SatCal 11.1 Tutorial

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This tutorial assumes that you have set up SatCal Version 11.1 according to the instructions of the README file. So there should be a directory SatCal with the four sample TLE files `visual.txt`, `iridium.txt`, `classfd.tle` and `hist.tle` and with the executable and auxilliary files in a subdirectory `bin`. You also should have set up your observer's location.

It is recommended that you perform this tutorial step by step in the sequence given here. It is probably a good idea to print out the few pages and have the pages next to you while doing this tutorial.

NOTE: When you press a particular key (like D for the Date dialog) you may do so in upper or lower case. If nothing happens in this case try pressing <crtl> + the key in question. This should clear up the problem. (The recommended procedure is to always use the <crtl> + key combination but most of us are lazy and the shortcut usually works.)

1 Real time position of satellites and times of passes.

First let's see where the ISS and ENVISAT are right now and when it would be possible to see them. The orbit elements of both satellites are on visual.txt. Unless you have updated this file recently the orbit elements will probably be out of date, particularly for the ISS which performs maneuvers every now and then but for this demonstration we don't care.

Select the TLE file by File, Open TLE file or click the leftmost icon or press F. Select the file visual.txt from the SatCal directory (if upon starting SatCal a message Selected TLE file visual.txt appears you can skip this step). Select the satellites via Input, Select Satellite (or click the respective icon or press S). Enter iss as satellite name, click Find. Information about the found ISS orbit elements should appear in the field of the right side in the dialog. Click Select. Repeat the Find and Select procedure with Envisat (it's enough to search for env as SatCal will try to find all satellites which match these initial letters).

Select Plot, Real Time or click the real time icon or press R. A world map will appear with the current positions of the two satellites. Data of the first satellite (e.g. the ISS) are displayed below the map. To show the data for the second satellite (e.g. Envisat) press 2. Select View, Show Names or press N. The names of the satellites are now displayed on the map next to their positions. Moving the mouse to a particular position on the map and clicking with the right mouse button (or with the left if the left button was enabled via View, Enable Left Button) will show the coordinates of the respective map position and the azimuth and elevation of the various satellites with respect to that position. This helps to quickly check the visibility conditions for sites other than the set observer's location.

Select Plot, Next Pass or press the Page Down key. The plot should jump to the next time the selected satellite (in this case Envisat) is visible from the set observer's location. If no suitable pass was found over the next three days a respective message will be displayed. Select View, Visibility or click the respective icon or press V. The Visibility dialog is central to what SatCal does. Change the parameter Max.Sun Elevation which was probably set to -6 to +90. This means you allow daytime passes also. You wouldn't be able to visually observe a daytime pass of Envisat but for the sake of this tutorial this will ensure that you do get passes when you issue the Next Pass command. Press the right or left cursor key to move the satellite forward or backward along its track.

To show how the satellite moves across the sky select View, Map View / Sky Map or click the respective icon or press `Y`. Mark the `Sky Map` checkbox. Moving via the right and left cursor key now lets you see how the satellite is viewed from the set observer's location. If the pre-selected step width of 15 sec is too large select `View`, `Time Step` or press `T` and change the step correspondingly. If the satellite moves into Earth shadow during the pass it will disappear from the sky map if the parameter `Visual Passes Only` was selected in the Visibility dialog (this is the default). To get an idea how bright the satellite might appear select `View`, `Magnitude` or press `M`. Specify a value of `2.5` in case of Envisat or of `15` in case of the ISS. The calculated magnitude will then be displayed as the lower right parameter. Moving the mouse to a particular position on the map and clicking the right mouse button will show you the coordinates of the corresponding position in the sky and its angular distance to the satellite. This is particulary useful if you want to know how far from a star (or planet) the satellite will pass.

Now select `Calculate`, `AOS` or click the respective icon or press `A`. A list of the passes during the selected time period is displayed. Given are the beginning, the maximum and the end of the pass (in line with the currently selected visibilty settings). Clicking with the mouse on a particular line will display a more detailed listing of the pass which has its special uses but you normally would prefer to work interactively by moving across the map to get these details step by step. Usually the summary table is enough.

Let's finish this first example by leaving SatCal via `File`, `Exit`. This will save the file and satellite names selected for the following example.

NOTE: Under Windows the timezone may be set wrongly by one hour during summer (daylight savings) time. If this occurs you will have to set the timezone manually (select `Input`, then `Date/Time` or click the respective icon or press the `D` key). If you leave SatCal via `File`, `Exit` this timezone will be saved. If you want to use SatCal in real/time mode this real/time will be wrong however by one hour. In this case set the parameter `R/T Offset` to -1 to remedy the situation. (This parameter will not be saved and has to be reset on a subsequent startup). No such problems have occurred under Linux.

