of "mean ayanamsha" is misleading though. The value 23°15' 00".658 is true ayanamsha, i. e. it includes nutation and is relative to the true equinox of date.

1) ayanamsha = 23°15' 00".658 21 March 1956, 0:00 TDT Lahiri, Spica roughly at 0 Libra

The Lahiri standard position of Spica is 179°59'04 in the year 2000, and 179°59'08 in 1900. In the year 285, when the star was conjunct the autumnal equinox, its position was 180°00'16. It was in the year 667 AD that its position was precisely 180°. The motion of the star is a result partly of its proper motion and partly of planetary precession, which has the ecliptic slightly change its orientation. But what method exactly was used to define this ayanamsha? According to the Indian pundit AK Kaul, an expert in Hindu calendar and astrology, Lahiri wanted to place the star at 180°, but at the same time arrive at an ayanamsha that was in agreement with the Grahalaghava, an important work for traditional Hindu calendar calculation that was written in the 16th century. (e-mail from Mr. Kaul to Dieter Koch on 1 March 2013)

In 1967, 12 years after the standard definition of the Lahiri ayanamsha had been published by the Calendar Reform Committee, Lahiri published another ayanamsha in his Bengali book *Panchanga Darpan*. There, the value of "mean ayanamsha" is given as 22°26'45".50 in 1900, whereas the official value is 22°27'37".76. The idea behind this modification was obviously that he wanted to have the star exactly at 180° for recent years, whereas with the standard definition the star is "wrong" by almost an arc minute. It therefore seems that Lahiri did not follow the Indian standard himself but was of the opinion that Spica had to be at exactly 180° (true chitrapaksha ayanamsha). At the moment, the Swiss only supports the official standard. However, it is rather trivial to calculate the positions of a planet and the star and then subtract the star from the planet.

Swiss Ephemeris versions below 1.78.01, had a slightly different definition of the Lahiri ayanamsha that had been taken from Robert Hand's astrological software Nova. It made a difference of only 0.01 arc sec.

Many thanks to Vinay Jha, Narasimha Rao, and Avtar Krishen Kaul for helping us to better understand the complicated matter.

Additional Citra/Spica ayanamshas:

Suryasiddhantic Spica on 180°:

The Suryasiddhanta gives Spica the position 180° in polar longitude (ecliptic longitude, but projection on meridian lines). From this, the following Ayanamsha can be derved:

26) *ayanamsha* = 2.11070444 21 Mar 499, 7:30:31.57 UT = noon at Ujjain, 75.7684565 E.
Citra/Spica at polar ecliptic longitude 180°.

If the reader finds errors in this documentation or is able to contribute important information, his or her feedback will be greatly appreciated.

Usually ayanamshas are defined by an epoch and an initial ayanamsha offset. However, if one wants to make sure that a particular fixed star always remains at a precise position, e. g. Spica at 180°, it does not work this way. The correct procedure here is to calculate the tropical position of Spica for the date and subtract it from the tropical position of the planet:

27) "True chitrapaksha ayanamsha": Spica is always exactly at 180° or 0° Libra in ecliptic longitude (not polar!).

The Suryasiddhanta also mentions that Revati/zeta-Piscium is exactly at 359°50' in polar ecliptic longitude (projection onto the ecliptic along meridians). Therefore the following two ayanamshas were added:

25) *ayanamsha* = -0.79167046 21 Mar 499, 7:30:31.57 UT = noon at Ujjain, 75.7684565 E.
Revati/zePsc at polar ecliptic longitude 359°50'

28) “True Revati ayanamsha”: Revati/zePsc is always exactly at longitude 359°50’ (not polar!).

Sources:
Burgess, E., *The Surya Siddanta. A Text-book of Hindu Astronomy*, Delhi, 2000 (MLBD).
Dikshit, S(ankara) B(alkrishna), *Bharatiya Jyotish Sastra (History of Indian Astronomy)* (Tr. from Marathi), Govt. of India, 1969, part I & II.
Kollerstrom, Nick, „The Star Zodiac of Antiquity“, in: *Culture & Cosmos*, Vol. 1, No.2, 1997).
Lahiri, N. C., *Panchanga Darpan* (in Bengali), Calcutta, 1967 (Astro Research Bureau).
Lahiri, N. C., *Tables of the Sun*, Calcutta, 1952 (Astro Research Bureau).
Saha, M. N., and Lahiri, N. C., *Report of the Calendar Reform Committee*, C.S.I.R., New Delhi, 1955.
The Indian astronomical ephemeris for the year 1989, Delhi (Positional Astronomy Centre, India Meteorological Department)

The sidereal zodiac and the Galactic Center

As said before, there is a very precise definition for the tropical ecliptic. It starts at one of the two intersection points of the ecliptic and the celestial equator. Similarly, we have a very precise definition for the house circle which is said to be an analogy of the zodiac. It starts at one of the two intersection points of the ecliptic and the local horizon. Unfortunately there is no such definition for the sidereal zodiac. Or can a fixed star like Spica be important enough to play the role of an anchor star?

One could try to make the sidereal zero point agree with the Galactic Center. The Swiss astrologer Bruno Huber has pointed out that the Galactic Center enters a new tropical sign always around the same time when the vernal point enters the next sidereal sign. Around the time, when the vernal point will go into Aquarius, the Galactic Center will change from Sagittarius to Capricorn. Huber also notes that the ruler of the tropical sign of the Galactic Center is always the same as the ruler of the sidereal sign of the vernal point (at the moment Jupiter, will be Saturn in a few hundred years).

A correction of the Fagan *ayanamsha* by about 2 degrees or a correction of the Lahiri *ayanamsha* by 3 degrees would place the Galactic Center at 0 Sagittarius. Astrologically, this would obviously make some sense. Therefore, we add an *ayanamsha* fixed at the Galactic Center:

17) Galactic Center at 0 Sagittarius

The other possibility – in analogy with the tropical ecliptic and the house circle – would be to start the sidereal ecliptic at the intersection point of the ecliptic and the galactic plane. At present, this point is located near 0 Capricorn. However, defining this point as sidereal 0 Aries would mean to break completely with the tradition, because it is far away from the traditional sidereal zero points.

Other ayanamshas

There are a few more *ayanamshas*, whose provenance is not known to us. They were given to us by Graham Dawson (”Solar Fire”), who took them over from Robert Hand’s Program ”Nova”:

2) De Luce
3) Raman
5) Krishnamurti

David Cochrane adds

7) Yukteshvar
8) JN Bhasin

Graham Dawson adds the following one:

6) Djwhal Khul

He comments it as follows: ”The "Djwhal Khul" ayanamsha originates from information in an article in the Journal of Esoteric Psychology, Volume 12, No 2, pp91-95, Fall 1998-1999 publ. Seven Ray Institute). It is based on an inference that the Age of Aquarius starts in the year 2117. I decided to use the 1st of July simply to minimise the possible error given that an exact date is not given.”

Conclusions

We have found that there are basically three definitions, not counting the manifold variations:
1. the Babylonian zodiac with Spica at 29 Virgo or Aldebaran at 15 Taurus:
   a) P. Huber, b) Fagan/Bradley c) refined with **Aldebaran** at 15 Tau
2. the Greek-Arabic-Hindu zodiac with the zero point between 10 and 20’ east of *zeta Piscium*:
   a) Hipparchus, b) Ushâshashî, c) **Sassanian**
3. the Greek-Hindu astrological zodiac with Spica at 0 Libra
   a) **Lahiri**

The differences are:
between 1) and 3) is about 1 degree
between 1) and 2) is about 5 degrees
between 2) and 3) is about 4 degrees

It is obvious that all of them stem from the same origin.

1) is historically the oldest one, but we are not sure about its precise astronomical definition. It could have been Aldebaran at 15 Taurus and Antares at 15 Scorpio.

In search of correct algorithms

A second problem in sidereal astrology – after the definition of the zero point – is the precession algorithm to be applied. We can think of five possibilities:

1) *the traditional algorithm (implemented in Swiss Ephemeris as default mode)*

In all software known to us, sidereal planetary positions are computed from an equation mentioned before:
sidereal_position = tropical_position – ayanamsha,
The *ayanamhsa* is computed from the *ayanamsha(t0)* at a starting date (e.g. 1 Jan 1900) and the speed of the vernal point, the so-called *precession rate*.

This algorithm is unfortunately too simple. At best, it can be considered as an approximation. The precession of the equinoxes is not only a matter of ecliptical longitude, but is a more complex phenomenon. It has two components:

a) The *soli-lunar precession*: The combined gravitational pull of the Sun and the Moon on the equatorial bulge of the earth causes the earth to spin like a top. As a result of this movement, the vernal point moves around the ecliptic with a speed of about 50”. This cycle lasts about 26000 years.

b) The *planetary precession*: The earth orbit itself is not fixed. The gravitational influence from the planets causes it to wobble. As a result, the obliquity of the ecliptic currently decreases by 47” per century, and this movement has an influence on the position of the vernal point, as well. (This has nothing to do with the precessional motion of the earth rotation axis; the equator holds an almost stable angle against the ecliptic of a fixed date, e.g. 1900, with a change of only a couple of 0.06” cty-2).

