

# SOLEX 12.1 User Manual and Technical Notes.

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## 1. Introduction

**1.0 About this manual.** This manual describes the full performances of the program. Two major differences from previous versions are worth mentioning at the very beginning: 1) There is no “light” version of the software, and a postcard registration is no longer necessary to access the full version at [www.solexorb.it](http://www.solexorb.it). 2) Use of the program is made easier by an included help. A short description of the functionality of every command pops up by right-clicking on the command. Changes from the previous version 11 are marked in red as **New** through this manual.

**1.1 What is Solex and what does Solex do?** The name comes from “**Solar** system integration by a fast extrapolation method”, and, indeed, **Solex** computes the positions of solar system bodies (planets, asteroids and comets) by a method which is *entirely based* on the *numerical integration* of the Newton equation of motion (upgraded to account for the major relativistic effects). This means that, once the position and velocity of each body is known at a given starting instant, the acceleration arising from the mutual gravitational forces is computed, and then the new position and velocity after a suitably short time interval (the stepsize) can be predicted. The procedure can be iterated, so that the whole orbits are generated. A beautiful and simple description of the general idea was given by Feynmann in his famous Physics textbook. The more sophisticated integration technique actually implemented by **Solex**, as well as the Solar System model adopted, have been described by the author.<sup>1</sup>

On one hand the numerical integration approach introduces a limitation for the user: it is *not possible* to feed a date to the program and to get the planetary configuration in response. If the date were to be changed, the planets would still travel following their original clock. Planets must instead travel from the initial starting epoch to the desired epoch, and the time required depends on the time interval between the two epochs and on the machine speed. On my notebook, based on the Intel I7-8550U processor, one century orbiting of the Solar System (including the three major asteroids Ceres, Pallas and Vesta) takes less than 1.5 seconds. Still, if we were interested in a night sky of year 2001 BC (astronomical year -2000), starting from the present epoch (say January 1st, 2018), more than a minute would be needed to reach the desired epoch. **Solex** overcomes this limitation by using a database of previously computed starting conditions, among which the program will choose the one that is closest in time to the target epoch. Therefore the initial “go to epoch” waiting time is reduced to not more than a few seconds (if the target epoch is within the time span covered by the library). After this affordable cost is paid, the reward comes back: whatsoever astronomical phenomenon is always *reproduced dynamically*. The Solar System is “alive”, and the moving bodies can be seen from any point of view, static or dynamic, according to various

coordinate systems and at variable speed, forward or backward in time. Everything combined with an *unmatched precision*, fully comparable to that given by the Astronomical Almanac or by the JPL Horizon system and generally superior to that given by computer programs implementing analytical methods. Libraries containing starting condition for more than 500,000 numbered asteroids and over 1000 comets are available to the program, which can then integrate the “expanded” solar system up to any desired epoch (at a rate of a fraction of a minute per millennium on most PCs). Besides the library objects **Solex** can easily handle custom bodies and also Earth’s satellites. Moreover, a fictitious Solar System can be loaded to the program, to model the gravitational dynamics of N-body systems and get insights on aspects such chaos, perturbing effects of heavy planets, relativistic effects of a very massive star and so on. **Solex 12** is also very useful when used in combination with its companion orbit-determination program **Exorb 8.1**, to investigate the past or future propagation of the orbits of newly discovered bodies, their approaches to major planets and the impact probabilities of NEOs.

In conclusion, **Solex 12** is a very precise ephemeris generator, a Planetarium, an advanced Celestial Mechanics' device and a serious research tool. Above all, it can be a self-instruction tool to be explored and enjoyed.

## 1.2 Major new features of Solex 12.1, compared to Solex 11

- New libraries of starting conditions, based on the JPL DE431 ephemerides.
- Additional libraries of starting conditions, including up to 35 perturbing asteroids.
- Extended time span of the libraries (+/- 50000 y for those including the Moon, +/- 1My for those not including the Moon).
- Improved precession model.
- On-line help on available by right-clicking on each command.
- Improved numerical precision in long integrations.
- Asymmetric model for cometary non-gravitational forces implemented.
- Enabled output of barycentric osculating orbital elements.
- Enabled output of osculating elements referred to orbital planes other than the ecliptic.
- Frame rotations enabled in the graphic output of orthogonal view.
- Generation of multiple (time lapse) image files of the graphic output, aimed at the construction of animations by an external software.

**1.3 What Solex 12 does *not* do ?** Although Solex 12 can accomplish a lot of advanced tasks related to the instantaneous positions and to the motion of Solar System bodies, it does *not* handle planetary satellites and the rings of Saturn. Also, Solex 12 does *not* compute physical ephemerides of the Moon and the planets, nor does display constellation boundaries or connectivity between stars belonging to the same constellation.

About the input-output functionality, Solex 12 does **not** support any *direct* output on a printer. However, printed hardcopies can be *indirectly* obtained by externally processing one of the many text or image files that Solex can write on disk.

**1.4 Installation and Startup.** The program is released as a self-installing file (SETUP121.EXE). The program should be run either from a (pseudo) DOS prompt or from Windows. At startup, the program will run in a window whose size and font depend on the settings of your Windows system. To optimize the size and font to suit your preferences, and as well fix an ugly appearance of the central picture of the Sun, you can make the appropriate choices in the “properties” of the console window created by the program (right-click on the rectangle at the top-left corner of the window). My personal choice is the bitmap 10 x 18 font. **Important: If the “QuickEdit” option is active, you need to disable it.**

**Uninstall the software.** The Solex/Exorb package can be uninstalled by running the Uninins000.exe utility, located in the Solex home directory. Upon uninstallation, no garbage is left in the Windows registry, except an addition to the PATH environment variable, that can be removed manually through the Windows control panel: Control panel/System/Advanced settings/Environment variables/System variables/Path.

**Important for Windows 10 users: It is strongly suggested to activate the option “Legacy console” in the “properties” of the console (CMD) window** (Click on the small rectangle at the top-left corner of the window). **To get a proper display of the starting screen image (it might appear out of center) it is necessary to edit the SOLEX.CFG file in the CFG subfolder, setting the flag “Windows 10” to -1 (default is 0).**

After startup, pressing a key or clicking a mouse button will let the program prompt for the maximum magnitude of stars to be read from the library file. Simply pressing Enter or clicking a mouse button will enter the default value 7.0, any other value must be entered from the keyboard. After reading the star library, the program enters the Main Menu. **In most cases, options that do not require explicit input of numeric data can be activated either by the appropriate keystroke or by mouse clicking on the word(s) describing the option.**

**Note:** Some of the output of Solex is (or can be) on disk ASCII files, which can be accessed by the user via any text editor. Solex 12 can also produce BMP image files, which can be accessed via an image processor (e.g. MS Paint). **All files output by Solex 12 are written in the working directory** (by default C:\SOLEXORB\Solex121\USERDATA). Most of the files which are *input* by Solex 12, but should *not* be modified by the user, are in the subdirectory BIN, IMG and ASC of the working directory. Some configuration files that may be changed by the user are in the subdirectory CFG.

**Important.** The program can be started from a (pseudo) DOS prompt (CMD window) in any directory chosen by the user. In this case this will become the working directory, and all file input/output will take place inside it. Personally I prefer this choice, which also offers the opportunity to run multiple instances of the program at the same time, so that the different file outputs won't interfere between each other.

**1.4 Conventions.** Commands are not case-sensitive: upper and lower-case letters, when entered from keyboard, do have the same meaning. Through this document, Solex12 commands and all characters or words that are supposed to be input from keyboard are enclosed in square brackets, commands are in bold typeface.

**1.5 Performance extension.** By default, Solex12 can handle up to about 16100 bodies simultaneously. This limit can however be extended to any value by starting Solex from a CMD window, and adding to the program name a blank, followed by the maximum number of bodies which the program should handle. For example, by typing SOLEX121 520000 it will be possible to load all the over 500,000 bodies of the asteroid library. This complication is motivated by the need to avoid the allocation of a large unused memory, which in some systems slows down the execution speed.

## 2. Main Menu.

**2.1 Main Menu Options.** The Main Menu presents the following options:

[1]. **DE431L. \*New\* “Large” library.** The starting conditions for the numerical integration are read from a library fitting the “long” JPL DE431 ephemerides (2013).<sup>2</sup> Obliquity and precessional angles are computed using IAU2006, Laskar and Williams’ formulae.<sup>3</sup> The library time span is from  $-50000$  to  $+50000$ . The nine planets, the Moon, the three major asteroids and 32 further asteroids – the most effective in perturbing Mars’ orbit - are included as perturbing bodies. The nine planets and the 3 major asteroids are handled by the integrator as “planets”: all their mutual gravitational interactions are taken in account as well as their gravitational effect on other bodies. The 32 extra asteroids are handled as “perturbing bodies”: their gravitational effects on planets and other bodies are taken in account but their mutual interactions are not.

[2]. **DE431M. \*New\* “Medium”** library. Same as above, but only the 3 major asteroids are included.

All of them are handled by the integrator as “planets”: all their mutual gravitational interactions are taken in account as well as their gravitational effect on other minor bodies which might be added.

[3]. **DE431S. \*New\* “Small”** library. Only the 9 planets and the Moon are included. The time span is from -50000 to +50000. This is normally the default library. The relative integration time for the three libraries is approximately 5/1.3/1.

[4]. **DE431NM. \*New\* “NoMoon”** library. The 3 major asteroids are included, but the Moon is missing, and the library is extended to a time span of +/- 1 million y. **Important Note:** Since the Moon is missing from the system, in this case the “geocentric” coordinates are referred to the Earth-Moon barycentre, and therefore are not truly geocentric. Also, the “topocentric” coordinates are referred to a fictitious Earth placed at the Earth-Moon barycentre.

[5]. **DE431O. \*New\* “Planets only”** library. As above, without the 3 major asteroids. The options 4 and 5 are suitable as starting points for the study of the very long term evolution of the orbits of minor solar system bodies.

[6]. **DE431MB. \*New\* “Big 16”** library. The Moon and the 16 heaviest perturbing asteroids are included, but the library is extended to a limited time span of little more than +/- 1000 y. The library is meant to have a higher accuracy for epochs close to the present and to match the system of perturbing bodies most often adopted by JPL when fitting the orbits of minor planets and comets to the observations.

[7]. **DE406. \*New\***. Same as option 2, with 9 planets, Moon and the 3 major asteroids, spanning +/- 50000 y, but tuned on the older DE406 ephemerides.

[8]. **DE406S. \*New\***. Same as option 3, with 9 planets and Moon spanning +/- 50000 y, but tuned on the older DE406 ephemerides.

[9]. **DE406O. \*New\* “Planets only”** library, same as option 5, with 9 planets and without Moon, spanning +/- 1 million y, but tuned on the older DE406 ephemerides.

[M]. **Minor body file.** Starting conditions for up to 16085 minor bodies (see section 1.5 for extending the default number) can be read from a custom file. The starting condition can be given either as status vectors (positions and velocities) or as classical osculating elements. The solar system starting conditions are read from the last-called library (or from DE431S if the option is called at startup), but if the bodies are satellites, the solar system is limited to the planets from Venus to Saturn and to the Moon. The default extension for the custom files is .SLX (only files with this extension will be listed in the input window), but any filename can be used. The detailed format of the input file is described later (see section 2.3.1).