2 Iridium Flares and Next Satellites to Pass.

Start SatCal. If you just performed the example above, the ISS and ENVISAT should have been already selected. If you press `R` the map with the real time positions of these two satellites will show up. Now let's check for Iridium flares. Select `Calculate`, `Iridium Flares` or simply press the icon with the flash on it. Leave the default for the limiting magnitude (1 mag). Even though our currently selected TLE file is still `visual.txt` SatCal will look for the file `iridium.txt` and use this file for the Iridium flare calculation. Afterwards it switches back to the original `visual.txt` file. A list of Iridium flares for the next three days should appear on the screen. The same list will also be written to the file `iridiumf.doc`. Depending on the time of year and your very location there may not be any suitable flares. In this case try daytime passes also by selecting `View`, `Visibility` and specifying a Max.SunElevation of `90`. (You could also try a different location. Equatorial sites seem to be at a disadvantage over higher latitudes.) The list gives the date and time of the flares, azimuth and elevation which antenna was responsible for the flare (left, right, front or solar panel), whether the satellite moves toward the North or toward the South and the expected magnitude and the name of the satellite.

If you press `R` again for the real time map you will see that the listed Iridium satellites have been added (up to the maximum number of 10 satellites which the display allows). Let's see where in the sky the flare happens and how the lightcurve looks like. Press `X` (or select `View`, `Show Last Text`) to see the list again. Pick a particular flare event. To select the respective satellite press `W` (or select `View`, `Switch`) then mark the satellite. Set the date and time to that of the flare event by pressing `D` (or select `Input`, `Date`). Select `View`, `Magnitude` (or press `M`). Specify a `Characteristic length` of `0.3` or so. Press `T` (or select `View`, `Time Step`) and specify a time step of `1` sec or even `0.1` sec. Press `V` (or select `View`, `Visibility`) and mark the `Iridium Flares` checkbox. Finally, press `Y` (or select `View`, `Map View / Sky Map`. If you now move the Iridium satellite forward or backward with the right or left cursor key you will see the magnitude displayed at the lower right and of course the position of the satellite in the sky. This allows you to preview how the flare moves across the sky.

Now let's check what bright satellites to expect next at our observation site. Press `Y` (or click the respective icon or select `View`, `Visibility`). Unmark the `Iridium Flares` checkbox. If you run this tutorial around (evening) twilight set the Max.Sun Elevation to something like `-6`. If it's plain daylight set it to `90` instead. If it's deep in the night you might want to unmark the `Visible Passes Only` checkbox. (You normally leave this box checked as you are only interested in satellites which are illuminated by the Sun. Also you would expect the Sun to be below the horizon at your observer's site. These special settings are just to let you perform this tutorial even when doing it at an unfavourable time. Alternatively you could offset the real time clock to a suitable time after sunset via `Input`, `Date` and then set `R/T Offset` to the number of hours needed to get from your present time to the time after sunset.)You could also change the magitude parameter (press `M`) to `1.0` (this is a good value for brighter satellites if you don't know any better). Now select `Input`, `Next Satellites` (or click the respective icon). SatCal will now check the currently selected TLE file (which should be `visual.txt`) for any satellites which will pass your observing location over the next two hours and which conform to the set visibility conditions. The real time plot will be started. If more than 10 satellites are found only the next 10 satellites will be displayed. If you had selelected the sky map it may take a few minutes before the first such satellites appears. You could select the world map instead to see how all those satellites are closing in on you. To see the information for the respective satellite press `W` for the Switch selection like you have done in the Iridium example. This time let's leave SatCal not by `File`, `Exit` but rather by clicking the upper right corner of the SatCal window to close this window. In this case the current settings will not be saved (otherwise SatCal would try to load the 10 satellites just found next time it is started but we are probably not interested in them at that time).

3 Identifying Satellites.

Let's find out which Iridium Satellites are above your observing site at this very moment. Start SatCal. Select `File`, `Open TLE File` (or press `F` or click the file open icon). Select the file `iridium.txt`. Next click the `Visibility` icon (or press `V`) and set `Max.Sun Elevation` to `90`, `Min.Sat.Elevation` to `0` and unmark the `Visible Passes Only` checkbox if it is night time. Now select `Calculate`, `Find Matching Sats` (or click the respective icon). Enter the current time in the Date dialog. In the `Find Matching Satellites` dialog unmark the `Position as R.A./Dec.` checkbox. Set the azimuth `0` and the declination `90` to specify the zenith. Set `Max.Distance` to `90` (so that SatCal will accept all satellites which are within 90° of the zenith - e.g. all satellites above the horizon). Leave the Time Interval at 1 min. Click `OK`. A list of Iridium satellites which are above the horizon at the time appears. Press `Y` or click the `MapView/Sky Map` icon and select Sky Map then press `N` (if you haven't done it before) to see where these satellites are in the sky (up to 10 satellites can be selected and shown on the map).