Because the ecliptic is not fixed, it cannot be correct just to subtract an *ayanamsha* from the tropical position in order to get a sidereal position. Let us take, e.g., the Fagan/Bradley *ayanamsha*, which is defined by:
ayanamsha = 24°02’31.36” + d(t)
24°02’... is the value of the *ayanamsha* on 1 Jan 1950. It is obviously measured on *the ecliptic of 1950*.

d(t) is the distance of the vernal point at epoch *t* from the position of the vernal point on 1 Jan 1950. This value is also measured on the ecliptic of 1950. But the whole *ayanamsha* is subtracted from a planetary position which is referred to the *ecliptic of the epoch t*. This does not make sense.

As an effect of this procedure, objects that do not move sidereally, e.g. the Galactic Center, seem to move. If we compute its precise tropical position for several dates and then subtract the Fagan/Bradley *ayanamsha* for the same dates in order to get its sidereal position, these positions will all be slightly different:

```
Date          Longitude         Latitude
01.01.-5000   2 sag 07'57.7237    -4°41'34.7123  (without aberration)
01.01.-4000   2 sag 07'32.9817    -4°49' 4.8880
01.01.-3000   2 sag 07'14.2044    -4°56'47.7013
01.01.-2000   2 sag 07' 0.4590    -5° 4'39.5863
01.01.-1000   2 sag 06'50.7229    -5°12'36.9917
01.01.0       2 sag 06'44.2492    -5°20'36.4081
01.01.1000    2 sag 06'40.7813    -5°28'34.3906
01.01.2000    2 sag 06'40.5661    -5°36'27.5619
01.01.3000    2 sag 06'44.1743    -5°44'12.6886
01.01.4000    2 sag 06'52.1927    -5°51'46.6231
01.01.5000    2 sag 07' 4.8942    -5°59' 6.3665
```

The effect can be much greater for bodies with greater ecliptical latitude.
Exactly the same kind of thing happens to sidereal planetary positions, if one calculates them in the traditional way. It is only because planets move that we are not aware of it.

The traditional method of computing sidereal positions is geometrically not sound and can never achieve the same degree of accuracy as tropical astrology is used to.

2) *fixed-star-bound ecliptic (not implemented in Swiss Ephemeris)*

One could use a stellar object as an anchor for the sidereal zodiac, and make sure that a particular stellar object is always at a certain position on the ecliptic of date. E.g. one might want to have Spica always at 0 Libra or the Galactic Center always at 0 Sagittarius. There is nothing against this method from a geometrical point of view. But it has to be noted, that this system is not really fixed either, because it is still based on the moving ecliptic, and moreover the fixed stars have a small proper motion, as well.

3) *projection onto the ecliptic of t0 (implemented in Swiss Ephemeris as an option)*

Another possibility would be to project the planets onto the reference ecliptic of the *ayanamsha* – for Fagan/Bradley, e.g., this would be the ecliptic of 1950 – by a correct *coordinate transformation* and then subtract 24.042°, the initial value of the *ayanamsha*.

If we follow this method, the position of the galactic center will always be the same (2 sag 06'40.4915   -5°36' 4.0652   (without aberration))

This method is geometrically sounder than the traditional one, but still it has a problem. For, if we want everything referred to the ecliptic of a fixed date t0, we will have to choose that date very carefully. Its ecliptic ought to be of special importance. The ecliptic of 1950 or the one of 1900 are obviously meaningless and not suitable as a reference plane. And how about that 18 March 564, on which the tropical and the sidereal zero point coincided? Although this may be considered as a kind of cosmic anniversary (the Sassanians did so), the ecliptic plane of that time does not have an "eternal" value. It is different from the ecliptic plane of the previous anniversary around the year 26000 BC, and it is also different from the ecliptic plane of the next cosmic anniversary around the year 26000 AD.

This algorithm is supported by the Swiss Ephemeris, too. However, it *must not be used with the Fagan/Bradley definition* or with other definitions that were calibrated with the traditional method of *ayanamsha* subtraction. It can be used for computations of the following kind:

a) Astronomers may want to calculate *positions referred to a standard equinox* like J2000, B1950, or B1900, or to any other equinox.
b) Astrologers may be interested in the calculation of *precession-corrected transits*. See explanations in the next chapter.

c) The algorithm can be applied to the *Sassanian ayanamsha* or to any user-defined sidereal mode, if the ecliptic of its reference date is considered to be astrologically significant.
d) The algorithm makes the problems of the traditional method visible. It shows the dimensions of the inherent inaccuracy of the traditional method.

For the planets and for centuries close to t0, the difference from the traditional procedure will be only a few arc seconds in longitude. Note that the Sun will have an ecliptical latitude of several arc minutes after a few centuries.

For the lunar nodes, the procedure is as follows:
Because the lunar nodes have to do with eclipses, they are actually points on the ecliptic of date, i.e. on the tropical zodiac. Therefore, we first compute the nodes as points on the ecliptic of date and then project them onto the sidereal zodiac. This procedure is very close to the traditional method of computing sidereal positions (a matter of arc seconds). However, the nodes will have a latitude of a couple of arc minutes.

For the axes and houses, we compute the points where the horizon or the house lines intersect with the sidereal plane of the zodiac, *not* with the ecliptic of date. Here, there are greater deviations from the traditional procedure. If *t* is 2000 years from *t0* the difference between the ascendant positions might well be 1/2 degree.

4) *The long-term mean Earth-Sun plane (not implemented in Swiss Ephemeris)*

To avoid the problem of choice of a reference ecliptic, we might watch out for a kind of ”average ecliptic”. As a matter of fact, there are some possibilities in this direction. The mechanism of the planetary precession mentioned above works in a similar way as the mechanism of the luni-solar precession. The movement of the earth orbit can be compared to a spinning top, with the earth mass equally distributed around the whole orbit. The other planets, especially Venus and Jupiter, cause it to move around an average position. But unfortunately, this ”long-term mean Earth-Sun plane” is not really stable, either, and therefore not suitable as a fixed reference frame.

The period of this cycle is about 75000 years. The angle between the long-term mean plane and the ecliptic of date is at the moment about 1°33’, but it changes considerably. (This cycle must not be confused with the period between two maxima of the ecliptic obliquity, which is about 40000 years and often mentioned in the context of planetary precession. This is the time it takes the vernal point to return to the node of the ecliptic (its rotation point), and therefore the oscillation period of the ecliptic obliquity.)

5) *The solar system rotation plane (implemented in Swiss Ephemeris as an option)*

The solar system as a whole has a rotation axis, too, and its equator is quite close to the ecliptic, with an inclination of 1°34’44” against the ecliptic of the year 2000. This plane is extremely stable and probably the only convincing candidate for a fixed zodiac plane.

This method avoids the problem of method 3). No particular ecliptic has to be chosen as a reference plane. The only remaining problem is the choice of the zero point.

This algorithm must not be applied to any of the predefined sidereal modes, except the Sassanian one. You can use this algorithm, if you want to research on a better-founded sidereal astrology, experiment with your own sidereal mode, and calibrate it as you like.

More benefits from our new sidereal algorithms: standard equinoxes and precession-corrected transits

Method no. 3, the transformation to the ecliptic of t0, opens two more possibilities:
You can compute positions referred to any equinox, 2000, 1950, 1900, or whatever you want. This is sometimes useful when Swiss Ephemeris data ought to be compared with astronomical data, which are often referred to a standard equinox.
There are predefined sidereal modes for these standard equinoxes:
18) J2000
19) J1900
20) B1950

Moreover, it is possible to compute *precession-corrected transits or synastries* with very high precision. An astrological transit is defined as the passage of a planet over the position in your birth chart. Usually, astrologers assume that tropical positions on the ecliptic of the transit time has to be compared with the positions on the tropical ecliptic of the birth date. But it has been argued by some people that a transit would have to be referred to the ecliptic of the birth date. With the new Swiss Ephemeris algorithm (method no. 3) it is possible to compute the positions of the transit planets referred to the ecliptic of the birth date, i.e. the so-called *precession-corrected* transits. This is more precise than just correcting for the precession in longitude (see details in the programmer's documentation *swephprg.doc*, ch. 8.1).

3. Apparent versus true planetary positions

The Swiss ephemeris provides the calculation of *apparent* or *true* planetary positions. Traditional astrology works with apparent positions. ”Apparent” means that the position where we *see* the planet is used, not the one where it actually is. Because the light's speed is finite, a planet is never seen exactly where it is. (see above, 2.1.3 ”The details of coordinate transformation”, light-time and aberration) Astronomers therefore make a difference between *apparent* and *true* positions. However, this effect is below 1 arc minute.

Most astrological ephemerides provide *apparent* positions. However, this may be wrong. The use of apparent positions presupposes that astrological effects can be derived from one of the four fundamental forces of physics, which is impossible. Also, many astrologers think that astrological ”effects” are a synchronistic phenomenon (the ones familiar with physics may refer to the Bell theorem). For such reasons, it might be more convincing to work with true positions.

Moreover, the Swiss Ephemeris supports so-called *astrometric* positions, which are used by astronomers when they measure positions of celestial bodies with respect to fixed stars. These calculations are of no use for astrology, though.

4. Geocentric versus topocentric and heliocentric positions

More precisely speaking, common ephemerides tell us the position where we would see a planet if we stood in the center of the earth and could see the sky. But it has often been argued that a planet’s position ought to be referred to the geographic position of the observer (or the birth place). This can make a difference of several arc seconds with the planets and even *more than a degree* with the moon! Such a position referred to the birth place is called the *topocentric* planetary position. The observation of transits over the moon might help to find out whether or not this method works better.

