SatTracker

User Manual

Version 2.0

May 2023

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# 1.	Summary

*S*atTracker was designed for real-world prediction of satellite ground tracks. It is highly accurate and, with fresh sets of orbital elements downloaded from within the application, it will keep that accuracy indefinitely. It provides ground tracks for multiple satellites, like some other applications, but unlike others, it will compute visibility for multiple ground stations.

SatTracker has been used during real satellite operations at the European Space Operations Centre, ESOC, in Germany!

As well as ground tracks, the application calculates daytime, twilight and night-time regions as well as calculating when each satellite is illuminated so that it can be seen – assuming there's no cloud. To help with this, *SatTracker* also displays global cloud cover updated hourly (though this needs a third-party data subscription). The various items which can be plotted are completely configurable, and so is the representation. The map can be displayed in two map projections: a simple rectangular projection or as a pair of azimuthal projections centred on the North and South poles.

Powerful database functionality is built-in to allow the management of thousands of satellites and ground stations.

Features of *SatTracker* 1.0:

▸ plots satellite positions and ground tracks;

▸ uses the SGP4/SDP4 algorithms tuned to work with the downloaded TLEs;

▸ Sun and Moon position (and Moon phase) are plotted;

▸ maps show the day and night coverage on the Earth;

▸ the time can be adjusted freely forwards and backwards, and run in simulated future or past times;

▸ current cloud cover is optionally downloaded and displayed;

▸ the location of the South Atlantic Anomaly (which can affect satellite operations) is shown for a given satellite;

▸ ground station horizons are plotted, taking account of the real horizon obstructions, for both transmit and receive links;

▸ ground stations are grouped into related sets;

▸ plots are either on a rectangular grid or a pair of polar projections.

SatTracker 2.0 adds significant new features:

▸ **Sky View**, showing satellite positions and tracks across the sky from the selected ground station;

▸ **Pass View**, showing a set of timelines with satellite passes plotted as elevation against time;

▸ both the **Sky View** and **Pass View** windows include sky shading to indicate time of day (and the **Sky View** can include stars and constellation lines too);

▸ on-screen and printed lists of satellite passes for a given ground station, or ground station passes for a given satellite;

▸ full support for ground station time zones;

▸ a database of commercial ground station antennas which can be used to populate new or existing ground stations;

▸ many more networks of ground stations, including the networks offering "Ground Station as a Service", GSaaS, for SmallSats;

▸ extension of ground station communications records to VHF, UHF and L-Band (of interest for direct broadcast of meteorological and other Earth observation data);

▸ great expansion of the contents of the default ground station database, including horizon profiles for most stations.

PLEASE NOTE: *SatTracker* is not a video-games quality, 3d graphics simulation with fancy sounds, and was never intended to be. It was designed with the needs of satellite professionals in mind, particularly those in Mission Control Rooms who need to see where relatively few satellites are with respect to the visibility horizons of the available ground stations. Specifically for these engineers, the location of the South Atlantic Anomaly is shown.

2. Motivation for *SatTracker*

In April 2010 the European Space Agency, ESA, launched CryoSat-2, the successor to the original CryoSat which was lost in a launch failure. I had my position in the Main Control Room in ESA's Space Operations Centre, ESOC, as I had for the launch of the first CryoSat. In each case there had been many months of simulating the launch, with many different types of failures, to train the whole team.

One of the displays on the front wall was a map showing the satellite position and the positions of the several ground stations we were using. Fig. 1 is a crop from a photo taken during one of the CryoSat-2 simulations.

Figure 1. *Display in ESOC's Main Control Room on 8 Dec 2009.*

I wanted something similar, but better, on my Mac laptop. I found a commercial software which was very well adapted to its target audience (radio amateurs), but only offered a 'many-satellites / one ground station' model, instead of the 'one satellite / many ground stations' model that we needed. The best I could do with the time available before the launch was to create a background map for this commercial software with our ground station horizons pre-drawn.

I eventually realised that to have the features I wanted, I would have to write my own software. By mid-2010 I sent a version to ESA colleagues for suggestions, and they proposed many useful things that they need in the Control Room and for analyses.

In 2013 the first version arrived in the Mac App Store.

3.   Quick Start: Main Window

When first starting up *SatTracker* you will see the standard map view – and a dialog box with an important reminder about the need to visit the Settings… dialog (or Preferences in earlier versions of macOS) to set things up the way you want. Let's overlook that for now.