The procedure you just performed is actually ment to identify satellites you observed. If you saw a bright satellite and want to know which one it was you could thus specify the time and direction in the sky where you saw the satellite. The time interval and the angular distance around which you want to check will be set appropriately. Unlike in our example the visibility settings would typically call for a `Max.Sun Elevation` of `-6` or so and `Min.Sat.Elevation` of `10` or 20 and the `Visible Passes Only` checkbox would be marked. For bright satellites the TLE file `visual.txt` might be helpful. But keep in mind that there are many (also bright) satellites up there which are not listed on this file. In order to find a match you should use a file containing several thousand objects like `ALL_TLE`.

Leave SatCal by clicking the upper right corner of the SatCal window.

4 Satellite Transits in Front of the Sun.

Start SatCal. The ISS and ENVISAT may already have been selected otherwise select these two satellites from the `visual.txt` file. Press `V` for the Visibility dialog (or click the Visibility icon). Mark the `Occulation/Transit` checkbox. Now press `D` (or select `Input`, `Date`) and set the duration to `0.5` days. Now select `Plot`, `Delta Time`. Instead of the usual groundtrack you will now find the positions from where the two satellites can be seen to transit in front of the Sun. The middle column below the map now shows the respective (observer's) coordinates. Note that there are gaps without transits - when the satellite is over the night side of the Earth.

Press `D` again and set the duration to `30` days. Now select `Calculate`, `AOS` (or click the respective icon). SatCal will now check whether there is any transit of the currently selected satellite close to your observer's site (how close is up to you - typically the default of 50km is reasonable). If you don't find suitable passes for the ISS try Envisat. If that doesn't work either try a different month (maybe a few months later). If you do get events the time, azimuth and elevation, your distance to the center line (where a central transit can be observed), the width of the zone around the central line where a transit can be observed, the duration of the event and the direction how the satellite moves across the Sun's disk will be listed. In order to see a transit your distance from the center line has to be within the given interval. If your observer's site is within this zone you could press `D` again and specify the exact date and time given in the list. Also mark the `Sun/Moon Plot` checkbox in the Visibility dialog. Press `T` and specify a time step of `0.1` sec. Press the right or left cursor key to follow the transit across the Sun.

Now let's check which satellites from the `visual.txt` file transit the Sun over the next day as seen from your observer's site. Press `D` and set the date correspondingly. Set the time to about sunrise and the duration long enough to last until sunset (but less than 1 day). Now select `Calculate`, `All Satellite Passes`. Specify a maximumn distance of 0 km to get only passes you can see directly from your site. You might have to be a bit patient depending on the speed of your computer. A list of suitable satellites will be written on the file `satsave.txt`. Also the respective satellites (up to 10) will have been selected. Via `View`, `Switch` you can check the selected satellites. Switch to one you are interested in and click the `AOS` icon to get the specific times for that satellite listed again. If you didn't find any suitable satellite pass try another day. Typically there is a good chance to see some satellite transits from your site within a period of a week or so (at least in theory - the ISS is easy to watch but many of the other satellites are just tiny dots in front of the Sun and you might easily miss them).

Analogously you can check for transits in front of the Moon.

Leave SatCal by clicking the upper right corner of the SatCal window.

5 Calculating Launch Orbits.

Start SatCal. If the ISS and/or ENVISAT have been automatically selected before we want to delete them as we are planning to do something quite different now. Press `Z` or select `Input`, `Remove Satellites`, then mark all satellites for removal. (An alternative way is to press `S` for the Select Satellites dialog and then click the `New Set` button and then leave the dialog.)

Let's assume the Chinese want to launch a manned spacecraft on 12-OCT-2005 at 9:00 Beijing time. Will you be able to visually observe it over the next day or so? Typically it is going to take a few hours after the launch until first orbit elements become available via the Internet. But with SatCal you can calculate an approximate orbit which would be good enough for the first day or so to find the spacecraft in the sky. We assume the new flight will follow the profile of former flights: First a launch orbit with perigee 195 km, apogee 332 km and inclination of 42.4°. About seven hours after launch the spacecraft will circularize the orbit at 332 km.

Select `Maneuver`, `Launch`. In the Date dialog set the planned launch date (remember to unmark the `Use System Timezone` checkbox and to enter `+8` as the timezone (for Beijing time). Click `OK` to leave the Date dialog. Now the `Edit Orbit Elements` dialog appears. Enter a satellite name (`Shen Zhou 6`), the inclination (`42.4`), mark the `Perigee/Apogee` checkbox and enter the values for perigee (`195`) and apogee (`332`) [1]. The rest of the orbit elements will be calculated by SatCal. Click `OK` to leave this dialog. Now comes the Launch dialog. From the list of launch sites select `Jiuquan`. The launch could be toward the North or toward the South. As a general rule you try to avoid populated areas during the ascent. If you try the launch toward the North with our specified 42° inclination you will see that the trajectory passes over Japan which might cause diplomatic problems. So mark `South` for the launch azimuth. Click `OK` to leave the dialog. A confirmation message appears giving you the actual launch azimuth. You could now check the visibility by clicking the `AOS` icon or following the groundtrack on the world map like we have done it in the first example. (Setting the `t-cutoff` parameter to `8.9` would have resulted in an even better orbit as a check with the actual TLE's showed after the launch.)