For very precise topocentric calculations, the Swiss Ephemeris not only requires the geographic position, but also its altitude above sea. An altitude of 3000 m (e.g. Mexico City) may make a difference of more than 1 arc second with the moon. With other bodies, this effect is of the amount of a 0.01”. The altitudes are referred to the approximate earth ellipsoid. Local irregularities of the geoid have been neglected.

Our topocentric lunar positions differ from the NASA positions (s. the *Horizons Online Ephemeris System* http://ssd.jpl.nasa.gov) by 0.2 - 0.3 arc sec. This corresponds to a geographic displacement by a few 100 m and is about the best accuracy possible. In the documentation of the *Horizons System*, it is written that: "The Earth is assumed to be a rigid body. ... These Earth-model approximations result in topocentric station location errors, with respect to the reference ellipsoid, of less than 500 meters."

The Swiss ephemeris also allows the computation of apparent or true *topocentric* positions.

With the lunar nodes and apogees, Swiss Ephemeris does not make a difference between topocentric and geocentric positions. There are manyfold ways to define these points topocentrically. The simplest one is to understand them as axes rather than points somewhere in space. In this case, the geocentric and the topocentric positions are identical, because an axis is an infinite line that always points to the same direction, not depending on the observer's position.

Moreover, the Swiss Ephemeris supports the calculation of *heliocentric* and *barycentric* planetary positions. Heliocentric positions are positions as seen from the center of the sun rather than from the center of the earth. Barycentric ones are positions as seen from the center of the solar system, which is always close to but not identical to the center of the sun.

5. Heliacal Events, Eclipses, Occultations, and Other Planetary Phenomena

5.1. Heliacal Events of the Moon, Planets and Stars

5.1.1. Introduction

From Swiss Ephemeris version 1.76 on, heliacal events have been included. The heliacal rising and setting of planets and stars was very important for ancient Babylonian and Greek astronomy and astrology. Also, first and last visibility of the Moon can be calculated, which are important for many calendars, e.g. the Islamic, Babylonian and ancient Jewish calendars.

The heliacal events that can be determined are:

- Inferior planets
    - Heliacal rising (morning first)
    - Heliacal setting (evening last)
    - Evening first
    - Morning last
- Superior planets and stars
    - Heliacal rising
    - Heliacal setting
- Moon
    - Evening first
    - Morning last

The acronychal risings and settings (also called cosmical settings) of superior planets are a different matter. They will be added in a future version of the Swiss Ephemeris.

The principles behind the calculation are based on the visibility criterion of Schaefer [1993, 2000], which includes dependencies on aspects of:

- Position celestial objects
  like the position and magnitude of the Sun, Moon and the studied celestial object,
- Location and optical properties observer
  like his/her location (longitude, latitude, height), age, acuity and possible magnification of optical instruments (like binoculars)
- Meteorological circumstances
  mainly expressed in the astronomical extinction coefficient, which is determined by temperature, air pressure, humidity, visibility range (air quality).
- Contrast between studied object and sky background
  The observer's eye can on detect a certain amount of contract and this contract threshold is the main body of the calculations

In the following sections above aspects will be discussed briefly and an idea will be given what functions are available to calculate the heliacal events. Lastly the future developments will be discussed.

5.1.2. Aspect determining visibility

The theory behind this visibility criterion is explained by Schaefer [1993, 2000] and the implemented by Reijs [2003] and Koch [2009]. The general ideas behind this theory are explained in the following subsections.

5.1.2.1. Position of celestial objects

To determine the visibility of a celestial object it is important to know where the studied celestial object is and what other light sources are in the sky. Thus beside determining the position of the studied object and its magnitude, it also involves calculating the position of the Sun (the main source of light) and the Moon. This is common functions performed by Swiss Ephemeris.

5.1.2.2. Geographic location

The location of the observer determines the topocentric coordinates (incl. influence of refraction) of the celestial object and his/her height (and altitude of studied object) will have influence on the amount of airmass that is in the path of celestial object's light.

5.1.2.3. Optical properties of observer

The observer's eyes will determine the resolution and the contrast differences he/she can perceive (depending on age and acuity), furthermore the observer might used optical instruments (like binocular or telescope).

5.1.2.4. Meteorological circumstances

The meteorological circumstances are very important for determining the visibility of the celestial object. These circumstances influence the transparency of the airmass (due to Rayleigh&aerosol scattering and ozone&water absorption) between the celestial object and the observer's eye. This result in the astronomical extinction coefficient (AEC: k_{tot}). As this is a complex environment, it is sometimes 'easier' to use a certain AEC, instead of calculating it from the meteorological circumstances.

The parameters are stored in the datm (Pressure [mbar], Temperature [C], Relative humidity [%], AEC [-]) array.

5.1.2.5. Contrast between object and sky background

All the above aspects influence the perceived brightnesses of the studied celestial object and its background sky. The contrast threshold between the studied object and the background will determine if the observer can detect the studied object.

5.1.3. Functions to determine the heliacal events

Two functions are seen as the spill of calculating the heliacal events:

5.1.3.1. Determining the contrast threshold (swe_vis_limit_magn)

Based on all the aspects mentioned earlier, the contrast threshold is determine which decides if the studied object is visible by the observer or not.

5.1.3.2. Iterations to determine when the studied object is really visible (swe_heliacal_ut)

In general this procedure works in such a way that it finds (through iterations) the day that conjunction/opposition between Sun and studied object happens and then it determines, close to Sun's rise or set (depending on the heliacal event), when the studied object is visible (by using the swe_vis_limit_magn function).

5.1.3.3. Geographic limitations of swe_heliacal_ut() and strange behavior of planets in high geographic latitudes

This function is limited to geographic latitudes between 60S and 60N. Beyond that the heliacal phenomena of the planets become erratic. We found cases of strange planetary behavior even at 55N.

An example:

At 0E, 55N, with an extinction coefficient 0.2, Mars had a heliacal rising on 25 Nov. 1957. But during the following weeks and months Mars did not constantly increase its height above the horizon before sunrise. In contrary, it disappeared again, i.e. it did a "morning last" on 18 Feb. 1958. Three months later, on 14 May 1958, it did a second morning first (heliacal rising). The heliacal setting or evening last took place on 14 June 1959.

Currently, this special case is not handled by swe_heliacal_ut(). The function cannot detect "morning lasts" of Mars and following "second heliacal risings". The function only provides the heliacal rising of 25 Nov. 1957 and the next ordinary heliacal rising in its ordinary synodic cycle which took place on 11 June 1960.

However, we may find a solution for such problems in future releases of the Swiss Ephemeris and even extend the geographic range of swe_heliacal_ut() to beyond +/- 60.

5.1.3.4. Visibility of Venus and the Moon during day

For the Moon, swe_heliacal_ut() calculates the evening first and the morning last. For each event, the function returns the optimum visibility and a time of visibility start and visibility end. Note, that on the day of its morning last or evening first, the moon is often visible for almost the whole day. It even happens that the crescent first becomes visible in the morning after its rising, then disappears, and again reappears during culmination, because the observation conditions are better as the moon stands high above the horizon. The function swe_heliacal_ut() does not handle this in detail. Even if the moon is visible after sunrise, the function assumes that the end time of observation is at sunrise. The evening fist is handled in the same way.

With Venus, we have a similar situation. Venus is often accessible to naked eye observation during day, and sometimes even during inferior conjunction, but usually only at a high altitude above the horizon. This means that it may be visible in the morning at its heliacal rising, then disappear and reappear during culmination. (Whoever does not believe me, please read the article by H.B. Curtis listed under “References”.) The function swe_heliacal_ut() does not handle this case. If binoculars or a telescope is used, Venus may be even observable during most of the day on which it first appears in the east.

5.1.4. Future developments

The section of the Swiss Ephemeris software is still under development. The acronychal events of superior planets and stars will be added. And comparing other visibility criterions will be included; like Schoch’s criterion [1928], Hoffman’s overview [2005] and Caldwall&Laney criterion [2005].

5.1.5. References

- Caldwell, J.A.R., Laney, C.D., First visibility of the lunar crescent, http://www.saao.ac.za/public-info/sun-moon-stars/moon-index/lunar-crescent-visibility/first-visibility-of-lunar-crescent/, 2005, viewed March, 30th, 2009

- H.B. Curtis, *Venus Visible at inferior conjunction*, in : *Popular Astronomy* vol. 18 (1936), p. 44; online at http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1936PA.....44...18C&data_type=PDF_HIGH&whole_paper=YES&type=PRINTER&filetype=.pdf

- Hoffman, R.E., Rational design of lunar-visibility criteria, *The observatory*, Vol. 125, June 2005, No. 1186, pp 156-168.

- Reijs, V.M.M., Extinction angle and heliacal events, http://www.iol.ie/~geniet/eng/extinction.htm, 2003, viewed March, 30th, 2009

- Schaefer, B., Astronomy and the limit of vision, *Vistas in astronomy*, 36:311, 1993

- Schaefer, B., New methods and techniques for historical astronomy and archaeoastronomy, *Archaeoastronomy*, Vol. XV, 2000, page 121-136

- Schoch, K., Astronomical and calendrical tables in Langdon. S., Fotheringham, K.J., *The Venus tables of Amninzaduga: A solution of Babylonian chronology by means of Venus observations of the first dynasty*, Oxford, 1928.