A typical ground station display
with the location and name,
and with the area where satellites
are above the horizon (yellow line)
and at more than 5° elevation
(orange line).

These tabs allow you to switch
between rectangular projection
(this one) or a pair of
polar projections

This locks the
aspect ratio
at 2.0, for the
best display

Current date and
time are shown here

This is an area where
messages are shown.
Older messages can be
called up with the arrows
at its right-hand edge

In this box some details
of the selected satellite are
shown, and a check box to
select if the ground track
should be shown

Button to force
update of passes

Here the time needed
for the calculations is
shown, compared to the
time available

The longitude and
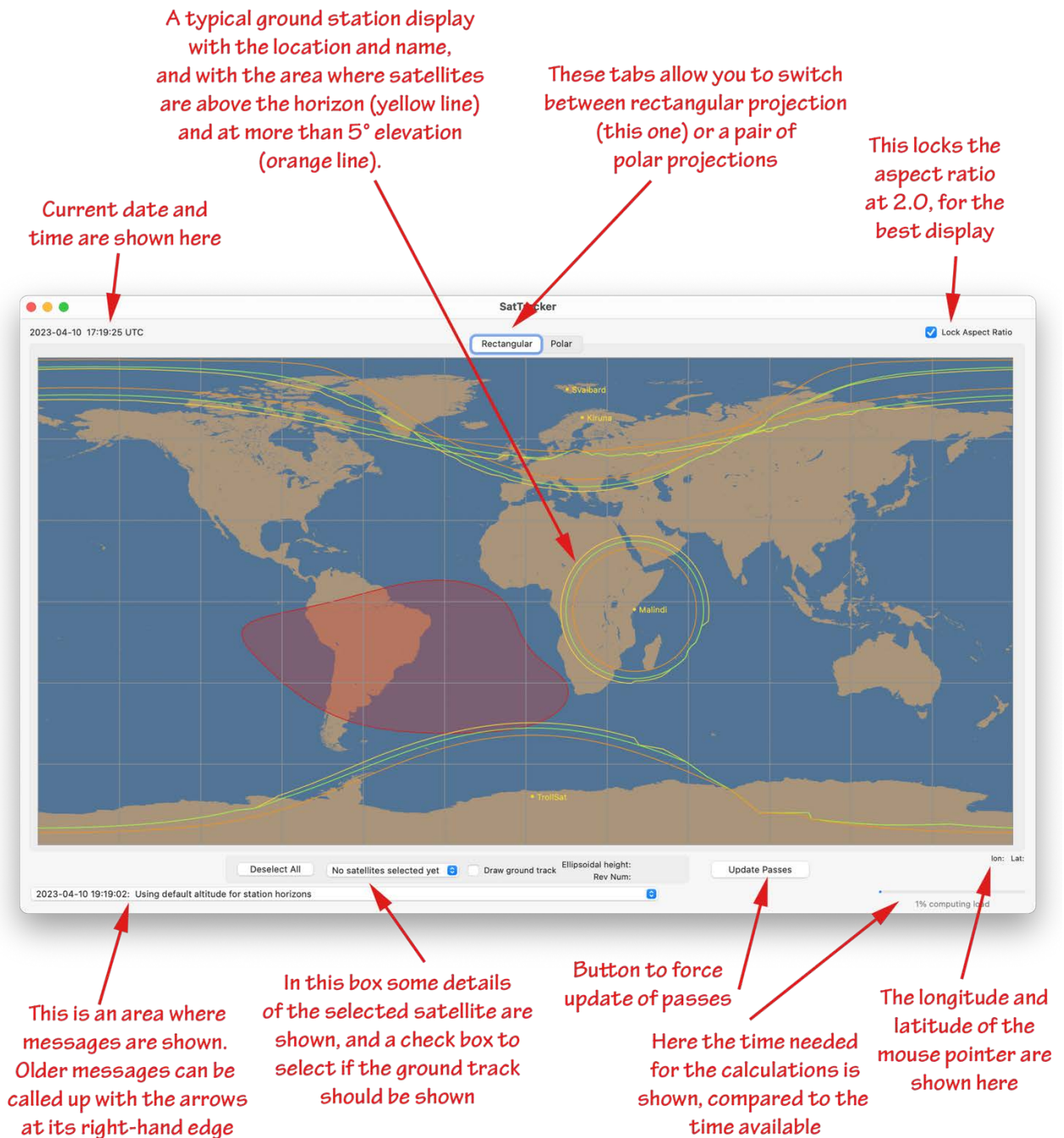latitude of the
mouse pointer are
shown here