[F]. **Full N-Body File.** The starting conditions of *all* bodies (up to 16100 bodies, see section 1.5 for extending this number) can be read from a custom file, which can contain either positions and velocities or classical elements. The default extension of a “full” file is .SLF. By this option not only a “real” solar system situation can be read into the program, but also a completely fictitious one.

The detailed format is described in section 2.3.2.

[\*]. **Asteroid Library.** Starting conditions for up to 16085 asteroids (see section 1.5 for extending this default number) can be read from an asteroid library. (Entering such a large number of bodies can be convenient only if the user intends to run a search for close approaches by the command [Y] in the main menu. Indeed, the screen tabular display can only show the first 2029 bodies). The extended library contains osculating elements of more than 500000 numbered asteroids at the epoch 2018/04/12 taken from Bowell and AstDys databases:

(<ftp://ftp.lowell.edu/pub/elgb/astorb.html>, <http://hamilton.dm.unipi.it/astdys/>)

The same library allows to switch between *four* different options: *Average* (default): the elements are set to the arithmetic mean of the (different) values given by the two databases, and uncertainty estimates are computed by the corresponding

positional differences and their time derivatives. *Astorb*: The data are taken from the Bowell's AstOrb database. *AstDys*: The data are taken from the AstDys database. *TwinLib*: A couple of "twin" asteroids is generated, using each of the two database, respectively. Asteroids can be selected by number, by name, by number range, or from a custom list file. For example entering [1-25] will select all the asteroids up to no. 25 Phocaea; entering [MYAST.LST] will select all the asteroids listed (by number or by name, one asteroid for each line) in the text file MYAST.LST (the extension .LST is mandatory). When creating a long list file, it is suggested to use numbers rather than names, in order to speed up the search procedure. A useful list of Near Earth Asteroids is provided with the file NEO.LST. Asteroids can also be "filtered" according to the criteria stated in the file FILTER.AST, by entering a range, followed by a slash and letter F, e.g. entering [1-10000/F] will load, among the first 10000 asteroids, only those which meet the criteria selected by the editable file FILTER.AST. Finally, "clones" of each selection can be generated. For example, entering [Apophis/C16] will generate 15 "clones" of asteroid 99942 Apophis (besides the parent one), whose orbital elements are randomly distributed around their nominal values in a way matching the estimated standard errors of the parameters. Generating clones by this way is a "quick and dirty" procedure. Two rigorous methods involve the use of the companion program **Exorb81**. Multiple successive selections are allowed. The solar system starting conditions are read from the last-called library (or from DE431S if the option is called at startup).

**[@]. Comet Library.** Starting conditions for a comet can be read from a comet library, containing position and velocity vectors given by P. Rocher (<http://www.imcce.fr/page.php?nav=en/ephemerides/>) in the ASCII file catalog and including non-gravitational parameters. A comet can be selected either by its official designation (e.g. [46P] or [P/2000 C1]) or by name (e.g. [Wirtanen] or [Hergenrother]) or by browsing through the whole list. The starting epoch is the epoch of the elements given by the IMCCE and depends on the particular comet. The solar system starting conditions are read from the last-called library (or from DE431S if the option is called at startup).

**[0]. Reload Stars.** Useful to change the upper magnitude limit. The star library is based mainly on the NOMAD1 catalogue. Positions from the PPM catalogues are used for ca. 60 bright stars missing in the NOMAD catalogue.

**Important Note:** If a very large number of stars is loaded into memory (typically when the limit magnitude is above 10.5) the computation time involving the stars (graphic display of stars or star conjunction search) can be disturbingly slow. In these cases, if the user is interested only in a specific region of the sky, the stars can be "filtered" during loading, matching a specified rectangular region of RA and decl. This can be done by entering the limit magnitude, followed by [/F], and then entering the appropriate values for the RA and decl window.

**[S]. Special Options.** Fourteen special options are available.

The first one (**A**) allows to change the Lunar tidal acceleration parameter from the default value (fitting the DE406 or the DE431 ephemerides) to a custom value. The value is reset to default every time the Main Menu is entered. If the option is activated, the initial conditions are read from the library record which is closer in time to J2000 rather than to the target epoch. Therefore, a long "go-to-epoch" initial computing time is required if a distant target epoch is to be reached.

The second special option (**B**) allows to neglect the perturbations acting on minor bodies by selected major planets. The planets to be neglected can be selected/deselected by right-clicking on the corresponding name in the text-output window. The mutual perturbations between major planets remain active. However only the "direct" accelerations are neglected, not the "indirect" ones.

The third option (**C**) switches on the perturbations exerted on major planets by minor bodies, which are normally not considered. Note that mutual minor body-minor body interactions are never considered, unless the starting conditions are read from a "full" .SLF or .ELE file (see **Appendix 1** for details).

The fourth option (**D**) switches off the relativistic perturbation acting on minor bodies, the major planets remaining affected. This is only useful for “measuring” the relativistic effect on orbits closely approaching the Sun, by comparison of the default output with that obtained after switching “off” the correction.

The fifth option (**E**) switches off **all** non-Newtonian-point mass perturbations for **all** bodies.

The sixth option (**F**) allows determining how the solar mass loss is handled by Solex. Differently from Solex11, in the default mode, the solar mass loss is **not** considered. In the alternate mode the solar mass loss is forced everywhere. It should be remembered that the stored library data are computed using the default option. Note that the quadratically growing effect of the solar mass loss affects the time at which planetary events (such as conjunctions) take place, but does not have a negligible influence on the events themselves, i.e. the same planetary configurations are reproduced at a different time, with the exceptions of those involving the Moon.

The seventh option (**G**) sets the order of the numerical integrator. The default order (14) is OK for all the cases involving relatively “short” integrations (i. e. shorter than a few thousand years from the starting library epoch). For preserving a good numerical accuracy in longer integrations, it might be advisable to adopt a higher order (16 or even 18). However higher order also means more computations and longer integration time.

The eighth option (**H**) allows the use of *extended precision arithmetic* (80 bits floating point) when computing planet-planet interactions. By default the extended precision arithmetic is used only when computing Sun-planet and Earth-Moon accelerations, because the planet-planet forces are normally much smaller and the extra digits gained by the extended precision would be lost anyway when adding up the contribution to the total acceleration. The option may be useful in the case of minor bodies undergoing repeated approaches to a major planet at a distance where the planet-body force becomes comparable or even larger than the Sun-body force.

The ninth option (**I**) is useful in dynamical studies on many-body systems. When activated, collisions between any two bodies are detected, the smaller body is removed from the system and its mass and momentum are added to the heavier body. The collision are recorded in a file named COLLIS.LOG.

The tenth option (**J**) removes frame rotations, including precession, from the execution. It was originally meant to reduce the accumulation of roundoff error during long integrations of planet-only (no Moon) systems. Due to the adoption of the extended precision in the frame rotation routines it is now of little use.

The next option (**L**) **New** allows to switch (on demand) the precessional model from IAU2006 to Lieske (IAU1978). Useful to check the agreement/disagreement of the Solex output with other software packages. The switch works only within +/- 2000 years from present.

The next option (**Y**) **New** switches the modelling of non-gravitational forces from the cometary Marsden model to an empirical modelling of the Yarkovsky effect on small bodies. Should not be used if the minor bodies are loaded from the asteroid library, but only if they are loaded from a SLX or SLE file where the appropriate coefficients are given in the fourth line of each record.

The next option (^) allows to handle a single impulse received by a minor body at a specific time. Makes sense to use it only in connection with the companion program **Exorb81**. See the pertinent on-line help.

The final option (>) implements an asymmetric non gravitational force model for comets. Makes sense to use it only in connection with the companion program **Exorb81**. See the pertinent on-line help.

**[Esc]. Quit.**            Exit program.

## 2.2 Input of Date and Tabulation Interval.

**2.2.1 Date.** If one of the options **1-9** is selected, the program prompts for a starting date. This has to be entered from keyboard in either of the two formats [YYYY,MM,DD] or [YYYY.MMDD]. However, there are a few shortcuts:

- If the [ENTER] key is pressed in response to the prompt, or mouse is clicked, the current system date and time is adopted.
- If only [YYYY] is entered, the date is set to January, 1<sup>st</sup> of year YYYY.
- If only [YYYY] and [MM] are entered, the date is set to the 1<sup>st</sup> day of the month MM.

DD is not necessarily an integer number, so that for example entering [2002.060133333333] (or [2002,6,1.3333333333]) will start the tabulation at 8.00 TDT of June 1<sup>st</sup>, 2002.

- If the date input is followed by typing [/L] then the program jumps at the library date closest in time to the selected epoch.

In options **M**, **F**, **\*** and **@** the initial date is read from the appropriate data file. To reach a different epoch, the command **[J]** (Jump to Date) in the Commands menu has to be used.

**2.2.2 Tabulation Interval.** This has to be entered from keyboard in the format [dd.hhmmss]. For example to set a tabulation step of 15 days, enter [15]. To set a tabulation step of 30 min, enter [0.0030]. Pressing just the [ENTER] key sets the tabulation step to 1 d. A negative entry causes the program to run backwards in time after the target epoch has been reached. The tabulation interval can be successively multiplied/divided by discrete factors through the commands **[U]** (Time Unit) and **[S]** (Step Scaling).

**2.3 Input Files.** When the options numbered **1-9** are selected, SOLEX 12 reads its input data only from library files (\*.BIN) and accessory files (\*.DAT), located in the subdirectories BIN and ASC, respectively, whose internal structure is not a concern for the user. When the options **M** or **F** are selected, SOLEX 12 reads part (or all) of the data from a file (\*.SLX or .SLF, respectively) which must be created by the user. There are three basic ways of creating such files: i) manual editing; ii) renaming or copying the SOLEX 12 output file FINAL.SLX, FINAL.SLF, FINAL.SLE or FINAL.ELE; iii) renaming or copying any of the EXORB output files (see the Exorb help). The extensions .SLX and .SLF are not mandatory for an input file, but only filenames having these extensions will be displayed in the input window. The file FINAL.SLE contains the same starting conditions as the file FINAL.SLX, in the format of osculating elements instead of position and velocity vectors. The file FINAL.ELE contains the same starting conditions as the file FINAL.SLF, in the format of osculating elements instead of positions and velocity vectors.

**2.3.1 Minor Bodies' Files (\*.SLX).** This file can contain starting conditions (pv vectors or osculating elements) of up to 8000 minor bodies (see section 1.5 for extension of this limit), provided they all refer to the same starting epoch and the provided classical elements are not mixed up with positions and velocities. The number of digits or characters used by alphanumeric data is free, as is the number of spaces used to separate each item in a line. If numbers are written in exponential format, either the letter E or the letter D can be used, in both lowercase and uppercase form (1.03445E-01, 10.3445d-02, 0.103445, or 1.03445D-1 are equivalent). The data in the file must be structured as follows.