5.2. Eclipses, occultations, risings, settings, and other planetary phenomena

The Swiss Ephemeris also includes functions for many calculations concerning solar and lunar eclipses. You can:

- search for eclipses or occultations, globally or for a given geographical position

- compute global or local circumstances of eclipses or occultations

- compute the geographical position where an eclipse is central

Moreover, you can compute for all planets and asteroids:

- risings and settings (also for stars)

- midheaven and lower heaven transits (also for stars)

- height of a body above the horizon (refracted and true, also for stars)
- phase angle
- phase (illumined fraction of disc)
- elongation (angular distance between a planet and the sun)
- apparent diameter of a planetary disc
- apparent magnitude.

6. Sidereal Time, Ascendant, MC, Houses, Vertex

The Swiss Ephemeris package also includes a function that computes the Ascendant, the MC, the houses, the Vertex, and the Equatorial Ascendant (sometimes called "East Point").

6.0. Sidereal Time

Swiss Ephemeris versions until 1.80 used the IAU 1976 formula for Sidereal time. Since version 2.00 it uses sidereal time based on the IAU2006/2000 precession/nutation model.

As this solution is not good for the whole time range of JPL Ephemeris DE431, we only use it between 1850 and 2050. Outside this period, we use a solution based on the long term precession model Vondrak 2011, nutation IAU2000 and the mean motion of the Earth according to Simon & alii 1994. To make the function contiuous we add some constant values to our long-term function before 1850 and after 2050.

Vondrak/Capitaine/Wallace, "New precession expressions, valid for long time intervals", in A&A 534, A22(2011).

Simon & alii, "Precession formulae and mean elements for the Moon and the Planets", A&A 282 (1994), p. 675/678.

6.1. Astrological House Systems

The following house methods have been implemented so far:

6.1.1. Placidus

This system is named after the Italian monk Placidus de Titis (1590-1668). The cusps are defined by divisions of semidiurnal and seminocturnal arcs. The 11th cusp is the point on the ecliptic that has completed 2/3 of its semidiurnal arc, the 12th cusp the point that has completed 1/3 of it. The 2nd cusp has completed 2/3 of its seminocturnal arc, and the 3rd cusp 1/3.

6.1.2. Koch/GOH

This system is called after the German astrologer Walter Koch (1895-1970). Actually it was invented by Fiedrich Zanzinger and Heinz Specht, but it was made known by Walter Koch. In German-speaking countries, it is also called the "Geburtsorthäusersystem" (GOHS), i.e. the "Birth place house system". Walter Koch thought that this system was more related to the birth place than other systems, because all house cusps are computed with the "polar height of the birth place", which has the same value as the geographic latitude.

This argumentation shows actually a poor understanding of celestial geometry. With the Koch system, the house cusps are actually defined by horizon lines at different times. To calculate the cusps 11 and 12, one can take the time it took the MC degree to move from the horizon to the culmination, divide this time into three and see what ecliptic degree was on the horizon at the thirds. There is no reason why this procedure should be more related to the birth place than other house methods.

6.1.3. Regiomontanus

Named after the Johannes Müller (called "Regiomontanus", because he stemmed from Königsberg) (1436-1476).

The equator is divided into 12 equal parts and great circles are drawn through these divisions and the north and south points on the horizon. The intersection points of these circles with the ecliptic are the house cusps.

6.1.4. Campanus

Named after Giovanni di Campani (1233-1296).

The vertical great circle from east to west is divided into 12 equal parts and great circles are drawn through these divisions and the north and south points on the horizon. The intersection points of these circles with the ecliptic are the house cusps.

6.1.5. Equal System

The zodiac is divided into 12 houses of 30 degrees each starting from the Ascendant.

6.1.6 Vehlow-equal System

Equal houses with the Ascendant positioned in the middle of the first house.

6.1.7. Axial Rotation System

Also called the "Meridian house system". The equator is partitioned into 12 equal parts starting from the ARMC. Then the ecliptic points are computed that have these divisions as their right ascension. Note: The ascendant is different from the 1st house cusp.

6.1.8. The Morinus System

The equator is divided into 12 equal parts starting from the ARMC. The resulting 12 points on the equator are transformed into ecliptic coordinates. Note: The Ascendant is different from the 1st cusp, and the MC is different from the 10th cusp.

6.1.9. Horizontal system

The house cusps are defined by division of the horizon into 12 directions. The first house cusp is not identical with the Ascendant but is located precisely in the east.

6.1.10. The Polich-Page (“topocentric”) system

This system was introduced in 1961 by Wendel Polich and A.P. Nelson Page. Its construction is rather abstract: The tangens of the polar height of the 11th house is the tangens of the geo. latitude divided by 3. (2/3 of it are taken for the 12th house cusp.) The philosophical reasons for this algorithm are obscure. Nor is this house system more “topocentric” (i.e. birth-place-related) than any other house system. (c.f. the misunderstanding with the “birth place system”.) The “topocentric” house cusps are close to Placidus house cusps except for high geographical latitudes. It also works for latitudes beyond the polar circles, wherefore some consider it to be an improvement of the Placidus system. However, the striking philosophical idea behind Placidus, i.e. the division of diurnal and nocturnal arcs of points of the zodiac, is completely abandoned.

6.1.11. Alcabitus system

A method of house division which first appears with the Hellenistic astrologer Rhetorius (500 A.D.) but is named after Alcabitius, an Arabic astrologer, who lived in the 10th century A.D. This is the system used in the few remaining examples of ancient Greek horoscopes.

The MC and ASC are respectively the 10th- and 1st- house cusps. The remaining cusps are determined by the trisection of the semidiurnal and seminocturnal arcs of the ascendant, measured on the celestial equator. The houses are formed by great circles that pass through these trisection points and the celestial north and south poles.

6.1.12. Gauquelin sectors

This is the “house” system used by the Gauquelins and their epigones and critics in statistical investigations in Astrology. Basically, it is identical with the Placidus house system, i.e. diurnal and nocturnal arcs of ecliptic points or planets are subdivided. There are a couple of differences, though.

- Up to 36 “sectors” (or house cusps) are used instead of 12 houses.
- The sectors are counted in clockwise direction.

- There are so-called plus (+) and minus (–) zones. The plus zones are the sectors that turned out to be significant in statistical investigations, e.g. many top sportsmen turned out to have their Mars in a plus zone. The plus sectors are the sectors 36 – 3, 9 – 12, 19 – 21, 28 – 30.
- More sophisticated algorithms are used to calculate the exact house position of a planet (see chapters 6.4 and 6.5 on house positions and Gauquelin sector positions of planets).

6.1.13. Krusinski/Pisa/Goelzer system

This house system was first published in 1994/1995 by three different authors independently of each other:

- by Bogdan Krusinski (Poland)
- by Milan Pisa (Czech Republic) under the name "Amphora house system".
- by Georg Goelzer (Switzerland) under the name "Ich-Kreis-Häusersystem" ("I-Circle house system")..

Krusinski defines the house system as "… based on the great circle passing through ascendant and zenith. This circle is divided into 12 equal parts (1st cusp is ascendant, 10th cusp is zenith), then the resulting points are projected onto the ecliptic through meridian circles. The house cusps in space are half-circles perpendicular to the equator and running from the north to the south celestial pole through the resulting cusp points on the house circle. The points where they cross the ecliptic mark the ecliptic house cusps." (Krusinski, e-mail to Dieter Koch)

It may seem hard to believe that three persons could have discovered the same house system at almost the same time. But apparently this is what happened. Some more details are given here, in order to refute wrong accusations from the Czech side against Krusinski of having "stolen" the house system.

Out of the documents that Milan Pisa sent to Dieter Koch, the following are to be mentioned: Private correspondence from 1994 and 1995 on the house system between Pisa and German astrologers Böer and Schubert-Weller, two type-written (apparently unpublished) treatises in German on the house system dated from 1994. A printed booklet of 16 pages in Czech from 1997 on the theory of the house system ("Algoritmy noveho systemu astrologickych domu"). House tables computed by Michael Cifka for the geographical latitude of Prague, copyrighted from 1996. The house system was included in the Czech astrology software Astrolog v. 3.2 (APAS) in 1998. Pisa's first publication on the house system happened in spring 1997 in "Konstelace" No. 22, the periodical of the Czech Astrological Society.

Bogdan Krusinski first published the house system at an astrological congress in Poland, the ""XIV Szkola Astrologii Humanistycznej" held by Dr Leszek Weres, which took place between 15.08.1995 and 28.08.1995 in Pogorzelica at cost of the Baltic Sea." Since then Krusinski has distributed printed house tables for the Polish geographical latitudes 49-55° and floppy disks with house tables for latitudes 0-90°. In 1996, he offered his program code to Astrodienst for implementation of this house system into Astrodienst's then astronomical software Placalc. (At that time, however, Astrodienst was not interested in it.) In May 1997, Krusinski put the data on the web at http://www.ci.uw.edu.pl/~bogdan/astrol.htm (now at http://www.astrologia.pl/main/domy.html) In February 2006 he sent Swiss-Ephemeris-compatible program code in C for this house system to Astrodienst. This code was included into Swiss Ephemeris Version 1.70 and released on 8 March 2006.

Georg Goelzer describes the same house system in his book "Der Ich-Kosmos", which appeared in July 1995 at Dornach, Switzerland (Goetheanum). The book has a second volume with house tables according to the house method under discussion. The house tables were created by Ulrich Leyde. Goelzer also uses a house calculation programme which has the time stamp "9 April 1993" and produces the same house cusps.