Figure 2*. SatTracker's main window, with the main elements indicated.*

SatTracker comes with a database of ground stations pre-loaded, and a few of them show up by default in the first window. Here we see stations in the Arctic, Antarctica,

and Kenya – they are actually the same ones shown on the screen photograph in Chapter 2. Each station has orange, green and yellow lines around it. These lines are the so-called *horizons* for the station.
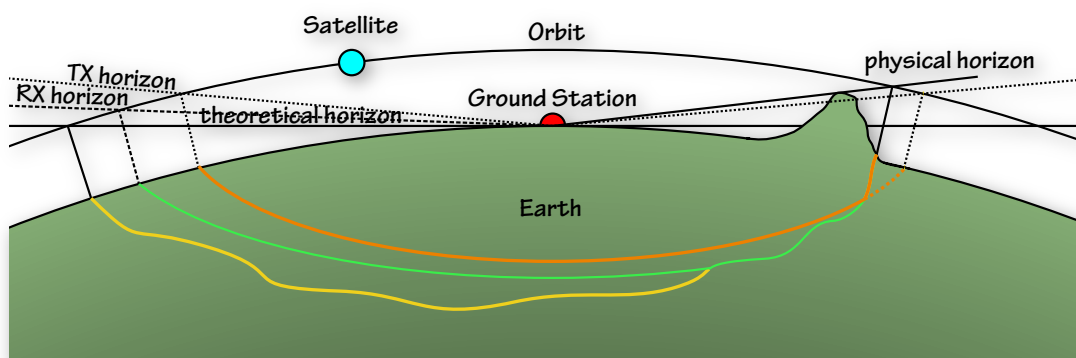

Figure 3. *An illustration of the meaning of the term 'horizon' in SatTracker's context.*

Fig. 3 shows what it means. Imagine a satellite in its orbit over a ground station. If the horizon is nice and featureless (like an ocean horizon), as it is on the left-hand side here, then the satellite can be seen when it's far away – in fact as soon as it comes above the geometrical horizon. On the right-hand side, we've drawn a mountain. Now the horizon line is higher up: if the satellite is behind the mountain the ground station can't see it. If we imagine this situation all around the ground station, we can plot out the line on the Earth (in yellow) where satellites can be seen if they're inside, but not if they're outside. Our yellow line is a bit 'wiggly' indicating that there are some more obstructions on the horizon.

The green and orange lines correspond to the zones where the satellite is more than a certain elevation above the geometrical horizon – these are the regions where it's considered safe to receive data and send commands to the satellite respectively, without them being potentially corrupted due to the long atmospheric path length, or where local licensing conditions restrict these functions.

These are often nice smooth contours but where there are obstructions to the horizon greater than the receive (RX) or transmit (TX) horizons (like our mountain here) the green and orange contours will follow this line too.

Each of the horizon indicators can be disabled in Settings (called Preferences in older versions of macOS), if you find them distracting.

Another contour line on the map shows up in red, with a colour-fill, and covers much of South America. This is the contour of the *South Atlantic Anomaly*: a region where the Earth's magnetic field is unusually weak, allowing the radiation belts surrounding the Earth to come a bit closer to the surface (but nowhere near ground level, so don't worry about it). It's important for satellites because sometimes strange effects can happen, such as computer glitches, when they pass through this region.

Around the central map area there are a few controls and some places where bits of information show up. Let's describe them.

At the top left you'll find the current date and time. Very likely it won't match your clock, because this always shows the time in Universal Time Coordinated (UTC), sometimes called Greenwich Mean Time, or Zulu[1]. That's because all the calculations in *SatTracker* are done in UTC.

The message box at the bottom of the window also has time labels. But these are in the same time zone as your computer clock because they are meant to help *you*, not the calculations.

On the right-hand side, just under the map, is an indicator of the latitude and longitude of the mouse pointer on the map. This is just for fun, but maybe helpful from time to time.

Just below that is an indicator of how much of the available computer time within the screen update cycle is being spent on the calculations (so if you double the update cycle, the processor load should halve). It's very rough but does give an idea of how much load you're putting on things.