We can even perform the orbit adjustment after seven hours. Select `Maneuver`, `Delta-V`. As time for the maneuver specify 16:00 on 12-OCT-05 (still on Beijing time). Next you could actually specify the increment in speed of the maneuver if we knew it. But instead we click `OK` to leave this dialog (thus having performed a null maneuver). The purpose of this exercise has been to change the epoch of the orbit elements to the specified maneuver time. When we now go into the `Edit Orbit Elements` dialog (`Maneuver`, `Edit Orbit Elements`) all we have to do is change the Perigee height to `332` and we're done. Once again we can check for visibility (we could have changed our timezone back to our local time to have more familiar data). Using this simplified method you probably find the calculation to be within a few minutes of the actual orbit. (As it turned out the difference with the actual data 24 hours after the maneuver was 2 minutes.)

As a bonus let's try to deorbit the spacecraft after one day (the actual flight lasted 5 days). If you have performed the example just as stated above you will find that at 5:36 Beijing time on 13-OCT-05 the spacecraft is close to the South-West African coast (within range of the Swakopmund groundstation). Move to that position. Select `Maneuver`, `Edit Orbit Elements`. Mark the `Numeric Prop` checkbox as this can only be handled by numeric integration. Click `State Vec` and change the `Area/Mass` field to `1.0` and the `Drag Coefficient`

[1] SatCal assumes that the flight angle at insertion is 0° so that perigee is at that moment. For some launches the flight angle at insertion is a few degrees (some 4° for Shuttle launches I think) which results in perigee being extended backward. In these cases you might get better results by assuming a circular orbit of some mean hight.

to `1.0` (In orbit a drag coefficient of 2.0 or more is typical. But while in the dense atmosphere below 90 km a coefficient of 1.0 would be better.) Unmark the `Reset Current State Vector` checkbox (this will save us time as otherwise the calculation would be repeated numerically from the set epoch). Leave the State Vector and the Edit Orbit Elements dialogs. Select `Maneuver, Delta-V`. As time for the maneuver specify 5:36 on 13-OCT-05 (still on Beijing time). Specify a `Delta-V` of `-110` meters/sec. You can now follow the de-orbit over the next 36 minutes until the spacecraft hits the ground in Northern China. (It would actually take some 10 minutes or so longer as a parachute will be deployed at an altitude of 10 km and from then on descent very slowly but the position would not change much anymore.)

As a second example let's assume we learn that the European ATV supply satellite is going to be launched from Kourou on 15-FEB-2006 and will dock with the ISS two days later. (The first ATV flight actually flew in 2008 and tool longer to finally dock with the ISS to to in-orbit tests.) We would probably learn about the exact launch time in advance given the popularity of the ISS but SatCal can calculate an approximate launch time on its own.

Press `S` or click the `Select Satellite` icon. Press the `New Set` button and then select the `ISS` (assuming that `visual.txt` is the current TLE file). Leave the dialog. Now select `Maneuver, Rendezvous`. Leave the `Time until close approach` as is (`1.30` - this time should be a little less than the forseen period until docking). In the Date dialog specifiy the date as 15-FEB-2006 and a time of 12:00 (let's set the timezone back to 0 or something like that - we are no longer on Beijing time). In the `Edit Orbit Elements` dialog which follows change the name to `ATV`. Mark the `Perigee/Apogee` checkbox and specify values of `220` km for both the perigee or apogee. This height is a first guess. Typically you want to specify a height which allows the ATV to catch up with the ISS after a day and a half or so. You might need a few iterations. But for the first few hours of the flight the height is not so critical if all you want to do is to check for visibility conditions. Click `OK` to leave the dialog. Now comes the Launch dialog. Select `Kourou` as the launch site (and launch azimuth toward the `North`). You will get a confirmation with the expected launch time and you can now follow the groundtrack of both the ATV and the ISS. If the ISS orbit elements you used are old (with respect to the planned launch date) the calculated launch time would be off too otherwise it should be within a few minutes of the actual launch. If you wanted to repeat the calculation to check other heights for instance you first have to reset the ISS as the prime satellite then proceed again.

Our third example shows a more complex launch trajectory. The ALOS (Daichi) spacecraft was launched into a sun-synchronous orbit (697 x 698 km, 98.22°) from Tanegashima, Japan, on 24-JAN-2006 at 10:33 local time. The problem with this launch is that due to range safety you cannot launch directly from that launch site into the intended 98° orbit. The actual launch first moves toward the South-East (launch azimuth 115°) and only when well out over the ocean it will arc South toward the correct orbit (this costs more fuel). SatCal assumes a direct launch so we have to improvise.