Line 1: One entry. Epoch (JD) of the elements. **Very important:** if the files contains **classical osculating elements**, then the epoch must be set as negative (as an implicit flag telling to the program what to expect). If the data refer to a **satellite**, then the number 90,000,000 (or -90,000,000 in the case of classical elements) must be added to the epoch (as another implicit flag telling to the program that it is a satellite and the elements or pv vectors are geocentric). So, the number -92451544.5 in line 1 means that the following data are geocentric osculating elements of satellite(s) at epoch January 1, 2000, 00h TDT. **Note:** What stated above implies that **starting**

**conditions for minor bodies referring to epochs before JD 0 (-4712, January 1) cannot be stored in a SLX or SLE file. In such cases, the “full system” SLF or ELE files (see below) must be used.**

Line 2: Five entries. + optional reference equinox of the elements (if not J2000.0) + optional color code

1: If the body is *not* a comet, then this entry is the mass of the body, in units of  $10^{24}$  kg (in these units, the mass of the Sun is 1989095.324, that of Earth is 5.974227112). **Important:** Do not bother about the mass! The mass is only needed in special cases when the user wants to investigate perturbations by large asteroids (See Appendix 1 for details). Normally, the mass is *not* needed (**a zero value is OK**) and, if a non-zero value is present, it is *not* used (defaults to zero). **Important option :** In the case the orbital elements are not referred to J2000.0, but to some other epoch (a frequent case with old data) this entry (mass or  $k$  magnitude) can be set as negative, which is an implicit flag telling the program to read a further number as the fifth entry (before the body’s name). This number should be the number of julian days from J2000.0 to the epoch to which the elements are referred. For example, if the epoch is B1950.0 the number should be -18262.5765.

If the body *is* a comet, the 1<sup>st</sup> entry is the  $k$  magnitude parameter (the mass always defaults to zero).

2: Radius of the body, in units of Gm, i.e. millions of km (in this unit, the equatorial radius of Earth is 0.00637814). The radius is relevant in eclipses and occultations studies. **Important:** If the body is a comet, the radius must be set as negative, as an implicit flag telling the program that the body is a comet.

3: Absolute magnitude.

4: Relativistic parameter (don’t bother about it; if the file is manually edited, just set it to zero).

5: **Optional.** (Note: Can be used only in the case of keplerian elements, not in the case of position/velocity vectors). Reference equinox epoch of the orbital elements, if not J2000, expressed as number of days from J2000.0. **Important:** if this datum is inserted, the mass (or  $k$  magnitude when comet) must be set as negative to flag the presence of the datum.

5 (or 6): Name of the body.

6 (or 7): **Optional** color code for the graphic output. A six digits number: the last (least significant ones) two give the amount of red (from 00 to 99), the middle two give the amount of green (from 00 to 99) and the first (most significant) two give the amount of blue (from 0 to 99).

Line 3: Three entries. Either  $X$ ,  $Y$  and  $Z$  equatorial heliocentric coordinates (gigameters) or  $e$ ,  $i$  and  $\omega$  ecliptic elements (eccentricity, inclination and argument of perihelion in degrees). **Note:** if the body is a satellite, the elements must be equatorial and geocentric.

Line 4: If the entry in line 1 is positive (file contains status vectors) then this line contains three entries.  $V_x$ ,  $V_y$  and  $V_z$ , that is heliocentric equatorial velocity components (km/s).

If the entry in line 1 is negative (file contains classical elements) then this line contains five entries.

$\Omega$ ,  $a$ ,  $MO$ ,  $q$ ,  $Tp$  (Node, semimajor axis, mean anomaly, perihelion distance and time of perihelion)

**Note:** Either  $a$  and  $MO$  or  $q$  and  $Tp$  must be set as zero. Angles are in degrees and distances are in AU. If the body is a satellite, the elements must be equatorial and geocentric.

Line 5: Four entries.

- If asteroid, all four entries can be set to zero (the first one *must* be set to zero). Normally, the second and third entries are interpreted by the program as the positional uncertainty (km) of the asteroid and its time derivative (km/y), respectively. However, if the Yarkowsky effect flag is activated in the special options, the first three entries in line 5 are interpreted as the coefficients of the transverse, tangential and perpendicular components, respectively, of the Yarkowsky acceleration.



- If comet, the entries are the non-gravitational parameters  $A1$ ,  $A2$ ,  $A3$ ,  $AF$  ( $AF$  is a scale factor usually set to 0.1112620). Additional entries should be used if either of the special options of the single impulse (^) and asymmetric model (>) is activated. The latter make sense only in connection with the companion program **Exorb81** for advanced investigations. See the on-line help for details.
- If satellite, the entries are  $Qd$  (Drag empiric coefficient);  $QE2$  (proportional to the Oblate Earth's  $J2$  coefficient);  $QE3$  (proportional to the Oblate Earth's  $J3$  coefficient);  $QEX$  (free for future implementations). If both  $QE2$  and  $QE3$  are set to zero, the program assigns default values to them, otherwise, they might be optimized for a specific satellite by using EXORB.

Line 6: Same as line 2 if another body is present and so on ..., otherwise no line.

**Important:** The last edited line (such as as line 5 described above) must be terminated by a CR-LF (Enter key of the keyboard). The total number of lines must be  $(N*5+1)$  where  $N$  is the number of bodies included in the file. See the DEMO.SLX file for an example. Examples of the structure of SLX files are given by the FINAL.SLX and FINAL.SLE files, written by Solex when asteroids or comets are loaded from the respective libraries. Note that a minor body file in the format of orbital elements can as well be renamed with the extension .SLX, because what tells the program to interpret the data as elements is the negative value of the TJ at the beginning of the file, not the extension of the name.

**2.3.2 Full N-Body Files (\*.SLF and \*.ELE).** The format of these files can be seen looking at the files FINAL.SLF and FINAL.ELE, written by the program every time the program runs. The former contains the starting conditions in form of status vectors (position and velocities), the latter contains the same data in form of classical osculating elements.

The first line of the file is the epoch (Julian day) of the starting conditions. The first entry in the second line of the file gives the default integration stepsize that is to be used by Solex. This is normally 3 d or 5 d for the solar system, depending on whether or not the Moon is included in the file, but can be set to more appropriate values in the case of fictitious planetary systems. A decent choice is about  $1/20^{\text{th}}$  of the period of the fastest orbit, if it has a moderate eccentricity. (See below for further information about the FINAL.SLX and FINAL.SLF files). SLF files can contain starting conditions in the form of position and velocity vectors, or osculating elements. A negative stepsize in this case flags the program to interpret the data as osculating elements. Differently from SLX files, a negative Julian day plainly means an epoch before  $y-4712$  and does not have a flag value.

The following entries in the second line are Mass of the central body (normally the Sun, in units of  $10^{24}$  kg), radius (in units of Gm = millions of km), two zeros and the name. For the first body (the Sun), the next two lines always contain a triplet of zeros.

For the following bodies, the first line gives the mass (in units of  $10^{24}$  kg), radius (in Gm), absolute magnitude, a relativistic parameter (see section 2.3.1) and the name of the body. The following two lines contain either Position-Velocity vectors  $X$ ,  $Y$ ,  $Z$  and  $V_x$ ,  $V_y$ ,  $V_x$  (in Gm and km/s, respectively), in the J2000 equatorial frame, or classical osculating elements  $e$ ,  $i$ ,  $\omega$  and  $\Omega$ ,  $a$ ,  $M0$

Note that in the case of comets the full (\*.SLF) files do not contain the non-gravitational parameters (or positional uncertainty estimates in the case of asteroids). If these are needed, the minor-body files (\*.SLX or \*.SLE) must be used instead. **Important:** If an SLF file contains asteroids, their masses *are* considered by Solex 12 (they do *not* default to zero as for SLX files). The use of SLF files is actually one of the two ways by which the masses of minor bodies can be taken into account (see Appendix 1).

### 3. Tabular Output Command Menu.

After the starting data have been entered, the program reads the solar system starting conditions from the appropriate library and integrates up to the target epoch. In the case of options **M** to **@** the data for the additional minor bodies are then added in memory. At this point, two full N-Body files named FINAL.SLF and FINAL.ELE are written to disk in the working directory, the latter containing the starting conditions in form of osculating elements. If minor bodies are present, two Minor-body files named FINAL.SLX and FINAL.SLE are also written to disk, the latter containing the starting conditions in form of osculating elements. The output screen for the target epoch is displayed, together with the menu of the available commands and/or toggles. Note that although up to 16100 bodies can be simultaneously handled by the program (see section 1.5 for extending the default number), only data for the first 2035 bodies will be displayed.

Since the action of many commands is rather obvious (or becomes so after a couple of trials), in the rest of this section only commands which might require more explanations are commented.

**3.1 [W] Graphic Window.** Switches to Graphic (Planetarium) mode, creating a Graphic Window and displaying a Graphic Menu (see next section for the Graphic Menu commands). When switching to Graphic mode, all the options selected in the Main menu are retained. Some of them can be changed from within the Graphic Command Menu, some cannot be changed without exiting the Graphic mode. Details are given in the next section.

**3.2.1 [O] Orthogonal Coordinates.** The distance from origin and the light-time has been added to the output. In this case the output distance is “apparent”, i.e. is affected by light time and aberration if these toggles are ON. The command **[^] Display Velocity** outputs the components of the velocity vector relative to the origin and the radial velocity, affected by light-time and aberration if the toggles are ON.

**3.2.2 [T] Topocentric Coordinates.** For proper use, before activating the topocentric coordinates, the appropriate Geographic Coordinates should be set by the command **[G]**. However, if the Graphic display is what you need, this can be done *graphically* from within the Graphic menu. Note that the activation of topocentric coordinates automatically activates the use of DeltaT, i.e. the UT as time unit instead of TT. If topocentric coordinates are successively turned off, the DeltaT is turned off. To turn it on again (if UT instead of TT is desired), the command **[D]** must then be used.

**3.3 [C] PlanetoCentric Coordinates.** Note that the orientation of the reference frame remains bound to the Earth-based celestial reference system, i.e. the Ecliptic and Equator. Horizontal coordinates are not allowed if this option is ON. Besides setting the origin on any chosen body, this option allows to set the origin on a fixed point, whose orthogonal coordinates must be entered by the user. The latter option is especially useful to get a picture (in the graphic mode) of the Solar System as seen from “outside”, possibly with the background of the stars. **Note:** It is possible to get **barycentric positions** by setting the fixed point to 0, 0, 0.

**3.4 [Z] Horizontal Coordinates.** Automatically sets the origin on Earth. The appropriate Geographic Coordinates have to be set by the command **[G]**. In the Tabular output mode, this is the only way to display approximate magnitudes of the bodies. The visual magnitudes are computed with the formula appropriate to either a minor planet or to a comet according to the case. Formula for a comet:  $m = g + 5 \log(\Delta) + K \log(r)$

Please note that magnitudes are approximate ! The error ranges from 0.0 to 0.3 units for the planets and from 0.0 to 1.0 units for the asteroids. Rising, setting and transit times, rounded to the closest minute, are given. **Note: If the body is above the horizon, the program gives the previous rise time and the next set time. If the body is below the horizon, the program gives the previous set time and the next rise time. If the hour angle is positive, the program gives the past transit time, if negative it gives the next transit time.**

The rising and set times can be referred to the upper limb or to the centre of the body by toggling ON/OFF the command [D] **Limb Ri/Set**. The effect of atmospheric refraction on rising and set times can be toggled ON/OFF by the command [A] **Refrac Ri/Set**.

**3.4.1 [R] Reference Equinox.** All the output can be referred to the ecliptic, equator and equinox of a custom epoch, which must be entered as year and fraction of year (1900.0 means 0 TT of January 1, 1900; 1900.2464 means 0 TT of April, 1, 1900).