Taking most of this lower region is a box with the details of the selected satellites. We haven't selected any yet, so this isn't going to show anything. Once we *have* selected some (as we will in the next Chapter), we can control if satellites are just shown as a mark on the map, or if they also show the trace of their orbit over the map.

To the right of this is a button marked **Update Passes**. You will probably never need this. It is used to force the calculation in the background of the sets of passes used by some of the other windows (discussed in later Chapters). It is automatically activated when needed and a message to say the process is running appears below the map, on the left-hand side, when it is running. If you have very many satellites and/or ground stations it may take a while for this background task, as it goes through all the combinations for a largish set of passes.

The final thing to note is the map projection tab. This tab, at the top-centre, allows us to choose a **Rectangular** (as in Fig. 2) or a **Polar** projection. The rectangular projection looks more familiar, but the polar one has some advantages. In Fig. 4, below, we can see that the stations in the Arctic and Antarctica have a more regular horizon plot than the 'stretched out' representation in the rectangular projection.

At the top-right of the window there's a small checkbox marked **Lock Aspect Ratio**. As you resize the window this will force it to maintain its proportions so that the two types of map projection look correct. If this is unchecked, they will take whatever aspect ratio results from the resizing.

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[1] Why is Greenwich Mean Time (GMT) called Zulu? It's the 'reference time' with **Z**ero offset from UTC. The standard phonetic term for the letter 'Z' is Zulu. A complementary explanation is derived from the 'nautical time zones' established in 1917, where time zones were assigned letters, based only on longitude, with Z being a 15° zone centred on 0° longitude.
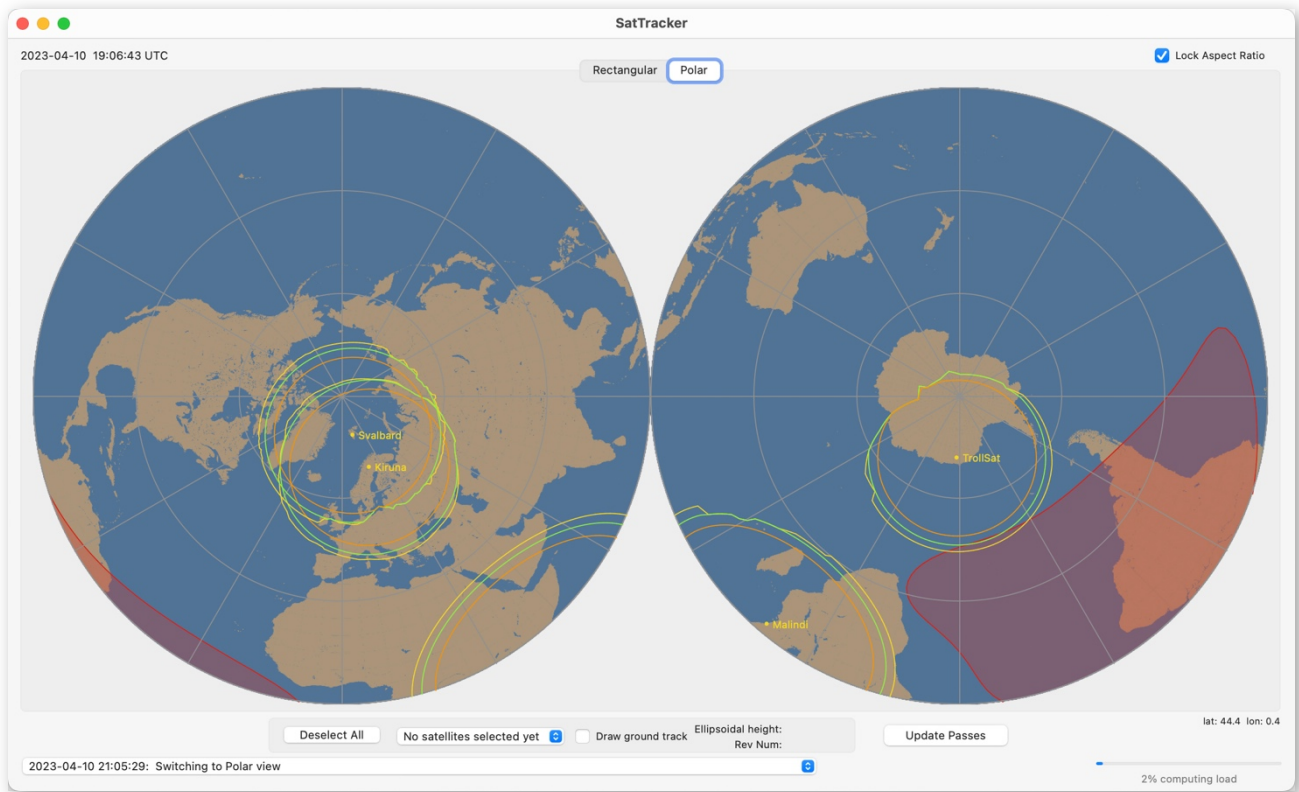
Figure 4*. Polar view of the same main window*.