By March 2006, when the house system was included in the Swiss Ephemeris under the name of "Krusinski houses", neither Krusinski nor Astrodienst knew about the works of Pisa and Goelzer. Goelzer heard of his co-discoverers only in 2012 and then contacted Astrodienst.

Conclusion: It seems that the house system was first "discovered" and published by Goelzer, but that Pisa and Krusinski also "discovered" it independently. We do not consider this a great miracle because the number of possible house constructions is quite limited.

6.2. Vertex, Antivertex, East Point and Equatorial Ascendant, etc.

The *Vertex* is the point of the ecliptic that is located precisely in western direction. The *Antivertex* is the opposition point and indicates the precise east in the horoscope. It is identical to the first house cusp in the *horizon house system.*

There is a lot of confusion about this, because there is also another point which is called the "*East Point*" but is usually *not* located in the east. In celestial geometry, the expression "East Point" means the point on the horizon which is in precise eastern direction. The equator goes through this point as well, at a right ascension which is equal to ARMC + 90 degrees. On the other hand, what some astrologers call the "East Point" is the point on the ecliptic whose right ascension is equal to ARMC + 90 (i.e. the right ascension of the horizontal East Point). This point can deviate from eastern direction by 23.45 degrees, the amount of the ecliptic obliquity. For this reason, the term "East Point" is not very well-chosen for this ecliptic point, and some astrologers (M. Munkasey) prefer to call it the *Equatorial Ascendant*. This, because it is identical to the Ascendant at a geographical latitude 0.

The Equatorial Ascendant is identical to the first house cusp of the *axial rotation system*.

Note: If a projection of the horizontal East Point on the ecliptic is wanted, it might seem more reasonable to use a projection rectangular to the ecliptic, not rectangular to the equator as is done by the users of the "East Point". The planets, as well, are not projected on the ecliptic in a right angle to the ecliptic.

The Swiss Ephemeris supports three more points connected with the house and angle calculation. They are part of Michael Munkasey's system of the 8 *Personal Sensitive Points* (PSP). The PSP include the *Ascendant*, the *MC*, the *Vertex*, the *Equatorial Ascendant*, the *Aries Point*, the *Lunar Node*, and the "*Co-Ascendant*" and the "*Polar Ascendant*".

The term "Co-Ascendant" seems to have been invented twice by two different people, and it can mean two different things. The one "Co-Ascendant" was invented by Walter Koch (?). To calculate it, one has to take the ARIC as an ARMC and compute the corresponding Ascendant for the birth place. The "Co-Ascendant" is then the opposition to this point.

The second "Co-Ascendant" stems from Michael Munkasey. It is the Ascendant computed for the natal ARMC and a latitude which has the value 90° - birth_latitude.

The "Polar Ascendant" finally was introduced by Michael Munkasey. It is the opposition point of Walter Koch's version of the "Co-Ascendant". However, the "Polar Ascendant" is not the same as an Ascendant computed for the birth time and one of the geographic poles of the earth. At the geographic poles, the Ascendant is always 0 Aries or 0 Libra. This is not the case for Munkasey's "Polar Ascendant".

6.3. House cusps beyond the polar circle

Beyond the polar circle, we proceed as follows:

1) We make sure that the ascendant is always in the eastern hemisphere.

2) *Placidus* and *Koch* house cusps sometimes can, sometimes cannot be computed beyond the polar circles. Even the MC doesn't exist always, if one defines it in the Placidus manner. Our function therefore automatically switches to Porphyry houses (each quadrant is divided into three equal parts) and returns a warning.

3) Beyond the polar circles, the MC is sometimes below the horizon. The geometrical definition of the *Campanus* and *Regiomontanus* systems requires in such cases that the MC and the IC are swapped. The whole house system is then oriented in clockwise direction.

There are similar problems with the *Vertex* and the *horizon house system* for birth places in the tropics. The *Vertex* is defined as the point on the ecliptic that is located in precise western direction. The ecliptic east point is the opposition point and is called the *Antivertex*. Our program code makes sure that the Vertex (and the cusps 11, 12, 1, 2, 3 of the horizon house system) is always located in the western hemisphere. Note that for birthplaces on the equator the Vertex is always 0 Aries or 0 Libra.

Of course, there are no problems in the calculation of the *Equatorial Ascendant* for any place on earth.

6.3.1. Implementation in other calculation modules:

a) PLACALC

Placalc is the predecessor of Swiss Ephemeris; it is a calculation module created by Astrodienst in 1988 and distributed as C source code. Beyond the polar circles, Placalc‘s house calculation did switch to Porphyry houses for all unequal house systems. Swiss Ephemeris still does so with the Placidus and Koch method, which are not defined in such cases. However, the computation of the MC and Ascendant was replaced by a different model in some cases: Swiss Ephemeris gives *priority* to the Ascendant, choosing it always as the eastern rising point of the ecliptic and *accepting an MC below the horizon*, whereas Placalc gave *priority* to the MC. The MC was always chosen as the intersection of the meridian with the ecliptic *above the horizon*. To keep the quadrants in the correct order, i.e. have an Ascendant in the left side of the chart, the Ascendant was switched by 180 degrees if necessary.

In the discussions between Alois Treindl and Dieter Koch during the development of the Swiss Ephemeris it was recognized that this model is more unnatural than the new model implemented in Swiss Ephemeris.

Placalc also made no difference between Placidus/Koch on one hand and Regiomontanus/Campanus on the other as Swiss Ephemeris does. In Swiss Ephemeris, the geometrical definition of Regiomontanus/Campanus is strictly followed, even for the price of getting the houses in ”wrong” order. (see above, chapter 4.1.)

b) ASTROLOG program as written by Walter Pullen

While the freeware program Astrolog contains the planetary routines of Placalc, it uses its own house calculation module by Walter Pullen. Various releases of Astrolog contain different approaches to this problem.

c) ASTROLOG on our website

ASTROLOG is also used on Astrodienst's website for displaying free charts. This version of Astrolog used on our website however is different from the Astrolog program as distributed on the Internet. Our webserver version of Astrolog contains calls to Swiss Ephemeris for planetary positions. For Ascendant, MC and houses it still uses Walter Pullen's code. This will change in due time because we intend to replace ASTROLOG on the website with our own charting software.

d) other astrology programs

Because most astrology programs still use the Placalc module, they follow the Placalc method for houses inside the polar circles. They give priority to keep the MC above the horizon and switch the Ascendant by 180 degrees if necessary to keep the quadrants in order.

6.4. House position of a planet

The Swiss Ephemeris DLL also provides a function to compute the house position of a given body, i.e. in which house it is. This function can be used either to determine the house number of a planet or to compute its position in a ***house horoscope***. (A house horoscope is a chart in which all houses are stretched or shortened to a size of 30 degrees. For unequal house systems, the zodiac is distorted so that one sign of the zodiac does not measure 30 house degrees)

Note that the actual house position of a planet is not always the one that it seems to be in an ordinary chart drawing. Because the planets are not always exactly located on the ecliptic but have a latitude, they can seemingly be located in the first house, but are actually visible above the horizon. In such a case, our program function will place the body in the 12th (or 11 th or 10 th) house, whatever celestial geometry requires. However, it is possible to get a house position in the "traditional" way, if one sets the ecliptic latitude to zero.

Although it is not possible to compute *Placidus* house *cusps* beyond the polar circle, this function will also provide Placidus house positions for polar regions. The situation is as follows:

The Placidus method works with the semidiurnal and seminocturnal arcs of the planets. Because in higher geographic latitudes some celestial bodies (the ones within the circumpolar circle) never rise or set, such arcs do not exist. To avoid this problem it has been proposed in such cases to start the diurnal motion of a circumpolar body at its "midnight" culmination and its nocturnal motion at its midday culmination. This procedure seems to have been proposed by Otto Ludwig in 1930. It allows to define a planet's house position even if it is within the circumpolar region, and even if you are born in the northernmost settlement of Greenland. However, this does not mean that it be possible to compute ecliptical house cusps for such locations. If one tried that, it would turn out that e.g. an 11 th house cusp did not exist, but there were *two* 12th house cusps.

Note however, that circumpolar bodies may jump from the 7th house directly into the 12th one or from the 1st one directly into the 6th one.

The *Koch* method, on the other hand, cannot be helped even with this method. For some bodies it may work even beyond the polar circle, but for some it may fail even for latitudes beyond 60 degrees. With fixed stars, it may even fail in central Europe or USA. (Dieter Koch regrets the connection of his name with such a badly defined house system)

Note that Koch planets do strange jumps when the cross the meridian. This is not a computation error but an effect of the awkward definition of this house system. A planet can be east of the meridian but be located in the 9th house, or west of the meridian and in the 10th house. It is possible to avoid this problem or to make Koch house positions agree better with the Huber "hand calculation" method, if one sets the ecliptic latitude of the planets to zero. But this is not more correct from a geometrical point of view.

6.5. Gauquelin sector position of a planet

The calculation of the Gauquelin sector position of a planet is based on the same idea as the Placidus house system, i.e. diurnal and nocturnal arcs of ecliptic points or planets are subdivided.

Three different algorithms have been used by Gauquelin and others to determine the sector position of a planet.

1. We can take the ecliptic point of the planet (ecliptical latitude ignored) and calculate the fraction of its diurnal or nocturnal arc it has completed
2. We can take the true planetary position (taking into account ecliptical latitude) for the same calculation.
3. We can use the exact times for rise and set of the planet to determine the ratio between the time the planet has already spent above (or below) the horizon and its diurnal (or nocturnal) arc. Times of rise and set are defined by the appearance or disappearance of the center of the planet's disks.