**3.4.2 [D] DeltaT.** Allows setting the value of DeltaT, either in Auto mode (using the formulas given in Section 7), or as a fixed value, or by a custom second order polynomial whose coefficients are entered by the user.

**3.5 [X] Osculating Elements.** The output shows osculating elements (referred to J2000) instead of positional ephemerides. Four toggles plus the File Output option are available. The command [M] dumps the current screen to a file named OSCEL.DAT. The toggle [D] switches the elements from being referred to the standard ecliptic and equinox of J2000 or to the mean ecliptic and equinox either of the ephemeris date or the date set by the Reference Equinox (command [R]). The Toggle [Q] switches the elements between Ecliptic, Equatorial or Mean Plane elements. If the planetocentric option is activated for a specific planet other than Earth, the elements can also be referred to the orbital plane of center planet (**New**).

**3.6.1 [V] Adaptive Stepsize.** The “normal” status of this toggle is *off* and the command should not be a concern for the user, unless the loaded data contain a minor body undergoing close approaches with major planets or the Sun. Under the latter circumstances the default integration engine does not give accurate results, and the adaptive stepsize control should be toggled *on*. In this case the integration speed is reduced by about 30%. See section 5.3 for more details.

**3.6.2 [/] Hide Planets.** Selected planets can be hidden by using this option. When the toggle is *on* (green) it means that at least one body is hidden. Hidden bodies are excluded from file output and from any search for close approaches. The option is particularly useful to get a desired subset of close approaches and multiple conjunctions.

**3.6.3 [!] Extra options.** The special options described in section 2.1 (command [S] of the main menu) can be activated or modified from within the text output menu. However, the Moon tidal acceleration and the Solar mass loss factor can be changed only from the Main Menu.

**3.7 [F] File Output.** The output (in the current optional settings) can be redirected to files. The program prompts for the number of records to be written on disk and for the time unit to be used in the output. When expressed in Julian years, centuries or millennia (options Y, C and M, respectively), the time is measured from J2000. The file OUTPUT.LOG will contain a sequence of “pages” as they would have appeared on screen. This file is written only when less than 4096 records are required to be written on disk. The files “\*.OUT” will contain successive records, all referred to the same body. The output can be limited to the minor bodies or to the major planets. When the final epoch is reached, the files FINAL.SLF, FINAL.ELE, FINAL.SLX, FINAL.SLE and FINEL.DAT are rewritten (the latter three only if minor bodies are present).

**Note:** If more than 2030 bodies are loaded to the program, only data for the first 2030 bodies will be recorded. Be aware that when many bodies are loaded, the output on so many files will considerably slow down the program execution, especially if a short tabulation step has been selected.

**3.8 [U] Time Unit.** The default time unit is *day*, but can be switched to *h*, *m*, or *s*. If this is done, the tabulation step is scaled to the new unit (if it was 1d will become 1h or 1m and so on).

**3.9 [S] Step Scaling.** A further way of changing the tabulation step. If the original tabulation interval was set at the default value of 1d, the range of steps actually available by a combination of [U] and [S] toggles is from 0.001 s to 1000 d.

**3.10 [G] Geographic Coordinates.** Prompts for manual input of the latitude and longitude (and height on the sea level) of the observation site, or for loading them from a location library or by observatory code. The location library contains all major cities in the world (more than ca. 50000 inhabitants). Try it just by entering the name of the city closest to you. The input of latitude and longitude can be done *graphically* from within the Graphic menu (see next section). Note that the site coordinates will not be active unless the Topocentric Coordinates option [T] is on.

**3.11 [J] Jump to Date.** This command is most useful when the Asteroid or Comet libraries (or the File options) are used, in order to jump to any target epoch starting from the library (or File) epoch. When the target epoch is reached, the files FINAL.SLF, FINAL.ELE, FINAL.SLX, FINAL.SLE and FINEL.DAT are rewritten (the latter three only if minor bodies are present). Note that these files can be renamed and directly used as custom files by the starting options M and F. Also note that the FINAL.SLX and FINAL.SLF files are in the format of position/velocity files, while the files FINAL.SLE and FINAL.ELE are in the format of osculating elements files.

**3.12 [Y] Close Approaches.** A major feature in Solex 12. Allows to perform a systematic search for close approaches between the currently loaded bodies and for other special circumstances. The use of this function is the only reason why it can be convenient (and allowed) to load a very large number of bodies to the program. This command presents the following seven options, that in turn can be “modulated” by the addition of a sub-option:

**3.12.1 Spatial approaches.** Close approaches within a given distance (in units of 1000 km) can be searched either between a selected body and all other bodies, or between *all* the bodies, or between a specified couple of bodies, or between *a range of* bodies and *all* the bodies. Approaches between Earth and Moon are not considered, unless specifically requested. The program first prompts for selecting a body. To search for *all* mutual encounters [-1] must be entered, (simply pressing [Enter] will search for encounters with body #0, i.e. the Sun. Entering e.g. [Iris] will search all the encounters between asteroid Iris and all the other bodies (provided of course Iris was loaded from the Asteroid library). Entering [3/4] will search for the approaches between body No. 3 (Earth) and body No.4 (Mars). Entering [2-4] will search for the approaches between the bodies 2, 3 and 4 and all the bodies (thus neglecting the mutual approaches between the bodies having a progressive number different from 2, 3 or 4). After prompting for the maximum distance to consider as a close approach (in units of 1000 km), the program prompts for a final epoch to reach and starts the search, displaying some information about its progress (progress bar, speed, number of hits etc ...). An additional option is that the maximum distances between bodies (such as aphelia) can be alternatively requested, by entering [/A] immediately following the number indicating the maximum distance to be considered. The results are finally displayed on the screen and written to disk in the file MINDIST.DAT. A list of the bodies giving close approaches is written in the file CLOSAPP.LST, suitable to be used to reload from the asteroid library the starting conditions of only the asteroids that have given close approaches. In the case an impact is detected, data are written to the file **IMPACT.DAT**. If the planet where the impact takes place is Earth, then the geographic coordinates of the impact site are also written to the file.

Each line of the file **MINDIST.DAT** contains the following columns:

#1 & #2: Number of the bodies. Planets (including Ceres, Pallas and Vesta) are assigned negative numbers coinciding with their progressive number in the Solex usual tabulated list. Asteroids (excluding Ceres, Pallas and Vesta) are assigned their official number. Comets and other bodies are assigned #0.

*Date and Time:* epoch (TT) of minimum distance between the two bodies.

*JD2000:* number of Julian days from epoch J2000.0 (2000, January 1.5)

*Dm:* minimum distance (in units of Gm, i.e. million km).

*V:* relative velocity (km/s) at the minimum distance.

*pImp:* Logarithm (base 10) of the ratio between *Dm* and the impact distance (sum of the radii).

*pDefl* : Negative logarithm of the deflection angle (arcsec) undergone by the lighter body as a consequence of the close approach. (The deflection angle is  $10^{-pDefl}$  arcsec).

*pDa* : Negative logarithm of the relative change in semimajor axis undergone by the lighter body upon the close approach. ( $da/a = 10^{-pDa}$ ).

*pDn* : Negative logarithm of the mean motion variation (arcsec/y) undergone by the lighter body as a consequence of the close approach. (The mean motion variation is  $10^{-pDn}$  arcsec/y).

*Error*: estimated uncertainty (Gm) in the minimum distance (only in the case of asteroids).

*Long & lat*: ecliptic longitude and latitude (J2000) of the 1<sup>st</sup> body at the epoch of minimum distance.

*r1 & r2*: heliocentric distances (AU) of the two bodies at the epoch of minimum distance.

In the final two columns are the names of the two bodies.

**Important:** For proper handling of close spatial approaches between asteroids and planets, it is necessary to activate the option [V] (adaptive stepsize).

**3.12.2 Angular approaches.** Close conjunction within a given geocentric, topocentric or planetocentric angular distance are searched between all bodies (excluding the Moon) or between a selected body and all the others, or (between a selected couple of bodies, or between the first K bodies and all bodies. After prompting for selecting a body (see section 3.12.1 above), for the maximum angular distance (in degrees) to be considered, and for the final epoch to be reached, the program starts the search, displaying progress information. **Conjunctions in Right Ascension** (or **conjunctions in Longitude** according to the selected coordinate system) can be searched rather than minimum angular distances by entering [C] after typing the selection of the body. **Multiple conjunctions** (simultaneous conjunctions of 3 or more bodies) within for example 2 degrees can be searched by entering [2/m] as the program prompts for entering the maximum angular distance (entering [2/m4] will restrict the search to multiple conjunctions within 2 degrees involving at least 4 bodies). **Note:** If the search is run under *topocentric* coordinates, events taking place more than 30° below the horizon are not recorded.

Similarly to conjunctions in RA or longitude, **opposition** and **quadrature** conditions can be searched by entering the subcommand [/O] or [/Q], respectively, after the value of the angle (which must be a dummy value in the case of oppositions and quadratures). Maximum elongations [/E] from a given body can also be searched. **Note that oppositions, quadratures and maximum elongations can only be searched when a single target body has been selected.**

The results are in part displayed on screen and written to a number of files:

**MINDIST.DAT.** The column headings and the corresponding data are the following:

*#1 & #2*: number of the two bodies (see details given above for spatial approaches).

*Date & Time*: epoch of closest *apparent* (i.e. corrected for aberration and light-time) angular separation (TDT if geocentric, TU if topocentric coordinates are selected).

*Dm*: Minimum *apparent* angular separation (degrees).

*DI*: This is shown when geocentric (or planetocentric) coordinates are selected. Gives the limit angular separation for observing a mutual occultation. If  $Dm < DI$  then an occultation can be observed somewhere on the surface of the center planet.

*Alt*: This is shown when topocentric coordinates are selected. Gives the altitude on the horizon of the 1<sup>st</sup> body at the time of minimum angular distance.

*Err*: Estimated angular uncertainty (degrees) of *Dm*.

**RA & Dec:** Right ascension and declination (in degrees) of the 1<sup>st</sup> body at the epoch of minimum separation, referred to the mean equinox of date. If ecliptic coordinates are selected, ecliptic Longitude and Latitude are given rather than RA & Decl.

**r1 & r2:** Geocentric (or planetocentric) distances (AU) of the two bodies at the epoch of minimum separation.

**p :** Position angle (degrees) of body #2 with respect to the center of body #1 at the minimum angular separation, measured *counterclockwise from North = 0*.

**e:** Elongation (degrees) from the Sun of body #1, positive towards East (in the positive direction of longitudes).

**m1 & m2:** Approximate visual magnitudes of the two bodies.

**tm:** Maximum observable occultation time, in seconds (only present in the case of an occultation, when  $Dm < Dl$ ).

**tw:** Approximate time half-window (in hours) within which the angular distance is smaller than the selected value.

**ECLIPSES.DAT.** Contains only the data of the close approaches resulting in an occultation, in the same format as the file MINDIST.DAT.

**\*.OCC** These files are written only in the case of an occultation, when the central body is Earth, **and when the central line of the “umbra” intersects the Earth’s surface**. They contain information about the path, size and shape of the “shadow” on the Earth surface, assuming a spherical shape for the two occulting bodies. The path can be traced on a map by using the utility PATHMAP4.EXE provided in the package, separately or from within Solex 11. See Appendix 2 for more details.