Now, let's get some satellites. To do this we must open the Settings window (it's in the usual place in the application's main menu bar, under **SatTracker > Settings...** or, for older versions of macOS, **SatTracker > Preferences**

This also brings us to the next Chapter!

4.   Quick Start: Settings

On first opening the Settings (or Preferences) window, it looks like this (Fig. 5, below):
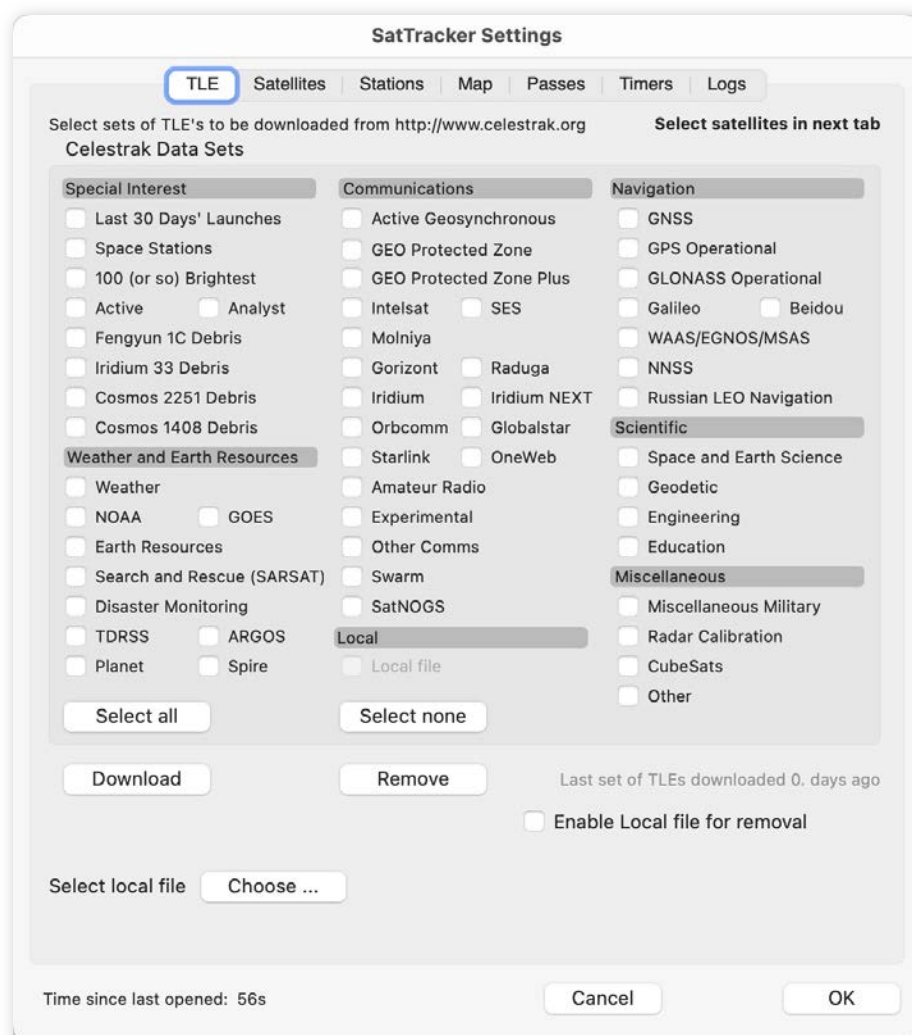

Figure 5. *Settings (or Preferences) window.*

Choosing Families of Satellites: There's a row of tabs across the top which allows access to other parts of the Settings window. In this first one, **TLE**,[2] we can choose the families of satellites we're interested in. For this first test let's just try a few. Click the boxes marked **Space Stations** (second one down in the left column under *Special Interest*), **Active Geosynchronous** (first one down in the middle column under *Communications*) and **Space and Earth Science** (first in the group *Scientific* on the right-hand side) – see Fig. 6 below if this isn't clear. Then press **Download** on the left side.