All three methods are supported by the Swiss Ephemeris.

Methods 1 and 2 also work for polar regions. The Placidus algorithm is used, and the Otto Ludwig method applied with circumpolar bodies. I.e. if a planet does not have a rise and set, the “midnight” and “midday” culminations are used to define its semidiurnal and seminocturnal arcs.

With method 3, we don't try to do similar. Because planets do not culminate exactly in the north or south, a planet can actually rise on the western part of the horizon in high geographic latitudes. Therefore, it does not seem appropriate to use meridian transits as culmination times. On the other hand, true culmination times are not always available. E.g. close to the geographic poles, the sun culminates only twice a year.

7. ΔT (Delta T)

The computation of planets uses the so called *Ephemeris Time* (ET) which is a completely regular time measure. Computations of sidereal time and houses, on the other hand, depend on the rotation of the earth, which is not regular at all. The time used for such purposes is called *Universal Time* (UT) or *Terrestrial Dynamic Time* (TDT). It is an irregular time measure, and is roughly identical to the time indicated by our clocks (if time zones are neglected). The difference between ET and UT is called ΔT (”Delta T”), and is defined as ΔT = ET – UT.

The earth's rotation decreases slowly, currently at the rate of about 0.5 – 1 second per year. Even worse, this decrease is irregular itself. It cannot precisely predicted but only derived from star observations. The values of ΔT achieved like this must be tabulated. However, this table, which is published yearly by the Astronomical Almanac, starts only at 1620, about the time when the telescope was invented. For more remote centuries, ΔT must be estimated from old eclipse records. The uncertainty is in the range of hours for the year 3000 B.C. For future times, ΔT is estimated from the current and the general changing rate, depending on whether a short-term or a long-term extrapolation is intended.

NOTE: The ΔT algorithms have been improved with the Swiss Ephemeris release 1.64 (Stephenson 1997), with release 1.72 (Morrison/Stephenson 2004) and 1.77 (Espenak & Meeus). These changes result in significant changes of the ephemeris for remote historical dates, if Universal Time is used.

The Swiss Ephemeris computes ΔT as follows.

1633 - today + a couple of years:

The tabulated values of ΔT, in hundredths of a second, were taken from the Astronomical Almanac page K8 and K9 and are yearly updated.

The ΔT function adjusts for a value of secular tidal acceleration ndot that is consistent with the ephemeris used (LE430 has ndot = -25.82 arcsec per century squared, LE405/406 has ndot = -25.826, ELP2000 and DE200 ndot = -23.8946).

To change ndot, one can either redefine SE_TIDAL_DEFAULT in swephexp.h or use the routine swe_set_tid_acc() before calling the Swiss Ephemeris.

Bessel's interpolation formula was implemented to obtain fourth order interpolated values at intermediate times.

-before 1633:

For dates before 1600, the polynomials published by Espenak and Meeus (2006) are used, with linear interpolation. They are based on an assumed value of ndot = -26. The program adjusts for an ndot that is consistent with the ephemeris used. These formulae include the long-term formula by Morrison/Stephenson (2004, p. 332), which is used for epochs before -500.

future:

For the time after the last tabulated value, we use the formula of Stephenson (1997; p. 507), with a modification that avoids a jump at the end of the tabulated period. A linear term is added that makes a slow transition from the table to the formula over a period of 100 years. (Need not be updated, when table will be enlarged.)

Differences between the old and new algorithms (before and after release 1.77):

year	difference in seconds (new - old)
-3000	3
-2000	2
-1100	1
-1001	29
-900	-45
-800	-57
-700	-696 (is a maximum!)
-500	-14
until -200	3 > diff > -25
until 100	3 > diff > -15
until 500	3 > diff > -3
until 1600	4 > diff > -16
until 1630	1 > diff > -30
until 1700	0.1 |diff|
until 1900	0.01
until 2100	0.001

The differences for –1000 to + 1630 are explained as follows:
Espenak & Meeus ignore Morrison & Stephenson's values for -700 and -600, whereas the former Swiss Ephemeris versions used them. For -500 to +1600 Espenak & Meeus use polynomials whereas the former Swiss Ephemeris versions used a linear interpolation between Morrison / Stephenson's tabulated values.

Differences between the old and new algorithms (before and after release 1.72):

year	difference in seconds (new - old)
-3000	-4127
-2000	-2130
-1000	-760
0	-20
1000	-30
1600	10
1619	0.5
1620	0

Differences between the old and new algorithms (before and after release 1.64):

year	difference in seconds (new - old)
-3000	2900
0	1200
1600	29
1619	60
1620	-0.6
1700	-0.4
1800	-0.1
1900	-0.02
1940	-0.001
1950	0
2000	0
2020	2
2100	23
3000	-400

In 1620, where the ΔT table of the Astronomical Almanac starts, there was a jump of a whole minute in the old algorithms. The new algorithms has no jumps anymore.

The smaller differences for the period 1620-1955, where we still use the same data as before, is due to a correction in the tidal acceleration of the moon, which now has the same value as is also used by JPL for their ΔT calculations.

References:

- Borkowski, K. M., "ELP2000-85 and the Dynamical Time - Universal Time relation," *Astronomy and Astrophysics* 205, L8-L10 (1988)
- Chapront-Touze, Michelle, and Jean Chapront, *Lunar Tables and Programs from 4000 B.C. to A.D. 8000*, Willmann-Bell 1991
- Espenak, Fred, and Jean Meeus, "Five-millennium Catalog of Lunar Eclipses –1900 to +3000", 2009, p. 18ff., http://eclipse.gsfc.nasa.gov/5MCSE/TP2009-214174.pdf.
- *Explanatory Supplement of the Astronomical Almanach*, University Science Books, 1992, Mill Valley, CA, p. 265ff.
- Morrison, L. V. and F. R. Stephenson, *Sun and Planetary System*, vol 96,73 eds. W. Fricke, G. Teleki, Reidel, Dordrecht (1982)
- Morrison, L. V., and F.R. Stephenson, "Historical Values of the Earth's Clock Error ΔT and the Calculation of Eclipses", JHA xxxv (2004), pp.327-336
- Stephenson, F. R., and L. V. Morrison, "Long-term changes in the rotation of the Earth: 700 BC to AD 1980", *Philosophical Transactions of the Royal Society of London*, Series A 313, 47-70 (1984)
- Stephenson, F. R., and M. A. Houlden, *Atlas of Historical Eclipse Maps*, Cambridge U. Press (1986)
- Stephenson, F.R. & Morrison, L.V., "Long-Term Fluctuations in the Earth's Rotation: 700 BC to AD 1990", in: *Philosophical Transactions of the Royal Society of London*, Ser. A, 351 (1995), 165-202.
- Stephenson, F. Richard, *Historical Eclipses and Earth's Rotation*, Cambridge U. Press (1997)
- For a comprehensive collection of publications and formulae, see R.H. van Gent at http://www.phys.uu.nl/~vgent/astro/deltatime.htm.

8. Programming Environment

Swiss Ephemeris is written in portable C and the same code is used for creation of the 32-bit Windows DLL and the link library. All data files are fully portable between different hardware architectures.

To build the DLLs, we use Microsoft Visual C++ version 5.0 (for 32-bit).

The DLL has been successfully used in the following programming environments:

Visual C++ 5.0 (sample code included in the distribution)

Visual Basic 5.0 (sample code and VB declaration file included)

Delphi 2 and Delphi 3 (32-bit, declaration file included)

As the number of users grows, our knowledge base about the interface details between programming environments and the DLL grows. All such information is added to the distributed Swiss Ephemeris and registered users are informed via an email mailing list.

Earlier version up to version 1.61 supported 16-bit Windows programming. Since then, 16-bit support has been dropped.

9. Swiss Ephemeris Functions

9.1 Swiss Ephemeris API

We give a short overview of the most important functions contained in the Swiss Ephemeris DLL. The detailed description of the programming interface is contained in the document `swephprg.doc` which is distributed together with the file you are reading.

Calculation of planets and stars

```
/* planets, moon, asteroids, lunar nodes, apogees, fictitious bodies;
 * input time must be ET/TT */
swe_calc();
/* same, but input time must be UT */
swe_calc_ut();

/* fixed stars; input time must be ET/TT */
swe_fixstar();
/* fixed stars; input time must be UT */
swe_fixstar_ut();
```

Date and time conversion

```
/* delta t from Julian day number
 * Ephemeris time (ET) = Universal time (UT) + swe_deltat(UT)*/
swe_deltat();

/* Julian day number from year, month, day, hour, */
swe_date_conversion ();
/* Julian day number from year, month, day, hour */
swe_julday();

/* year, month, day, hour from Julian day number */
swe_revjul ();

/* UTC to Julian day number */
swe_utc_to_jd ();

/* Julian day number TT to UTC */
swe_jdet_to_utc ();

/* Julian day number UT1 to UTC */
swe_jdut1_to_utc ();

/* utc to time zone or time zone to utc*/
swe_utc_time_zone ();

/* get tidal acceleration used in swe_deltat() */
swe_get_tid_acc();

/* set tidal acceleration to be used in swe_deltat() */
swe_set_tid_acc();
```

Initialization, setup, and closing functions

```
/* set directory path of ephemeris files */
swe_set_ephe_path();

/* set name of JPL ephemeris file */
swe_set_jpl_file();

/* close Swiss Ephemeris */
swe_close();
```

House calculation

```
/* sidereal time */
```

```
swe_sidtime();

/* house cusps, ascendant, MC, armc, vertex */

swe_houses();
```

Auxiliary functions

```
/* coordinate transformation, from ecliptic to equator or vice-versa. */

swe_cotrans();

/* coordinate transformation of position and speed,

 * from ecliptic to equator or vice-versa*/

swe_cotrans_sp();

/* get the name of a planet */

swe_get_planet_name();

/* normalization of any degree number to the range 0 ... 360 */

swe_degnorm();
```

Other functions that may be useful

PLACALC, the predecessor of SWISSEPH, included several functions that we do not need for SWISSEPH anymore. Nevertheless we include them again in our DLL, because some users of our software may have taken them over and use them in their applications. However, we gave them new names that were more consistent with SWISSEPH.