Select `Maneuver`, `Launch`. In the Date dialog set the planned launch date (remember to unmark the `Use System Timezone` checkbox and to enter `+9` as the timezone (for Japan time). For the launch time enter `10:36` rather than the correct 10:33 to allow for the extra time the arcing trajectory takes compared to a direct insertion. Click `OK` to leave the Date dialog. Now the `Edit Orbit Elements` dialog appears. Enter a satellite name (`ALOS`), the inclination (`98.22`), mark the `Perigee/Apogee` checkbox and enter the values for perigee (`697`) and apogee (`698`). The rest of the orbit elements will be calculated by SatCal. Click `OK` to leave this dialog. Now comes the Launch dialog. From the list of launch sites select `Tanegashima`. The latitude and longitude of the launch site will be shown. We keep the latitude (`30.38`) but to model the arcing launch trajectory we shift the longitude 5° to the East. In the list of launch sites go to the top and select `User`. You can now edit the longitude and change it to `135.97`. Mark `South` for the launch azimuth. Set the `t-cutoff` parameter to `14.` Click `OK` to leave the dialog. A confirmation message appears giving you the (ficticious, incorrect) launch azimuth. (A comparison with the actual orbit showed this rather crude method to have deviated less than 40 km over the first few orbits.)

6 Hubble Space Telescope Flares

Let us assume that the Hubble Space Telescope (HST) points toward the (center of the) Andromeda nebula (M31) at a particular time[2]. Would there be any flares visible from the rear surface (the "Aft Skirt") of the HST?

Start SatCal. The TLE's of the HST are on `visual.txt`. Select the HST via `Input`, `Select Satellite`, `HST`. (For this example you could actually select any satellite you want and simply pretend it's the Hubble - we are not concerned with an actually observed situation.) Now select `View`, `Visibility` for the Visibility Settings dialog. Mark the `Flares` checkbox und UNMARK the `Local Attitude` checkbox as we are dealing with inertial attitudes here (attitudes with regard to the fixed sky). The coordinates of M31 would be Right Ascension 0h43m and Declination 41°18′. The surface of the rear surface would be pointing in the opposite direction, so enter `12.43` in the `R.A.` field and `-41.18` in the `Dec.` field. You would also have to set the correct time via the Date/Time dialog but for this exercise let's just assume that whatever time is just set is the right one even though it may not be possible for the HST to point toward M31 at the time due to various restrictions. Switch to the Map display if you haven't done so already (`View`, `Refresh`) and use the left or right arrow key to move forward or backward in time. In the middle column under the map you would now see the coordinates of the place where a flare from the Aft Skirt of the HST would be visible at the very time. More often you will probably find the words `No Intersection` which would mean that there would be no flare visible at that time (in that case try some different coordinates just for this exercise

[2]The timeline of the Hubble Space Telescope can be found on `www.stsci.edu/observing/weekly_timeline.html`.

- make sure that the text in the middle column is not in black as the satellite would not be illuminated at that time). If flares are happening you would also see their position on the map.

SatCal also lets you check whether there is a brightening (if not an outright flare) from the cylindrical surface of the HST. To do so unmark the `Known Surface` checkbox in the Visibility dialog and mark the checkbox labeled `Cylindrical Flares.` The `R.A.` field and the `Dec.` field should already contain the pointing direction (or rather the opposite direction) of the HST. If you now step through a satellite pass you will see the flare angles needed for a perfect specular flare (with regard to the set observer's location) displayed below the map but in addition the angle between the specified pointing direction and that flare ange is displayed in the final column (at the lower right) as `CylAng`. If this number is close to 90° you might expect a flare.

You could also try the opposite problem: Assume you have seen a flare what was the HST pointing at? For this you would have to unmark the `Known Surface` checkbox in the Visibility dialog. In this case the coordinates of the point in the sky where the flare surface was pointing at would be displayed in the middle column under the world map. If this surface was the Aft Skirt then the opposite direction in the sky would have been the respective HST target. Most observed HST flares seem to come from the cylindrical sides of the satellite rather than the rear surface, however, in which case the actual pointing would be different.

7 Geostationary Flares and Solar Eclipses.

At certain times of the year (typically in the weeks around equinox) geostationary satellites show flares from their solar panels just before entering or just after leaving Earth shadow. The days when to expect this depend on the geographic latitude. An example is given how to check this with SatCal.