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[2] TLE stands for Two-Line Element, which is perhaps the most common way of distributing orbit data for a satellite. There's much more to say about this: we have a reference chapter on the subject in Chapter 13.
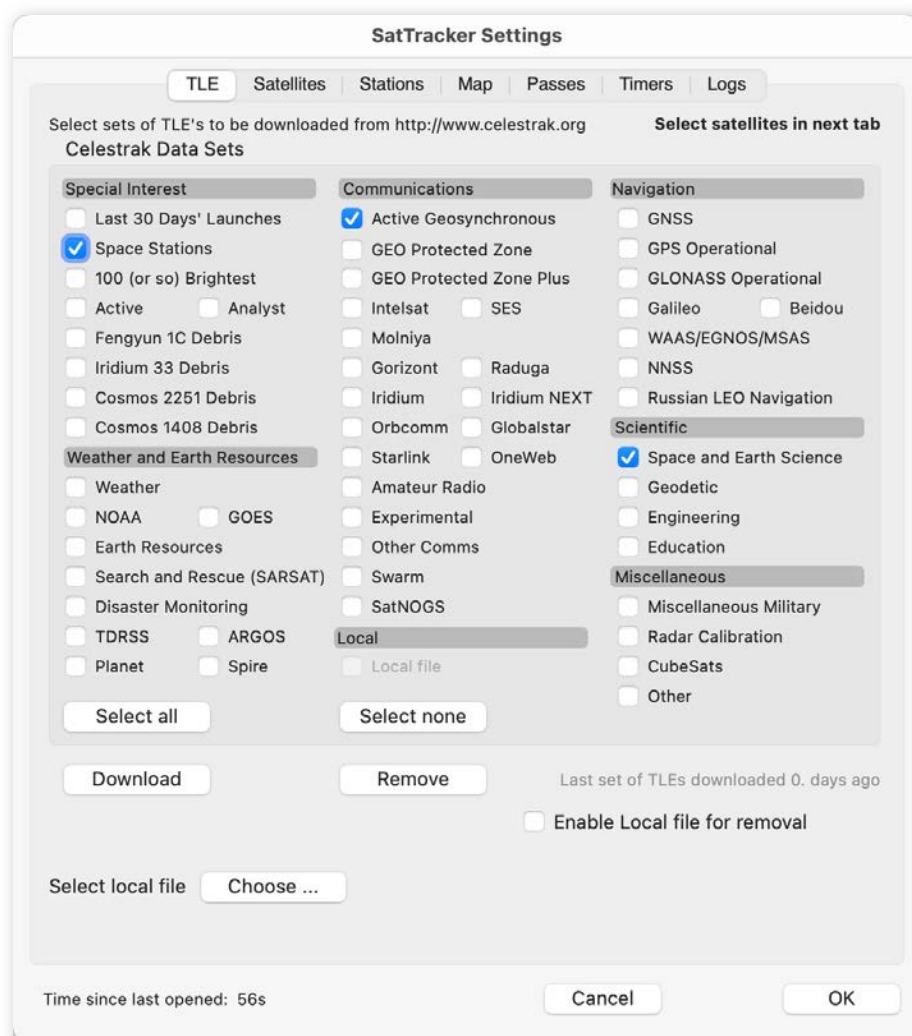
Figure 6. *Example of specific satellite 'families' selected.*

Of course, this assumes that you've got an internet connection. Although *SatTracker* comes with a few satellites pre-loaded, the orbital elements for these are not particularly fresh. They'll help you get started but you'll really need more up-to-date information. Since you downloaded *SatTracker* over the internet, it's probably safe to assume that you *do* have a connection.

You'll see some messages flash just below the **Download** button, informing you of the download status followed by the progress of unpacking the downloaded files into the internal database. Details of this unpacking process are given in the *Log file* (see Section 7.7).

When this process is finished a message to the right of the **Remove** button will announce that it's '0. days' since the last download.