PLACALC used angular measurements in centiseconds a lot; a centisecond is 1/100 of an arc second. The C type CSEC or centisec is a 32-bit integer. CSEC was used because calculation with integer variables was considerably faster than floating point calculation on most CPUs in 1988, when PLACALC was written.

In the Swiss Ephemeris we have dropped the use of centiseconds and use double (64-bit floating point) for all angular measurements.

```
/* normalize argument into interval [0..DEG360]
 * former function name: csnorm() */
swe_csnorm();

/* distance in centisecs p1 - p2 normalized to [0..360[
 * former function name: difcsn() */
swe_difcsn ();

/* distance in degrees  * former function name: difdegn() */
swe_difdegn ();

/* distance in centisecs p1 - p2 normalized to [-180..180[
 * former function name: difcs2n() */
swe_difcs2n();

/* distance in degrees
 * former function name: difdeg2n() */
swe_difdeg2n();

/* round second, but at 29.5959 always down
 * former function name: roundsec() */
swe_csroundsec();

/* double to long with rounding, no overflow check
 * former function name: d2l() */
swe_d2l();

/* Monday = 0, ... Sunday = 6
 * former function name: day_of_week() */
```

```
swe_day_of_week();

/* centiseconds -> time string
 * former function name: TimeString() */
swe_cs2timestr();

/* centiseconds -> longitude or latitude string
 * former function name: LonLatString() */
swe_cs2lonlatstr();

/* centiseconds -> degrees string
 * former function name: DegreeString() */
swe_cs2degstr();
```

9.2 Placalc API

Placalc is a planetary calculation module which was made available by Astrodienst since 1988 to other programmers under a source code license. Placalc is less well designed, less complete and not as precise as the Swiss Ephemeris module. However, many developers of astrological software have used it over many years and like it. Astrodienst has used it internally since 1989 for a large set of application programs.

To simplify the introduction of Swiss Ephemeris in 1997 in Astrodienst's internal operation, we wrote an interface module which translates all calls to Placalc functions into Swiss Ephemeris functions, and translates the results back into the format expected in the Placalc Application Interface (API).

This interface (`swepcalc.c` and `swepcalc.h`) is part of the source code distribution of Swiss Ephemeris; it is not contained in the DLL. All new software should be written directly for the SwissEph API, but porting old Placalc software is convenient and very simple with the Placalc API.

Appendix

A. The gravity deflection for a planet passing behind the Sun

The calculation of the apparent position of a planet involves a relativistic effect, which is the curvature of space by the gravity field of the Sun. This can also be described by a semi-classical algorithm, where the photon travelling from the planet to the observer is deflected in the Newtonian gravity field of the Sun, where the photon has a non-zero mass arising from its energy. To get the correct relativistic result, a correction factor 2.0 must be included in the calculation.

A problem arises when a planet disappears behind the solar disk, as seen from the Earth. Over the whole 6000 year time span of the Swiss Ephemeris, it happens often.

Planet	number of passes behind the Sun
Mercury	1723
Venus	456
Mars	412
Jupiter	793
Saturn	428
Uranus	1376
Neptune	543
Pluto	57

A typical occultation of a planet by the Solar disk, which has a diameter of approx. _ degree, has a duration of about 12 hours. For the outer planets it is mostly the speed of the Earth's movement which determines this duration.

Strictly speaking, there is no *apparent* position of a planet when it is eclipsed by the Sun. No photon from the planet reaches the observer's eye on Earth. Should one drop gravitational deflection, but keep aberration and light-time correction, or should one switch completely from apparent positions to true positions for occulted planets? In both cases, one would come up with an ephemeris which contains discontinuities, when at the moment of occultation at the Solar limb suddenly an effect is switched off.

Discontinuities in the ephemeris need to be avoided for several reasons. On the level of physics, there cannot be a discontinuity. The planet cannot jump from one position to another. On the level of mathematics, a non-steady function is a nightmare for computing any derived phenomena from this function, e.g. the time and duration of an astrological transit over a natal body, or an aspect of the planet.

Nobody seems to have handled this problem before in astronomical literature. To solve this problem, we have used the following approach: We replace the Sun, which is totally opaque for electromagnetic waves and not transparent for the photons coming from a planet behind it, by a transparent gravity field. This gravity field has the same strength and spatial distribution as the gravity field of the Sun. For photons from occulted planets, we compute their path and deflection in this gravity field, and from this calculation we get reasonable *apparent* positions also for occulted planets.

The calculation has been carried out with a semi-classical Newtonian model, which can be expected to give the correct relativistic result when it is multiplied with a correction factor 2. The mass of the Sun is mostly concentrated near its center; the outer regions of the Solar sphere have a low mass density. We used the a mass density distribution from the Solar standard model, assuming it to have spherical symmetry (our Sun mass distribution m® is from Michael Stix, The Sun, p. 47). The path of photons through this gravity field was computed by numerical integration. The application of this model in the actual ephemeris could then be greatly simplified by deriving an effective Solar mass which a photon "sees" when it passes close by or "through" the Sun. This effective mass depends only from the closest distance to the Solar center which a photon reaches when it travels from the occulted planet to the observer. The dependence of the effective mass from the occulted planet's distance is so small that it can be neglected for our target precision of 0.001 arc seconds.

For a remote planet just at the edge of the Solar disk the gravity deflection is about 1.8", always pointing away from the center of the Sun. This means that the planet is already slightly behind the Solar disk (with a diameter of 1800") when it appears to be at the limb, because the light bends around the Sun. When the planet now passes on a central path behind the Solar disk, the virtual gravity deflection we compute increases to 2.57 times the deflection at the limb, and this maximum is reached at _ of the Solar radius. Closer to the Solar center, the deflection drops and reaches zero for photons passing centrally through the Sun's gravity field.

We have discussed our approach with Dr. Myles Standish from JPL and here is his comment (private email to Alois Treindl, 12-Sep-1997):

```
.. it seems that your approach is
entirely reasonable and can be easily justified as long
as you choose a reasonable model for the density of
the sun.  The solution may become more difficult if an
ellipsoidal sun is considered,  but certainly that is
an additional refinement which can not be crucial.
```