**SELOCC.DAT.** When a search for close conjunction is run while the reference frame is set to Topocentric Coordinates, this file contains only the data of the close approaches resulting in a **central** occultation/eclipse visible in a region surrounding (within an angle specified at the beginning of the search) the selected Geographic Site. The data are in the same format as the files MINDIST.DAT and ECLIPSES.DAT.

**TOPOCECL.DAT.** Includes all the conjunctions that would result in an occultation/eclipse at the selected Geographic Site, even if not actually visible at that site (occurring below the horizon or during daylight).

**CLOSAPP.LST.** A list of all the bodies giving close conjunctions, suitable to be used as a LST file when loading data from the asteroid library.

**MULTCNJ.DAT** If multiple conjunctions have been optionally searched, (entering [/m] after the limit angular value), this file will contain a list of all the events detected. The columns named *emin* and *mmax* in this file contain the minimum elongation and the maximum magnitude of the involved planets, respectively. The second largest magnitude is also indicated.

**Warning:** All the above files are erased and/or rewritten if a new search for close approaches is performed. It is therefore necessary to rename those containing information worth to be saved, *before* running another search. A warning message is issued by the program to prevent useful data from being inadvertently overwritten.

**Important Note:** Close approaches involving objects in fast relative motions might occasionally go undetected by SOLEX. This is often the case with star occultations by NEO (Near Earth Objects) when the asteroid is close to the Earth. In this case it is recommended to run the search with the option [V] (adaptive stepsize) on.

**3.12.3 Moon-Planets.** Close conjunctions involving the Moon and other bodies (excluding Sun) are searched. The same files as in the above section 3.11.2 are written to disk. Note that in order not to miss some events, a rather large minimum angle (typically 2 degrees) should be entered. **Conjunctions in Right Ascension** (or Longitude according to the selected coordinate system) can be searched rather than minimum angular distances by entering [/C] after typing the

selection of the minimum distance. **Oppositions** and **quadratures** can be searched by entering [/O] or [/Q], respectively, after a dummy angular distance has been typed.

**3.12.4 Moon-Sun.** Close conjunctions between Moon and Sun (typically Solar eclipses) are searched. The same files as in the above section 3.11.2 are written to disk. Note that in order not to miss some events, a rather large minimum angle (typically 2 degrees) should be entered. **Conjunctions in Right Ascension** (or Longitude according to the selected coordinate system, i.e. **New Moons**) can be searched rather than minimum angular distances by entering [/C] after typing the selection of the minimum distance. **Oppositions** and **quadratures (i.e Full Moons and First/Last Quarters)** can be searched by entering [/O] or [/Q], respectively, after a dummy angular distance has been typed.

**3.12.5 Star Conjunctions.** Close conjunctions between the solar system bodies (except the moon), or between a selected body and all the currently loaded stars are searched. The same files as above are written to disk. The number assigned to the star (#2) is the progressive number in the Solex star catalog (file STARLX.BIN, which is sorted in ascending order of South polar distance). It is also possible to search for conjunctions to a single star. To do this, the progressive catalog number of the star must be found by clicking on the specific star in the graphic display (see section 4.10). Suppose this number is 1576914 ( $\alpha$ -Leonis Regulus in the full library). Now, entering the planet number (-1 for *all* planets) at the program prompt, followed by [/1576914], will search only for the conjunctions involving Regulus. **Conjunctions in Right Ascension** (or Longitude according to the selected coordinate system) can be searched rather than minimum angular distances by entering [/C] after typing the selection of the body. **Multiple conjunctions** can be searched by entering [/m] directly following the value of the maximum angle.

**3.12.6 Moon-Star conjunctions.** Same as above, but involving the Moon. Note that in order not to miss some events, a rather large minimum angle (typically 2 degrees) should be entered. **Conjunctions in Right Ascension** (or Longitude according to the selected coordinate system) can be searched rather than minimum angular distances by entering [/C] after typing the selection of the minimum distance.

**3.12.7 Custom Coordinates** The program prompts for a couple of celestial coordinates (equatorial or ecliptic according to the active coordinate system, in degrees) and the close approaches to this position are searched with the same rules as for angular approaches. Note that, differently from approaches to a star, in this case the condition of minimum angle or conjunction in RA or longitude ([/C] sub-command) is affected by the active coordinate options (precession, nutation, aberration and light time). For example, if the given position is  $0^\circ$  and the selected body is the Sun, Solex will find (and write to the file MINDIST.DAT) all the vernal equinoxes up to the target epoch. However, these will be the **true** equinoxes only if the Aberration, Light time, Precession and Nutation switches are all set ON, and the reference equinox is set to Date. If Nutation is switched OFF, then the **mean** equinoxes will be found.

**3.13 [I] MinMaxZer** Search for minimum and maximum values of Declination or Latitude (according to the selected coordinate systems) or for zero values of the same, or for stationary points in Right Ascension or Longitude. The data are written to the files **MAXMILAT.DAT** or to the file ZEROLAT.DAT, according to the option selected. Stationary points in Longitude (or R.A.) are written to the file **MAXMILON.DAT**.

**3.14 [+][\*] Add asteroids, Add Comets.** Asteroids and comets can now be added to the currently loaded bodies from within the "text output" menu. Following these commands, the program integrates the currently loaded bodies

up to the asteroid or comet library epoch, picks up the selected body (bodies) and then integrates the expanded system back to the starting epoch.

**3.15**    **[#]**    **Save Preferences.**    **(New)**    Writes the current settings to a file named SOLEX.CFG, located in the subdirectory CFG of the Solex home folder. These settings are recovered at the next startup of the program

## 4. Graphic Output Command Menu.

When the **[W]** command is given in the Tabular Output Menu a graphic window appears and a new menu is displayed. A description of most of the graphic commands and toggles follows. An **important preliminary information** is that **Right Clicking** on any point of the graphic window has the effect of reorienting the view toward the clicked point (see section 4.24). **Left Clicking** gives information on the clicked point. Moreover, the **arrow keys, PgUp, PgDn, End, and Home keys are active!** The arrow keys perform small rotations (or translations when in orthogonal view) along the x and y axes. The other keys perform large rotations (or translations) by half of the window size along the same axes.

**4.0**    **[O]**    **Orthogonal view.**    Toggles orthogonal coordinates.

**4.01**   **[D]**    **Dirac. View.**    This toggle is active only in orthogonal coordinates. The program prompts for selecting a body, and the reference frame is dynamically oriented by constantly pointing the Y axis towards the selected body. Very useful to look at special dynamical phenomena such as the “librations” of the Trojans asteroids (by selecting Jupiter as the oriented body).

**4.02**   **[Y]**    **Switch YZ.**    This toggle is active only in orthogonal coordinates. The vertical axis of the plot is switched between the Y and Z axes of the current reference frame (equatorial, ecliptical or Mean Plane).

**4.1**    **[P]**    **Polar view.**    This toggle is only available under angular coordinates, i. e. when the toggle **[O]** is *off*. The toggle **[P]** switches between a rectangular projection and a polar projection. Under the rectangular projection the two angular coordinates (could be right ascension and declination) are represented along the horizontal and vertical axes of the window, respectively. Under the polar projection (the same given in common sky maps) one angular coordinate of any point P (could be the declination) is given by the distance  $r$  from the center, the other coordinate (could be right ascension) is given by the polar angle  $\phi$  formed by the vector  $r$  with the vertical axis.

**4.2**    **[B]**    **Back-Step.**    Reverses the direction of motion (when the toggle is *on*, time flows backwards).

**4.3**    **[C]**    **Continuous Motion.**    If this toggle is *off*, a relatively slow stepwise motion can be obtained by pressing the **[spacebar]** or the **[Enter]** key. When the toggle is *on*, there is no stop or pause between each step, and a faster and continuous motion is obtained.

**4.4**    **[.]**    **Trace.**    The motion of the planet can be traced as single dots, a continuous line, or a continuous line with time marks, according to the status of this toggle. The marks in the L&M mode are set every 10 stepsizes.

**4.4.1**   **[X]**    **Set Mark.**    Active when the Trace **[.]** option is active. Sets a mark on the current position of all visible bodies.

**4.5**    **[/]**    **Hide Planets.**    Selected planets can be hidden by using this option. When the toggle is *on* (green) it means that at least one body is hidden. This option is useful to generate a single trajectory, in connection with the **Trace** option. Hidden bodies are excluded from file output and from any search for close approaches.

**4.6**    **[E]**    **Ecliptic.**    Switches between equatorial and ecliptic coordinates.

**4.7**    **[T]**    **Topocentric.**    Switches between Geocentric and Topocentric coordinates, based on the defined Geographic location (**[G]**). If activated while a Heliocentric or Planetocentric view is active (toggles **[H]** and **[C]** in the tabular output menu) it automatically goes back to Earth-based coordinates.



- 4.8 [Z] Horizontal.** Switches to (and from) Horizontal coordinates, based on the currently defined Geographic location ([G]).
- 4.9 [#] Grid.** Generates a coordinate grid which can be Equatorial, Ecliptic or Horizontal (switchable by successive pressing of the command). The grid is independent of the defined coordinate system (Equatorial, Ecliptic or Horizontal), that is, an ecliptic grid can be displayed while the active system of coordinates is Horizontal and so on. However, a Horizontal grid cannot be displayed if the coordinates are Ecliptic. When the coordinate are orthogonal, the grid is orthogonal and shows units of AU or Gm.
- 4.9.1 [L] Grid Labels.** Draws the appropriate numeric scale on the grid (Active only when a grid is displayed).
- 4.10 [\*] Stars.** Draws the stars, up to the maximum imported magnitude (sections 1.1 and 2.1). Information on a specific star can be obtained by **left clicking** on it. Among the displayed information is the angular distance (Cdist) from the center of the window.
- 4.10.1 [M] Proper Mot.** Turns ON/OFF the correction for the proper motions of stars.
- 4.10.2 [>] [<] More Bright, Less Bright.** Increase/Decrease the brilliance of the stars by a factor of about 0.25 magnitude units. The number displayed on the right of the command indicates how many times the default brilliance has been increased (or decreased) by 0.25 units.
- 4.10.3 [&] Star Colors.** When *off*, the stars are all drawn using the same color *hue*. When *on*, the hue is different according to the different spectral types.
- 4.10.4 [\$] Star Names.** Draws the names of the brightest stars (scaled up when zooming).
- 4.10.5 [@] Nebulae.** Displays the Messier objects and galaxies included in the library file.
- 4.10.6 [%] Nebul.Names** Draws the designations of the displayed Messier objects and galaxies.
- 4.11 [F] Full Screen.** Toggles the graphic window from the normal size to the maximum possible area of the screen. When active, the menu disappears but the keyboard commands remain active (they just have to be remembered).
- 4.12 [R] Rot. Frame.** Under the default conditions, it is *off*. If the command is *off* (default view), under angular coordinates pressing it prompts (**New**) for the coordinates of the direction towards which the view should be rotated, under orthogonal coordinates prompts (**New**) for the rotation axis (X, Y, or Z) and for the rotation angle. Alternatively the image can be rotated been rotated by reorienting the view through a **Right Click** (see section 4.24) on a specific point, or using the arrow keys. Many successive reorientations of the view are possible, and the view can be reset to default by resetting the toggle *off*.
- 4.13 [!] BW Map.** Toggles the image from “color on black” to “black on white”. Useful for saving BW maps (command [I]) to be printed on paper.
- 4.14 [N] Plan. Names.** Toggles the display of planets’ (and asteroids’) names.
- 4.15 [0] Plan. Size.** Changes the minimum apparent size of all bodies, to make them more or less visible on the screen.
- 4.16 [G] Geographic Location.** Allows the graphic setting of the Geographic Coordinates. A planisphere is displayed, which can be zoomed in by **left clicking** on any point. **Right Clicking** sets the geographic coordinates of the clicked point.
- 4.17 [+] [-] Zoom in, Zoom out.** Zooming takes place by a factor of  $\sqrt{2}$  at each pressing of the key. The number on the right of the command gives the current zoom factor (if the number is 6, this means that six zooming-in have been done, and the zoom factor is  $1.414^6 = 2^3 = 8$ ).
- 4.18 [V] Visible Field** Allows the manual input of the field of view (in degrees). Complementary to the zoom commands. The number of the right gives the magnification corresponding to the current field, assuming that a (vertical) field of 36 degrees corresponds to a 1:1 magnification.