We're not finished yet!

So far, we've downloaded sets of satellites into the internal database. In fact, we've got thousands of them! Now we must decide which ones we are going to show on the map.

Actually, *SatTracker* can show lots of satellites at the same time. But the display gets so full that it's not really interesting. In Fig. 7 we see 600 satellites, and the display is really crowded.
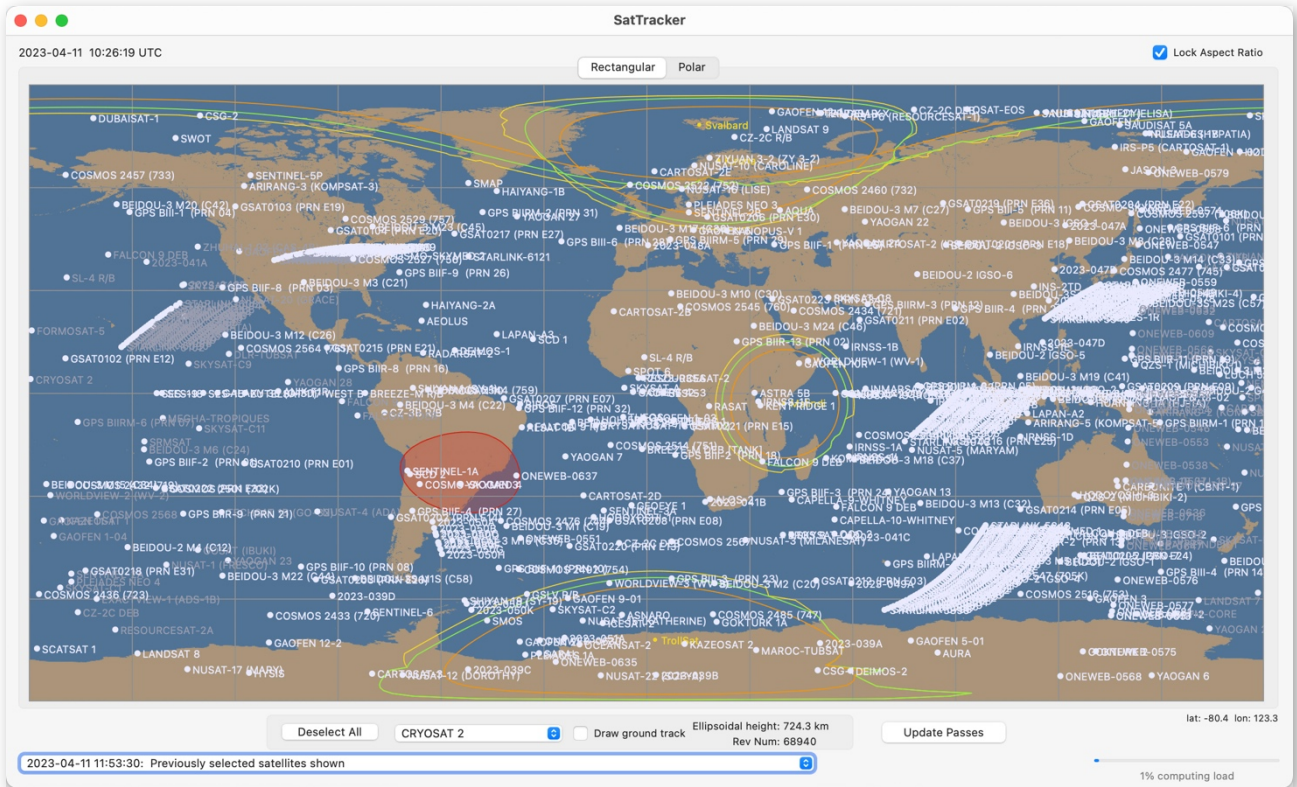

Figure 7. *Main window with 600 satellites displayed. An obvious feature is the sets of satellites very close together in an orbit, with overlapping names. These are recent, multiple mass launches of satellites such as Starlink, where they have not yet had time to manoeuvre away from the initial launch orbit.*

Then, the next image, Fig. 8, below, shows 6073 of them (of which 3927 are 'Starlink'[3] satellites), with labels switched off. There are really too many for a useful display (unless noticing that the Starlink satellites are mostly found within a limited latitude range counts as useful).