B. The list of asteroids

```
# ====================================
# At the same time a brief introduction into asteroids
# =====================================================
#
# As of the year 2010, there is no longer any CDROM. All
# parts of Swiss Ephemeris can be downloaded in the download area.
#
# Literature:
# Lutz D. Schmadel, Dictionary of Minor Planet Names,
#   Springer, Berlin, Heidelberg, New York
# Charles T. Kowal, Asteroids. Their Nature and Utilization,
#   Whiley & Sons, 1996, Chichester, England
#
#
# What is an asteroid?
# --------------------
#
# Asteroids are small planets. Because there are too many
# of them and because most of them are quite small,
# astronomers did not like to call them "planets", but
# invented names like "asteroid" (Greek "star-like",
# because through telescopes they did not appear as planetary
# discs but as star like points) or "planetoid" (Greek
# "something like a planet"). However they are also often
# called minor planets.
# The minor planets can roughly be divided into two groups.
# There are the inner asteroids, the majority of which
```

```
# circles in the space between Mars and Jupiter, and
# there are the outer asteroids, which have their realm
# beyond Neptune. The first group consists of rather
# dense, earth-like material, whereas the Transneptunians
# mainly consist of water ice and frozen gases. Many comets
# are descendants of the "asteroids" (or should one say
# "comets"?) belt beyond Neptune. The first Transneptunian
# objects (except Pluto) were discovered only after 1992
# and none of them has been given a name as yet.
#
#
# The largest asteroids
# ---------------------
# Most asteroids are actually only debris of collisions
# of small planets that formed in the beginning of the
# solar system. Only the largest ones are still more
# or less complete and round planets.

1    Ceres        # 913 km  goddess of corn and harvest
2    Pallas       # 523 km  goddess of wisdom, war and liberal arts
4    Vesta        # 501 km  goddess of the hearth fire
10   Hygiea       # 429 km  goddess of health
511  Davida       # 324 km  after an astronomer David P. Todd
704  Interamnia   # 338 km  "between rivers", ancient name of
                  #         its discovery place Teramo
65   Cybele       # 308 km  Phrygian Goddess, = Rhea, wife of Kronos-Saturn
52   Europa       # 292 km  beautiful mortal woman, mother of Minos by Zeus
87   Sylvia       # 282 km
451  Patientia    # 280 km  patience
31   Euphrosyne   # 270 km  one of the three Graces, benevolence
15   Eunomia      # 260 km  one of the Hours, order and law
324  Bamberga     # 252 km  after a city in Bavaria
3    Juno         # 248 km  wife of Zeus
16   Psyche       # 248 km  "soul", name of a nymph


# Asteroid families
# -----------------
# Most asteroids live in families. There are several kinds
# of families.
# - There are families that are separated from each other
#   by orbital resonances with Jupiter or other major planets.
# - Other families, the so-called Hirayama families, are the
#   relics of asteroids that broke apart long ago when they
#   collided with other asteroids.
# - Third, there are the Trojan asteroids that are caught
#   in regions 60 degrees ahead or behind a major planet
#   (Jupiter or Mars) by the combined gravitational forces
#   of this planet and the Sun.

# Near Earth groups:
# ------------------
#
# Aten family: they cross Earth; mean distance from Sun is less than Earth

2062 Aten         # an Egyptian Sun god
2100 Ra-Shalom    # Ra is an Egyptian Sun god, Shalom is Hebrew "peace"
                  # was discovered during Camp David mid-east peace conference

# Apollo family: they cross Earth; mean distance is greater than Earth

1862 Apollo       # Greek Sun god
1566 Icarus       # wanted to fly to the sky, fell into the ocean
                  # Icarus crosses Mercury, Venus, Earth, and Mars
                  # and has his perihelion very close to the Sun
3200 Phaethon     # wanted to drive the solar chariot, crashed in flames
                  # Phaethon crosses Mercury, Venus, Earth, and Mars
                  # and has his perihelion very close to the Sun

# Amor family: they cross Mars, approach Earth

1221 Amor         # Roman love god
433  Eros         # Greek love god

# Mars Trojans:
# -------------

5261 Eureka       a mars Trojan
```

```
# Main belt families:
# -------------------

# Hungarias: asteroid group at 1.95 AU

434  Hungaria     # after Hungary

# Floras: Hirayama family at 2.2 AU

8    Flora        # goddess of flowers

# Phocaeas: asteroid group at 2.36 AU

25   Phocaea      # maritime town in Ionia

# Koronis family: Hirayama family at 2.88 AU

158  Koronis      # mother of Asklepios by Apollo

# Eos family: Hirayama family at 3.02 AU

221  Eos          # goddess of dawn

# Themis family: Hirayama family at 3.13 AU

24   Themis       # goddess of justice

# Hildas: asteroid belt at 4.0 AU, in 3:2 resonance with Jupiter
# ---------------------------------------------------------------
# The Hildas have fairly eccentric orbits and, at their
# aphelion, are very close to the orbit of Jupiter. However,
# at those times, Jupiter is ALWAYS somewhere else. As
# Jupiter approaches, the Hilda asteroids move towards
# their perihelion points.

153  Hilda        # female first name, means "heroine"

# a single asteroid at 4.26 AU, in 4:3 resonance with Jupiter
279  Thule        # mythical center of Magic in the uttermost north

# Jupiter Trojans:
# ----------------
# Only the Trojans behind Jupiter are actually named after Trojan heroes,
# whereas the "Trojans" ahead of Jupiter are named after Greek heroes that
# participated in the Trojan war. However there have been made some mistakes,
# i.e. there are some Trojan "spies" in the Greek army and some Greek "spies"
# in the Trojan army.

# Greeks ahead of Jupiter:
624  Hector       # Trojan "spy" in the Greek army, by far the greatest
                  # Trojan hero and the greatest Trojan asteroid
588  Achilles     # slayer of Hector
1143 Odysseus

# Trojans behind Jupiter:
1172 Äneas
3317 Paris
884  Priamus

# Jupiter-crossing asteroids:
# --------------------------

3552 Don Quixote  # perihelion near Mars, aphelion beyond Jupiter;
                  # you know Don Quixote, don't you?
944  Hidalgo      # perihelion near Mars, aphelion near Saturn;
                  # after a Mexican national hero
5335 Damocles     # perihelion near Mars, aphelion near Uranus;
                  # the man sitting below a sword suspended by a thread

# Centaurs:
# ---------

2060 Chiron       # perihelion near Saturn, aphelion near Uranus
                  # educator of heros, specialist in healing and war arts
5145 Pholus       # perihelion near Saturn, aphelion near Neptune
                  # seer of the gods, keeper of the wine of the Centaurs
7066 Nessus       # perihelion near Saturn, aphelion in Pluto's mean distance
                  # ferryman, killed by Hercules, kills Hercules
```

```
# Plutinos:
# ---------
# These are objects with periods similar to Pluto, i.e. objects
# that resonate with the Neptune period in a 3:2 ratio.
# There are no Plutinos included in Swiss Ephemeris so far, but
# PLUTO himself is considered to be a Plutino type asteroid!

# Cubewanos:
# ----------
# These are non-Plutiono objects with periods greater than Pluto.
# The word "Cubewano" is derived from the preliminary designation
# of the first-discovered Cubewano: 1992 QB1

20001 1992 QB1    # will be given the name of a creation deity
                  # (fictitious catalogue number 20001!)

# other Transplutonians:

20001 1996 TL66   # mean solar distance 85 AU, period 780 years

# Asteroids that challenge hypothetical planets astrology
# -------------------------------------------------------

42   Isis         # not identical with "Isis-Transpluto"
                  # Egyptian lunar goddess
763  Cupido       # different from Witte's Cupido
                  # Roman god of sexual desire
4341 Poseidon     # not identical with Witte's Poseidon
                  # Greek name of Neptune
4464 Vulcano      # compare Witte's Vulkanus
                  # and intramercurian hypothetical Vulcanus
                  # Roman fire god
5731 Zeus         # different from Witte's Zeus
                  # Greek name of Jupiter
1862 Apollo       # different from Witte's Apollon
                  # Greek god of the Sun
398  Admete       # compare Witte's Admetos
                  # "the untamed one", daughter of Eurystheus

# Asteroids that challenge Dark Moon astrology
# --------------------------------------------

1181 Lilith       # not identical with Dark Moon 'Lilith'
                  # first evil wife of Adam
3753 Cruithne     # often called the "second moon" of earth;
                  # actually not a moon, but an asteroid that
                  # orbits around the sun in a certain resonance
                  # with the earth.
                  # After the first Celtic group to come to the British Isles.

# Also try the two points 60 degrees in front of and behind the
# Moon, the so called Lagrange points, where the combined
# gravitational forces of the earth and the moon might imprison
# rocks and stones. There have been some photographic hints
# that there are clouds of such material around these points.
# They are called the Kordylewski clouds.


# other asteroids
# ---------------

5    Astraea      # a goddess of justice
6    Hebe         # goddess of youth
7    Iris         # rainbow goddess, messenger of the gods
8    Flora        # goddess of flowers and gardens
9    Metis        # goddess of prudence
10   Hygiea       # goddess of health
14   Irene        # goddess of peace
16   Psyche       # "soul", a nymph
19   Fortuna      # goddess of fortune

# Some frequent names:
# --------------------
# There are thousands of female first names in the asteroids list.
# Very interesting for relationship charts!

78   Diana
170  Maria
234  Barbara
```

```
375  Ursula
412  Elisabetha
542  Susanna

# Wisdom asteroids:
# -----------------

134  Sophrosyne   # equanimity, healthy mind and impartiality
197  Arete        # virtue
227  Philosophia
251  Sophia       # wisdom (Greek)
259  Aletheia     # truth
275  Sapientia    # wisdom (Latin)

# Love asteroids:
# ---------------

344  Desiderata
433  Eros
499  Venusia
763  Cupido
1221 Amor
1387 Kama         # Indian god of sexual desire
1388 Aphrodite    # Greek love Goddess
1389 Onnie        # what is this, after 1387 and 1388 ?
1390 Abastumani   # and this?

# The Nine Muses
# --------------

18   Melpomene    Muse of tragedy
22   Kalliope     Muse of heroic poetry
23   Thalia       Muse of comedy
27   Euterpe      Muse of music and lyric poetry
30   Urania       Muse of astronomy and astrology
33   Polyhymnia   Muse of singing and rhetoric
62   Erato        Muse of song and dance
81   Terpsichore  Muse of choral dance and song
84   Klio         Muse of history

# Money and big busyness asteroids
# --------------------------------

19   Fortuna      # goddess of fortune
904  Rockefellia
1338 Duponta
3652 Soros

# Beatles asteroids:
# ------------------

4147 Lennon
4148 McCartney
4149 Harrison
4150 Starr

# Composer Asteroids:
# -------------------

2055 Dvorak
1814 Bach
1815 Beethoven
1034 Mozartia
3941 Haydn
And there are many more...

# Astrodienst asteroids:
# ----------------------

# programmers group:
3045 Alois
2396 Kochi
2968 Iliya        # Alois' dog

# artists group:
412  Elisabetha

# production family:
612  Veronika
```

```
1376 Michelle
1343 Nicole
1716 Peter

# children group
105 Artemis
1181 Lilith

# special interest group
564 Dudu
349 Dembowska
484 Pittsburghia

# By the year 1997, the statistics of asteroid names looked as follows:

# Men (mostly family names)           2551
# Astronomers                         1147
# Women (mostly first names)           684
# Mythological terms                   542
# Cities, harbours buildings           497
# Scientists (no astronomers)          493
# Relatives of asteroid discoverers    277
# Writers                              249
# Countries, provinces, islands        246
# Amateur astronomers                  209
# Historical, political figures        176
# Composers, musicians, dancers        157
# Figures from literature, operas      145
# Rivers, seas, mountains              135
# Institutes, observatories            116
# Painters, sculptors                  101
# Plants, trees, animals                63
```