- 4.19 [U] Time Unit.** See section 3.8.
- 4.20 [S] Step Scaling.** See Section 3.9.
- 4.21 [J] Jump to date.** Can be run from within the Graphic Menu (no need to go back to text).
- 4.22 [K] Clear Screen.** Refreshes the graphic window.
- 4.23 [=] Search Object.** A star, a deep space object or a planet can be searched by its name (or portion of name) and located on the screen. A constellation can be highlighted by entering its official abbreviation (e.g. [Cyg] for Cygnus, [UMa] for Ursa Major and so on). For a star, a search based on the Greek or Flamsteed designation is possible. For example, it is possible to locate Albireo (Beta Cyg) by entering the name, or by entering [beta cyg], or by entering [6 cyg]. If the object is within the window, the cursor jumps on the object. In any case, if the object (star or planet) is found, it is possible to reorient the view on it by pressing [D].
- 4.24 [I] Save Image.** The whole graphic window is saved as a bitmap file named SOLEX???.BMP, where ??? progressively increases from 000, 001, 002 ... and so on, when successive images are saved during the same session.  
**Warning:** If a new session is started after quitting the program, images are rewritten starting from SOLEX000.BMP. Therefore, to really save screen images, it is necessary to rename the SOLEX???.BMP file(s) to any other chosen name.  
**Important:** Some image processors fail to open the BMP images created by SOLEX. If this happens, don't panic. Open the image using MS Paint and save it in some other format (gif, jpg ...). The new image should now be successfully opened by your preferred image processor.
- 4.25 Right Click.** As previously, Right Clicking on any point of the graphic window has the effect of reorienting the view toward the clicked point. However, what happens later can be different according to the following:  
 If the Horizontal coordinates are ON, then the view is successively kept fixed (and made parallel) with respect to the local *horizon*, otherwise the view is successively kept fixed with respect to the celestial frame (*equator* or *ecliptic* according to which coordinates are active) and made parallel to it. In the latter case however, if the clicked point is a *planet* (or asteroid), then the view is successively *dynamically oriented* towards the clicked object (and kept parallel to the equator or the ecliptic according to which coordinates are active). If the Continuous Motion [C] option is active and the stars are displayed, you will see in this case the planet stay centered on the screen, and the whole sky move in a beautiful animation. Remember that the original default view can be restored at any time by the command [R] (Rot.Frame).
- 4.26 [A] Auto Frames.** (New) Continuously saves up to 999 frames, corresponding to successive time steps, as BMP images named SOLEX###.BMP, where ### is a 3 digit progressive number from 000 to 998. The continuous recording process can be stopped by pressing the command [C].  
 The frames can be used to create an animation by means of a suitable software, as for example GIFanimator.

## 5. Precision

**5.1 Model precision.** As Gauss wrote in his *Theoria Motus*: "... all our measurements and observations are only approximations to the truth". What about *calculated* positions – in our case, the positions calculated by SOLEX ?

SOLEX computes the positions of the solar system bodies by numerical integration. In the case of the major planets and the moon, the starting conditions are read from a library file, whose content was in turn build up by a numerical integration fitted to the JPL DE431 or DE406 ephemerides. The latter were thus taken as the source "observations" upon which the model implemented by SOLEX was constructed. The maximum deviations of SOLEX 12 by the standard DE431 positions are given in Figures 1 and 2. Although these data give an idea of the "precision" of SOLEX 12, it should be kept in mind that these values do *not* represent the deviations of SOLEX output from the *true* positions of the planets, because the DE431 positions themselves are only approximations to the *true* positions. For all epochs not very close to the present, the accuracy of the data is limited by the intrinsic uncertainty in the mean motions of the planets, which in turn

mainly depends either on incomplete modelling of asteroidal perturbations (inner planets and especially Mars) or by inaccuracy of the optical observations (outer planets). According to JPL (Standish, personal communication) the present uncertainty in the mean motion of the inner planets is in the range of 0.01-0.02 arcsec/Century (the larger value applies to Mars), while that on the outer planets is in the range 0.1-0.3 arcsec/Century. The long-term uncertainty in the Moon's longitude does grow quadratically and is controlled by the present uncertainty in the tidal acceleration, which is of the order of  $0.025 \text{ arcsec/Century}^2$ . As an example, at epoch 1000 BC, the *intrinsic* DE431 uncertainties in Venus, Mars and Jupiter longitudes are about 0.3, 0.6 and 3 arcsec, respectively, which is well beyond the corresponding discrepancies between the SOLEX 12 values and the DE431 values, which are 0.01, 0.1 and 0.005 arcsec, respectively. At the same epoch, the DE431 uncertainty in the Moon's longitude is about  $0.5 * 0.025 * 30^2 = 11 \text{ arcsec}$ , which is far beyond the corresponding discrepancy (0.03 arcsec) in Figure 2. Again, at epoch 8000 BC (-100 Cy from J2000), the intrinsic uncertainty in the Moon's longitude is about  $0.5 * 0.025 * 100^2 = 125 \text{ arcsec}$ , more than 10 times larger than the discrepancy between DE431 and SOLEX 12 output plotted in Figure 2.

In summary, the SOLEX 12 output matches the DE431 ephemerides within less than 0.01 arcsec for epochs within +/- 50 years from the present and well within the DE431 intrinsic uncertainty for all other epochs falling in the range -13000/+15000. For epochs outside the range of the DE431 integration, as far as +/- 1000000 years, a rough estimate of the precision (this time intended as probable deviation from the *true* positions) can be obtained by comparing the outputs of the different options DE406 and DE431. Actually, one important reason to have so many different library options included in the Solex main menu is to get an estimate of the output uncertainty, just by comparison of the different outputs obtained for the same epoch or the same phenomenon.

**5.2 Integration Errors (major bodies).** The data included in the library are virtually free from integration error. Therefore this is totally negligible unless a long integration is undertaken by using the option "Jump to Date". In this case the integration error can be kept to a minimum by using a higher order of the integrator (16 or 18) compared to the default (14). See [S] Special options, section 2.1. The simplest way to estimate the integration error (either for major or minor bodies) is to run the same integration backwards to the starting point, and compare the final result with the starting coordinates.

**5.3 Integration Errors (minor bodies).** The integration errors are normally negligible also in the case of minor bodies, except when they come close to a planet (for example NEO approaching Earth or Venus within 0.1 AU or Centaurs getting close to an outer planet). In such cases, the integration errors can become significant, and the option [V] (adaptive stepsize) should be used to save precision. However, it should be kept in mind that close approaches generate chaotic motion, which means that small errors grow *exponentially* with time (and not linearly or perhaps quadratically as in the case of stable orbits). Therefore after a couple of close approaches the calculated positions can become totally unreliable, no matter how precise the integrator was or how precise the starting conditions were. It is very easy to test for chaotic motion with Solex 12. It is enough to run the integration twice over the time span of interest, the second time using slightly modified starting conditions (for example changing the X coordinate in the starting SLX file by 100 m) and compare the results of the two integrations. It should be noted that in the case of asteroids and for very long integrations the effects of chaos appear anyhow, partly due to close approaches between themselves and partly due to the "intrinsically chaotic" region containing their orbits.

**5.4 Agreement with JPL DE431 Ephemerides.** Comparison plots showing the discrepancies between the Solex12 output and DE431 are given in Appendix 1. It is worth to note that outside the range of a few millennia from J2000 the position of the Moon diverges from DE431 up to nearly one arcminute. This difference is still pretty smaller than the probable positional error due to the uncertainty in the tidal acceleration, and it is largely due to the different precessional

models adopted by DE431 and by Solex. DE431 (and JPL Horizon) adopt the Lieske IAU76 precessional formulas, which outside the range of a few millennia from J2000 give a wrong orientation of the Earth figure, while Solex12 uses the more accurate IAU2006 formulas in the interval  $\pm 2$  millennia from present, and specially constructed 10<sup>th</sup> degree polynomial formulas, fitting the data of the Laskar93 model,<sup>3b,c</sup> outside the above interval and within  $\pm 30$  millennia from present. Outside the  $\pm 30$  millennia interval and within  $\pm 1$  million years, Solex uses a linear interpolation of Laskar93 data. The accumulated discrepancy in the orientation of the Earth figure produces slightly different perturbations on the Earth-Moon acceleration and thereby a divergence in the DE431 and Solex12 integrations.

## 6. Satellites

Orbital data concerning artificial satellites are normally available in Internet through the TLEs (Two-Lines-Elements). These elements are specific to the NORAD orbital models for satellites and cannot be used directly by SOLEX without resulting in large errors. Nevertheless a file of reasonably good starting conditions can be created for a satellite by using the following procedure, which involves the use of the program EXORB 8 and is actually a very good practical exercise for the use of EXORB.

- Connect to the Internet site <http://www.celestrak.com> and download the freeware package TRAKSTAR by Dr. T. S. Kelso and the TLEs of the satellites you are interested in.
- Use the program TRAKSTAR to generate a file of ECI Position/Velocity spanning 1-2 days at 9-18 min intervals (use the smallest interval for orbits below 500 km). Pay attention that in the file TRAKSTAR.CFG the time difference from UTC is set to 0.
- Use the utility ECI2POS.EXE (provided within the SOLEX package) to convert the file generated by TRAKSTAR to a format readable by EXORB. By this way you generate two files: MySat.POS and MySat.ST. The first one is the .POS file that should be used by EXORB, the second one contains approximate starting positions and velocities which should be copied to STARTING.DAT to make the fitting easier and faster.
- Use EXORB 8 to determine the optimized starting conditions for the satellite, checking if the quality of the fitting improves by optimizing the Drag parameter  $Qd$  and/or the Oblateness parameters  $QE2$  and  $QE3$ . Remember that in the EXORB settings the toggles Orthogonal Coordinates [O], Earth's Satellite [S] must be ON, and the toggle Auto Starting Conditions [U] must be OFF.
- When a successful optimization has been completed, copy the file START0.DAT to the file MYSAT.SLX and read it into SOLEX.

**Caution:** The accuracy of the satellite ephemerides produced by SOLEX will be generally acceptable only for a limited time span, ranging from one week to a few months depending on the particular satellite. An estimate of the *initial* accuracy is given by the error estimates and residuals produced by EXORB.