Start SatCal. Select `Input`, `Location` and specify a latitude of `50` and a longitude of `9`. (Normally you would use your own observer's coordinates - but this way we can follow a common example.) Now select `Maneuver`, `Edit Orbit Elements` or press `E`. Specify any name you like for the satellite. Click `Edit Time` and enter as date 8-APR-2005. Click the `GEO` button and enter `60.0` as the geostationary longitude. SatCal now generates orbit elements for a geostationary satellite at 60° East with an epoch of 8-APR-2005. Leave the dialog. Press `D` for the Date dialog. Specify again 8-APR-2005 as the date and a time of 19:15 UT (unmark the `Use System Timezone` checkbox and set the timezone to `0`). Now press `V` or select `View`, `Visibility`. In the Visibility dialog mark the `Flares` checkbox and UNMARK the `Known Surface` and `Local Attitude` checkboxes. Mark the `Solar Panel Flares` checkbox which has now appeared[3]. Leave this dialog and select the sky map (`View`, `Map View`, `Sky Map`, mark the `Sky Map` checkbox. Now press the right cursor key to move forward in time. In the middle column under the map an entry `Solar Panel`

[3]This is one of the few cases where SatCal operations appear less logical. The reason it was done this way has to do with the internal way flares are handled within SatCal. Sorry.

appears and an angle is given. This angle is the difference between the normal direction of the solar panel (which is assumed to point to the Sun) and the ideal direction needed to cause a flare. The smaller the angle the larger the flare. You will see that this angle decreases until at 19:44 the satellite disappears into the Earth shadow. The minutes before that you could expect a flare from a satellite stationed at 60° East. If you have a TLE file of geostationary satellites (`geo.txt` at the Celestrak site) you could now check for actual satellites stationed close to this position: Noting the Azimuth and Elevation of our hypothetical satellite you could search for those actual satellites via the `Calculate`, `Find Matching Sats` option as explained in example 3 above. You could then check the exact flare times for each of the matches.

Next we want to check for solar eclipses at the position of geostationary satellites. Viewed from the ground you would see a corresponding dimming of the satellite. These eclipses happen at times when there are solar eclipses on Earth but also on the New Moons before and after those dates. You could use SatCal all by itself to find out about those eclipses by checking various geostationary satellite positions for the day around a suitable New Moon and once you found an event trying to zero in to the best time and position by trial and error. Given the speed of today's computers this is not as bad as it sounds. But if you want to do it more elegantly there's LunaCal which is also open source freeware and is kind of SatCal's little brother. If you have it start LunaCal (version 4.1 or later), then `Calculate`, `Special Eclipses` and set 8-APR-2005 as the date. You will get a world map with the central line of a solar eclipse projected onto the geostationary sphere. Whereever this line crosses the equator would be the best place and time to check for geostationary eclipses. Using the right and left cursor you can move along the line just like you move satellites along in SatCal. Check the positions below the map (there are usually two intersections, one at the Sun-facing side and one over the night side). You will find that at 0:57:15 UT there will be an annular eclipse at geostationary longitude 34.1° West. Now let's return to SatCal. Press `D` and set the date to 9-APR-2005 and the time to 0:57 UT. Press `E` or select `Calculate`, `Edit Orbit Elements`. Click the `GEO` button and enter `-34.1` as longitude. Next press `V` or select `View`, `Visibility` and mark the `Solar Eclipse Check` checkbox. Returning to the world map or the sky map you will now find the middle column indicating an annular eclipse. Also given is the apparent angle between the Sun and the Moon as viewed from the satellite. Moving forward or backward in time you can see the annular eclipse changing into a partial one and then into no eclipse. Press `M` or select `View`, `Magnitude` and specify something like `1` or `1.5` as `Characteristic length`. SatCal will now display the apparent magnitude of the satellite taking into account the eclipse. Note that in this case what is displayed below the Sun/Moon Angle is now the relative sunshine as a percentage of the (non-eclipsed) sunlight. This would correspond to the power available from solar panels during an eclipse. Like in the above example with the flares you could now check for actual satellites close to this position.

8 Rosetta Earth Flyby #1.

On 4-MAR-2005 the European Rosetta spacecraft passed the Earth on its first (of several) gravity assist maneuver and was actually observed during that time over a number of days even with amateur equipment. Let's see how to calculate this event with SatCal. To do this you need hyperbolic orbit elements or an osculating state vector which you might find on the web. In this case the following state vector was found somewhere:

```
   Epoch 4-MAR-2005, 22:09:28 UT
   7.265466667995e+03 2.898317181712e+03 2.877472417751e+03 (position,
km)
   5.047433653203e+00 -7.859036607166e+00 -4.828536339841e+00 (velocity,
km/s)
   (Mean Equator and Equinox of Date)
```

Start SatCal. If you are too lazy to enter the above numbers you could select `hist.tle` as TLE file, then select `Rosetta`. But here's how it would have to be done from scratch: Press `E` or select `Maneuver, Edit Orbit Elements`. The satellite name to enter would be `Rosetta`. Click `State Vector.` Click `Edit Time` and enter the given epoch. (Note that this time will always be taken as Universal Time no matter what timezone you have specified otherwise). Now enter the respective numbers for position and velocity. (Make sure the button Mean Equator of Date is marked in the State Vector dialog.) Leave the State Vector and the Edit Orbit Elements dialog. You can now follow the groundtrack on the world map or the track along the sky on the sky map. For most of the time Rosetta moves rather slowly. You could use a time step of 5 min or so. Only close to perigee which happened at 22:09:30 UT 4-APR-2005 will it be fast. To get an idea of the apparent magnitude to expect press `M` or select `View, Magnitude` and set the `Characteristic length` to `1` or so. On the days leading up to perigee the solar panels of Rosetta were pointing very closely to the direction needed for flares so that the actually observed brightness was more than would have been expected otherwise. Press `V` or select `View, Visibility`. Mark the `Flares` checkbox, unmark the `Known Surface` and the `Local Attitude` checkboxes and mark the now appearing `Solar Panel Flares` checkbox. You will find that the `Flare Angle` as indicated in the middle column under the map will be close to 2° or better until a few hours before perigee which caused a marked increase in brighness.

The way we just handled the problem was to enter a state vector but to use an undisturbed analytic Keplerian orbit calculation. This gives a good result close to epoch. But if you have a state vector to start with you can use SatCal's numeric propagation model to get more accurate results. The only difference to the procedure just mentioned is that you have to mark the `Numeric Prop` checkbox in the Edit Orbit Elements dialog before entering the State Vector dialog. That's all. (There are a few more parameters appearing in the State Vector dialog now but you can work with the defaults in this case as most of the parameters deal with calculating atmospheric density and Rosetta didn't come close enough to the surface to be affected by that.) Comparing the two calculations you would find that after a few hours they start diverging mostly due to the influence of the gravity of the Sun and Moon.

9 Online Update of TLE files.

Before our final example let's update our TLE files. Hopefully by the time you read this tutorial the Celestrak.com site is still active. You will have to be logged in to the Internet, of course. Just to make sure we have the file `visual.txt` currently selected press `F` or select `File`, `Open TLE File`. Select `visual.txt` if it hasn't been selected yet. Updating this file is very easy: Just select `File`, then `Online TLE Update`. The respective web address should have been filled out already and you can press OK to perform the update. After the update is finished you will get a confirmation. Let's also update the file `iridium.txt`. Select `File`, `Open TLE File` and select `iridium.txt`. Then select `File`, `Online TLE Update` again and press `OK` as the URL is already set. That's it.[4]

In the course of this tutorial we might have changed a few parameters to what you normally don't want them to be. Let's just make sure we are back in a standard configuration. Select `Input`, `Date` and mark the `Use System Timezone` if you want this. Select `Input`, `Location` and make sure that the coordinates of the observer's location is what you want them to be. Finally, select `View`, `Visibility`. You probably want `Max.Sun Elevation` to something like `-6`, `Min.Sat.Elevation` to `10` or `20`, have the `Visible Passes Only` checkbox marked but all other checkboxes unmarked. Click `OK`. Then select `File`, `Exit` to have this state placed on the configuration file. This is what you will start up with on your next SatCal run.

10 Flying to the Moon with Solar Electric Propulsion .

You may already have done two examples of how to use SatCal's numeric orbit propagation model (the Shen Zhou deorbit and the Rosetta exercise). Here is another example. The European Smart-1 spacecraft flew to the Moon using a solar electric ion engine. To save money it was launched as a secondary payload with an Ariane 5 into a Geostationary Transfer Orbit (GTO). From there it used its solar electric propulsion to get to the Moon. Let us model the first month of the orbit of Smart-1 in a very simplified way. The actual flight was much more complicated of course with first a thorough check out and

[4]If you are connected to the Internet via a proxy server these automatic updates from SatCal might not work. In this case you will have to use your internet browser, go to the URL address `www.celestrak.com/NORAD/elements` then select `100 brightest` and `Iridium` respectively.

then using the ion engine at different power levels and turning it on and off during certain periods to maximize fuel efficiency and also for phasing with the Moon. But at the beginning the strategy was to raise the perigee quickly to move Smart-1 out of the radiation belts and to this end the ion engine was left running almost continously. This is what we are trying to simulate here.

Let's start by creating a GTO. Select `Maneuver, Launch`. Just leave the date as is because we don't want to recreate the actual mission. We are just interested in the principle. In the Edit Orbit Elements dialog enter whatever name you like. Mark the `Numeric Prop` checkbox. Enter an Inclination of `7.0`, a Perigee of `500` and an Apogee of `35800`. Select `Kourou` as the launch site. You could mark `South` as the launch azimuth as this is what GTO launches out of Kourou seem to be but this is not important here. Let's assume that we start the ion engine right away. Select `Maneuver, Delta-V`. Leave the time as is. Once in the Delta-V dialog mark the `Continuous Thrust` checkbox. You will now find that the uppermost field has changed its label to `Acceleration (mm/s^2)`. Enter `0.2` into this field. There are also two new checkboxes now. Leave the `Sunshine required` checkbox marked because the Smart-1 ion engine needed sunlight for its solar panel in order to operate its ion engine. Also mark the `Update Epoch State` checkbox. This will make it easier to follow our progress as we can then check the osculating Kepler elements via the Edit Orbit Elements dialog. Click `Execute` to leave the dialog. Next press `T` or select `View, Time Step`. Enter a time step of 10 minutes. Now press `D` or select `Input, Date/Time` and change the `duration` to `30` days as we want to follow Smart-1 over one month. Now select `Plot, Delta Time` and let the simulation run for a month which shouldn't take too much of your computer time. To check the result press `E` or select `Maneuver, Edit Orbit Elements`. You should find something like 4150 km as perigee and 43700 km as apogee. The actual values will differ depending on your start time because this would determine the eclipse periods when Smart-1 was in shadow and the solar electric propulsion was halted. The important point is that the perigee has increased substantially during this first month of operations. Archeoastronomy with SatCal .