## 7. Reference Frame

As in the previous releases, no conversion is performed between the DE200 reference frame and the DE431/406 International Celestial reference frame (ICRS). The primary output resulting from the integration gives heliocentric equatorial rectangular coordinates referred to the DE431 reference frame of J2000. These are converted to the various optional angular or orthogonal coordinates by using Williams<sup>3a</sup> precessional formulae with 5<sup>th</sup> degree IAU2006 polynomial coefficients<sup>5</sup> in the range of  $\pm 2000$  years from J2000. Outside this interval and within  $\pm 30000$  years, the precessional angles are computed through specially developed 10<sup>th</sup> degree polynomials fitted on the Laskar La93 solution<sup>3b</sup> with basic linear and 2d degree correction terms given by Vondr ak.<sup>3c</sup> Nutation is computed using the IAU nutation series.<sup>6</sup>

For compatibility with the precessional formulas used by other software (from JPL and IMCCE) it is also possible to use the Lieske (IAU L76) formulas, only in the range of +/- 2 millennia from J2000.

**About Time reference, the formulas used for computing DeltaT (DT-UT) are taken From Espenak & Meeus (2005, Canon of Solar Eclipses)** , see <http://eclipse.gsfc.nasa.gov/SEcat5/deltatpoly.html>

**References**

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- (3) (a) Williams, J. G. *Astron. J.* **108** (1994), 711.  
(b) <http://vo.imcce.fr/insola/earth/online/earth/La93/index.html>  
(c) Vondràk, *et al.* *Astron. Astrophys.* **534**, (2011), A22.
- (4) Standish, E. M., documentation available on the JPL site: <ftp://navigator.jpl.nasa.gov/ephem/export/>
- (5) *Celestial Mechanics and Dynamical Astronomy* **94** (2006), 351–367
- (6) Meeus, J. *Astronomical Algorithms*, Willmann-Bell, Richmond, Virginia, (1991) pp. 131-134.

Figure 1.

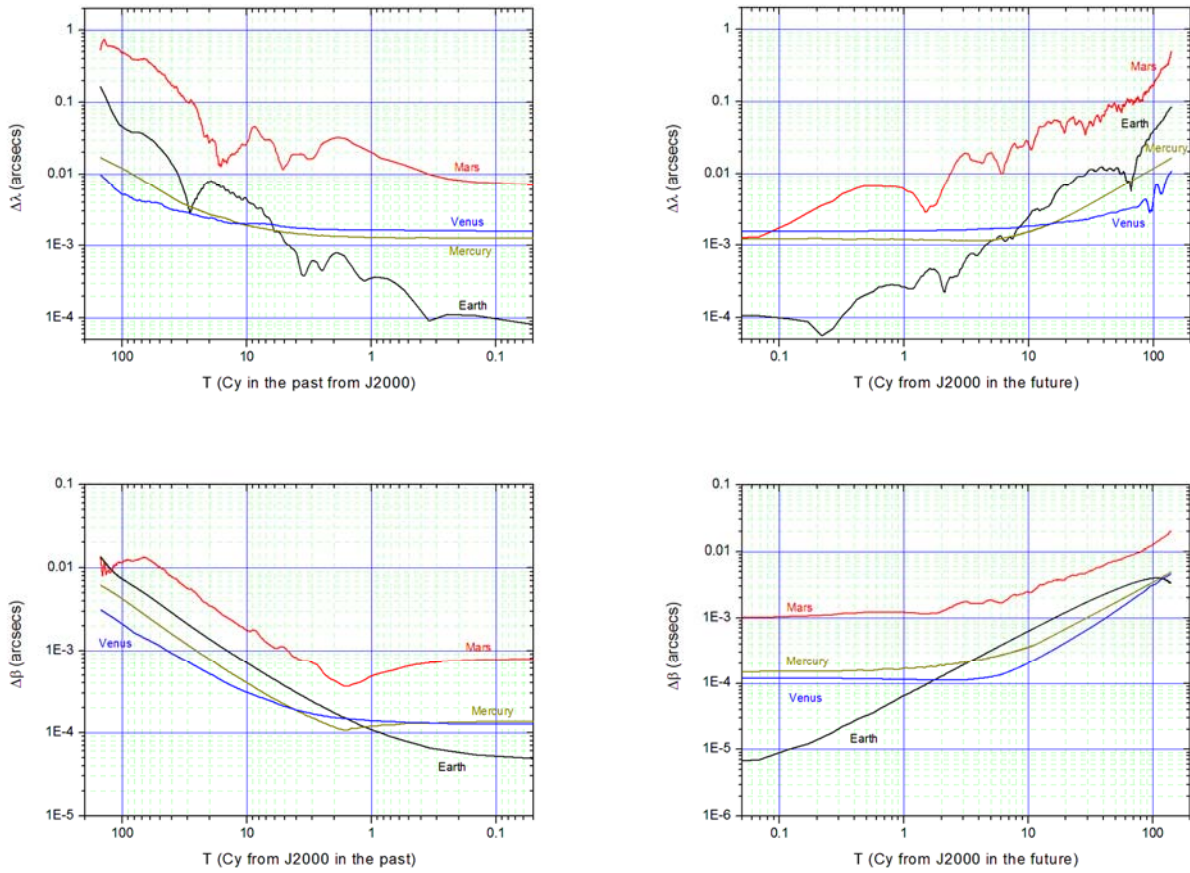


Figure 1. Maximum heliocentric deviations of SOLEX 12 positions from DE431 for the inner planets (DE431L library). The plotted values the maximum deviations within a range of a few years centered on the given epoch.

Figure 2

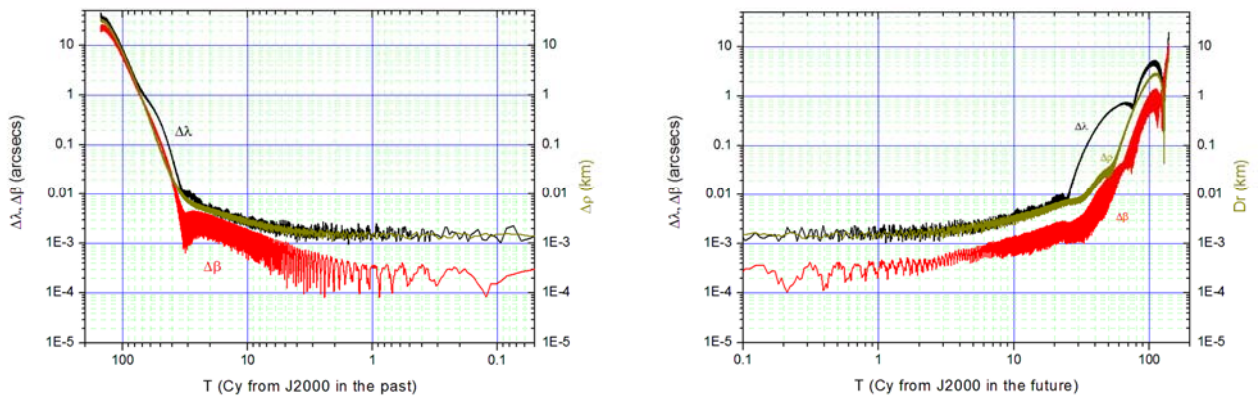
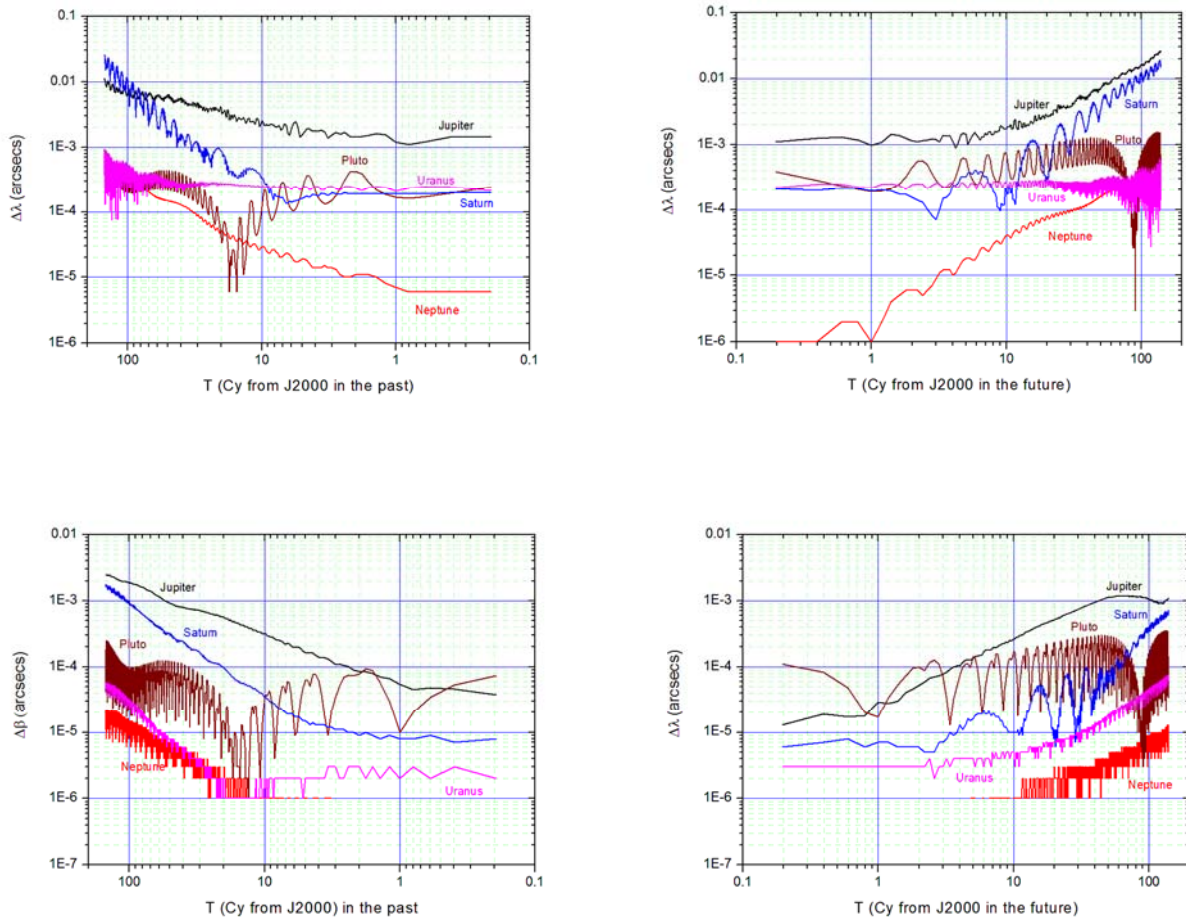


Figure 2. Maximum heliocentric deviations of SOLEX 12 positions from DE431 for the Moon (DE431L library). The plotted values the maximum deviations within a range of a few years centered on the given epoch.



Figure 3.



**Figure 3.** Maximum heliocentric deviations of SOLEX 12 positions from DE431 for the outer planets (DE431L library). The plotted values the maximum deviations within a range of a few years centered on the given epoch.



## Appendix 1. Handling special perturbations.

Normally, the masses of minor bodies (other than the three “big” asteroids Ceres, Pallas and Vesta) are not considered by Solex 10, unless the bodies are introduced via a SLF (or ELE) input file. Therefore, when a number of asteroids is introduced in the system from the asteroid library, they do not perturb themselves and the rest of the Solar system. Neglecting these perturbations usually has very little effects on the orbits of major planets, but it might have a substantial effect on the orbits of some asteroids. Solex 10 allows to take in account the masses of asteroids in two ways:

The first one is to input the asteroids from the library in the first place, and then using the FINAL.SLF file which is automatically generated (rename it to avoid overwriting) to re-input the same data. By this method the masses of *all* the input bodies will be considered.

The second method uses the FINAL.SLX (or SLE) file. If this file is edited (rename it to avoid overwriting), and a negative integer number is appended to it immediately under its last line, then the absolute value of that number will flag to Solex how many bodies of the file should be considered as having mass. Thus for example if the following SLX file is generated after loading the appropriate asteroids from the library and appending the number [-3] under the last line, then when Solex 10 will input data from

```

2452500.5
.00006364 .00020355 5.8 -2.832890E-08 Hygiea
4.3432488173445E+02 2.4532914180919E+02 1.4213982266936E+02
-7.4903604267871E+00 1.2166421688214E+01 4.9689092027218E+00
0 0 0 10
.00001003 .0000999 5.9 -3.722725E-08 Iris
2.7436456450136E+02 -1.5965344513580E+02 -3.7753573050049E+01
6.7856212773915E+00 1.8512333351539E+01 8.3533979419389E+00
0 0 0 7
.00003271 .00016305 6.6 -2.804715E-08 Davida
1.5765750181482E+02 3.5080231315676E+02 7.2016534974159E+01
-1.7948983291830E+01 5.3289245035840E+00 6.9083465689167E+00
0 0 0 511
.00000453 .00007665 6.9 -3.620058E-08 Parthenop
-1.9717026646171E+02 3.2116368659631E+02 1.3546487856060E+02
-1.5390409132668E+01 -7.8068846063993E+00 -1.8758529873682E+00
0 0 0 11
.0000018 .0000564 7.6 -3.805692E-08 Victoria
-3.8456619279099E+02 6.9365826180718E+01 -2.5582298783982E+01
6.6710199637201E-01 -1.6357205578379E+01 -5.4473785055443E+00
0 0 0 12
.00000938 .0001038 7.1 -3.447597E-08 Egeria
1.8918075913591E+02 -2.7937734140384E+02 -2.4657536973895E+02
1.4908480248837E+01 8.0143099318961E+00 2.0918378132882E+00
0 0 0 13
-3

```

this file, the masses of the asteroids Hygiea, Iris and Davida will be considered in all the successive integrations, while those of the remaining ones (Parthenope to Egeria) will not. It should be noted that taking in account minor bodies’ masses can considerably increase the computation time if many new interactions have to be considered. In the above example, taking in account the masses of the first three bodies adds an overhead of 12 more interactions to the “normal” situation in which all minor bodies are treated as massless. **Note: a negative number appended to a SLF file will flag how many bodies *in total* should be considered as having mass. However, as stated before, in absence of an appended negative number SLX files default to all bodies being massless, while SLF files default to all bodies being massive.**

## Appendix 2. Eclipses, occultations and the PATHMAP4 utility.

When a search for occultations is run (section 3.12), information about the path of each occultation (or eclipse) on the Earth's surface are written in the files \*.OCC, which are named after the names or numbers of the occulting bodies. The occulting bodies are assumed to be spherical.

If the search is run in Geocentric coordinates, then all occultations are recorded, no matter if they take place during daylight time. On the other hand, if the search is run in Topocentric coordinates, the recorded occultations are only those taking place during night time (or twilight), within a given angular distance from the main observation site.

In the \*.OCC files, the column headed "Wmin" gives the approximate transverse diameter of the "shadow" in km (if negative, it means that an "annular" eclipse is taking place). The columns headed "HWmin" and "HWmax" give the approximate minimum and maximum half-widths of the "shadow" along its elongation direction. The column headed "Hwerr" gives the estimated transverse uncertainty of the nominal shadow.

The \*.OCC files can be processed by the utility PATHMAP4.EXE, which is enclosed in the SOLEX package, producing a map of the occultation. The map is displayed on screen and written to a BMP file (default name is NONAME.BMP) which can then be read by image processors such as MS Paint and others. PATHMAP4 can also be called from within SOLEX immediately after the completion of the occultation search. PATHMAP4 reads a small configuration file named PATHMAP.CFG, which can be edited using a text editor. To edit it from within the PATHMAP4 program, the MS file EDIT.COM must be in the current directory or addressed by the current PATH. **Note:** the shadow contours plotted in the maps are accurate only in the case of relatively small shadows, such as those given by solar eclipses or asteroidal occultations. In the case of very large shadows (such as those projected by lunar occultations), the contours can be inaccurate, especially when they are close to the polar regions. The data in the .OCC files are nevertheless always reliable.

**Important:** Some image processors fail to open the BMP images created by PATHMAP. If this happens, don't panic. Open the image using MS Paint and save it in some other format (gif, jpg ...). The new image should now be successfully opened by your favourite image processor.

PATHMAP4 uses a small configuration file named PATHMAP4.CFG, located in the subdirectory CFG of the Solex home directory. This file can be edited by any text editor (also from within PATHMAP4) by double-clicking on the option "Change Defaults". An example of the file PATHMAP4.CFG follows:

```
"NONAME"      "Picture FileName"
1280          "Maximum X Width (Pixels)"
1020          "Maximum Y Height (Pixels)"
0.5           "X Border (longitude degrees)"
0.5           "Y Border (latitude degrees)"
16            "Font height (points)"
0             "Text X offset (points)"
-2            "Text Y offset (points)"
1             "Spots to skip"
3             "Unlabeled Spots"
1             "Error Bars (1=yes 0=no)"
1             "Multiple paths (1=yes 0=no)"
0             "Custom Locations (1=yes 0=no)"
0             "Full World map (1=yes 0=no)"
```

In the above file the editable data are in the first column. Although the second column only contains a description of the data in the first column, it must not be deleted and the double quotes are mandatory. Spacing between the two columns is unimportant and free.

**Multiple paths.** Except in the case of Solar eclipses, a single .OCC file is written by Solex 12 for a given couple of bodies. This means that, if many occultations take place between two given bodies during the searched interval of time, the corresponding data are appended to the same file. PATHMAP4 can either display all the data included in the .OCC file in the same image, or display them in successive images, according to the selection made for the corresponding flag in PATHMAP4.CFG.

**Custom Locations.** A file, named SITES.CRD is located in the subdirectory CFG of the Solex100 home directory, containing the geographic coordinates of custom locations can be edited by the user, who can add to it as many locations he wants. A small example is provided (it contains the coordinates of my favourite place in the Alps). The custom locations will be displayed in the maps by activating the corresponding flag in PATHMAP4.CFG.

### Appendix 3. Files written by Solex12

The following is an alphabetic list of the files that are (or might be) written by Solex 12, with a short explanation.

<b>AST.TMP</b>	Orbital elements, in the format of SLE files, written when asteroids are loaded from the library.
<b>CLOSAPP.LST</b>	List of asteroids that were found to give a close approach (spatial or angular) during the most recent search. It can be used to load to Solex the listed bodies, selectively.
<b>COLLIS.LOG</b>	Log file of the detected collisions, written only when the “Trap Collisions” option is ON.
<b>COMET.TMP</b>	Same as AST.TMP, in the case of a comet loaded from the comet library.
<b>ECLIPSES.DAT</b>	Collection of the circumstances resulting in an eclipse or an occultation, found during a search for angular approaches. Same format as MINDIST.DAT.
<b>EJEC????SLF</b>	In the case of long integrations of a N-body system, in which the “trap collision” options has been set ON, ejections from the system are also detected. These files contain the latest recorded state of the system before any ejection of a body.
<b>EJECTED.LOG</b>	Log file of the detected ejections from the system, written only when the “Trap Collisions” option is ON.
<b>ENERMOM.LOG</b>	Log file of the total energy and angular momentum of the system, written at time intervals during a long integration (Jump to Date), if no search for approaches is performed.
<b>FINAL.ELE</b>	Full system status file in form of orbital elements. Overwritten every time the loaded system gets to the target epoch.
<b>FINAL.SLE</b>	Minor body status file in form of orbital elements. Overwritten every time the loaded system gets to the target epoch.
<b>FINAL.SLF</b>	Full system status file in form of status vectors. Overwritten every time the loaded system gets to the target epoch.
<b>FINAL.SLX</b>	Minor body status file in form of status vectors. Overwritten every time the loaded system gets to the target epoch.
<b>FINAL???.SLF</b>	Full system status files in form of status vectors. Sequentially written at time intervals during a long integration (Jump to Date), if no search for approaches is performed.
<b>FINEL.DAT</b>	Orbital elements of the minor bodies (one set each line), overwritten every time the loaded system gets to the target epoch.
<b>FINSTAT.BIN</b>	Full system status files in form of status vectors, in binary format. Overwritten at time intervals during a long integration (Jump to Date), even during a search for spatial approaches.
<b>FINSTAT.SLF</b>	Full system status files in form of status vectors. Overwritten at time intervals during a long integration (Jump to Date), even during a search for spatial approaches
<b>FOUNDAST.LST</b>	List of all the asteroids loaded from the library. It can be used to reload to Solex the listed bodies, selectively.
<b>IMPACT.DAT</b>	List of all the impacts found during a search for close spatial approaches. If the impacted planet is Earth, the geographic coordinates of the impact point are written to the file.
<b>MAXMILAT.DAT</b>	Collection of the circumstances of minimum and maximum latitude (when in ecliptic coordinates) or declination (when in equatorial coordinates) found in the corresponding search.
<b>MAXMILON.DAT</b>	Collection of the circumstances of minimum and maximum longitude (or declination) found during a search for stationary points.

<b>MINDIST.DAT</b>	Collection of the circumstances of minimum (or maximum) spatial or angular distances found during the corresponding search. A search for oppositions, quadratures or maximum elongations also writes data to this file.
<b>MULTCNJ.DAT</b>	Collection of the circumstances of multiple conjunctions found during a search for angular approaches, when the corresponding option is activated. Each line is written at the epoch in which the minimum least squared sum of distances (within the given maximum) is reached.
<b>OSCEL.DAT</b>	Table of orbital elements of the whole system (one line per body) written by the command [M] when the output is in form of orbital elements.
<b>OUTPUT.LOG</b>	Log file of the output screen if the output is redirected to disk (command [F], File output).
<b>SELOCC.DAT</b>	Under topocentric coordinates, collection of the circumstances of the <b>central</b> occultations visible in a region surrounding the observation site. Same format as MINDIST.DAT and ECLIPSES.DAT.
<b>TOPOCECL.DAT</b>	Same as ECLIPSES.DAT, written when topocentric coordinates are active. Eclipses not actually visible at the site are also recorded to this file.
<b>WARNING.DAT</b>	Contains lines belonging to MINDIST.DAT which might occasionally be inaccurate due to an exceptionally fast motion of one body.
<b>ZEROLAT.DAT</b>	Collection of the circumstances of zero latitude or right ascension found during the corresponding search.
<b>*.OCC</b>	Files containing a table of the local circumstances of a central eclipse or occultation, found during a corresponding search. The files can be read by the utility PATHMAP4.EXE to produce a map of the eclipse/occultation path on the Earth surface.
<b>*.OUT</b>	Files written (one for each body) when the screen output is redirected to disk.