11 Astrometry with SatCal .

To do this example properly you would need a picture of the sky with a satellite trail on it. If you don't have that simply use any picture you like (maybe some flowers or a picture of yourself) and pretend that it shows a portion of the sky. This way you can see how in principle the astrometry feature of SatCal works.

Select `File`, then `Picture` to enter the Open Picture dialog. Choose a suitable image file. The picture will now be displayed instead of the usual world map or sky map. If the picture is too large try selecting `View`, then `Set Picture Size 50%` or `Set Picture Size 25%` . Now click with the mouse on three stars (or on three different positions in the picture pretending these are stars). You will be asked to enter the respective star coordinates in Right Ascension and Declination. If you have a proper sky picture you can supply the actual values, otherwise improvise and enter pairs of reasonable numbers.

Now click on two other positions in the picture (or better yet at the endpoints of a satellite trail). You will see the respective coordinates displayed at the top of the image. Next select `Maneuver`, then `Orbit Determination`. Select the last two positions marked on the picture by clicking the `Picture` button and then proceed to get a circular orbit fitting. If you had a real picture you should get a reasonable orbit otherwise it could be something strange but at least you see the principle! Pressing the right or left arrow key will show how the satellite moves across the image. If it was an unrealistic orbit you might not see anything but the time and imaginary coordinates at the top of the display. But never mind. Press `X` (or select `View`, `Show Last Text`) to toggle between the last text display and the picture. To return to the standard map display select `View`, then unmark the `Show Picture` checkbox.

Note: If you were using an actual picture don't forget to set the geographic coordinates correctly of the site where the picture was taken and make sure the time and delta-time (lenght of exposure) was properly set.

12 Archeoastronomy with SatCal .

Our final example is one you can easily skip. It shows something which SatCal was not designed for. If you have a good planetarium program you will be able to do the following example much better than with SatCal - or not at all! Which star was the pole star in the year -12000? Try entering that year into your planetarium program. Most such programs do not handle negative Julian dates (years less than -4712). SatCal extends the Julian calendar indefinitely back into the past. First set the observer's location to 90° North (`Input`, `Location`, `Latitude`). Now press `D` or select `Input`, `Date/Time` and enter `-12000` as the year. Of course there were no satellites in orbit at that time but in order to get the usual numbers displayed you could generate a dummy satellite. Just select `Maneuver`, `Edit Orbit Elements` or press `E`. Specify any name you like for the satellite. Click the `GEO` button and enter `180.0` as the geostationary longitude. SatCal now generates orbit elements for a geostationary satellite at 180° East (which makes sure it is out of view in your sky map). Leave the dialog. Now select the sky map (`View`, `Map View`, `Sky Map`, mark the `Sky Map` checkbox) and press the Refresh icon. The sky map appears and there is a bright star almost directly in the center (which means in the zenith and thus close to the celestial pole as we set the observer's location to the North Pole). Which star is it? Just place the cursor over it and click. The Local Details display should show something like R.A. 18.37, Declination 38.57. These are the coordinates of Vega in the J2000.0 epoch. Press `V` or select `View`, `Visibility`. Then enter `0` as the `Year of Epoch`. If you now click again at Vega's location you will find something like R.A. 3.11 and Declination 86.47. These would be the coordinates of Vega at epoch -12000.

You could also try to figure out the position of sunrise at winter solstice or something like that at a particular geographic location. (Be aware that seasons would shift over such long times because the Julian calendar lags behind in leap years. In the year -12000 solstices etc. would have shifted by about three months!) I leave it to you to figure out the details of how you could do that. But a word of caution: The further you go into the past or into the future the less accurate the formulae for precession and positions of the Sun and planets become. The above example with Vega as a pole star 14000 years ago agrees with something I read somewhere. But I wouldn't go back much further (and I wouldn't go much more ahead than 12000 years into the future). By the year -28000 SatCal shows the constellation Ursa Major over the South Pole which is definitely wrong! So do use your common sense and be skeptical of the results. SatCal really was meant for doing satellite calculations in our time!

This concludes our tutorial. You should have a fair idea now of how to use SatCal.

Enjoy your work with SatCal.