By the way, calculating the orbits of so many satellites, to the very high precision used by *SatTracker*, is quite a computational load. So *SatTracker* will automatically slow down the rate that it refreshes the screen. In the first of these 'overload' cases (with 600 satellites) you may see the message, at the bottom left, that the screen refresh has been reduced from 1 s to 5 s. This depends a bit on the speed of your computer. In the second the update rate will be further reduced (to 60s in Fig. 8). At this point you may think that the application has frozen (because it's taking 60s for a screen update) – but no, it's just very busy and has informed you of the fact.

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[3] Starlink satellites belong to a huge constellation of satellites developed and launched by SpaceX. They provide global internet services and annoy astronomers, because of the light trails they leave on astronomical images.

The screen refresh rate does not come back automatically if you stop displaying so many satellites (after all, you may have set this deliberately) so you'll have to bring it back to a fast refresh in the **Timers** tab (explained in Section 7.6).
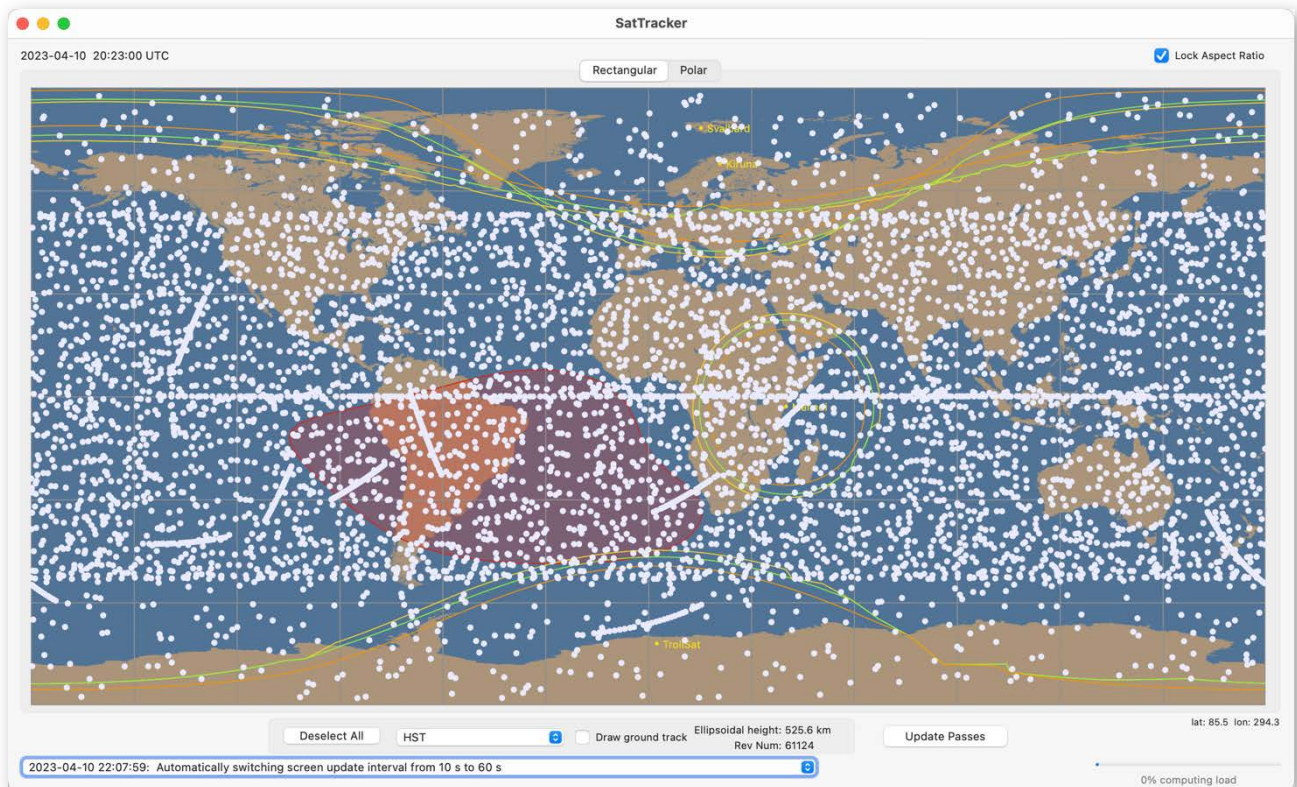

Figure 8. *Main window with more than 6000 satellites displayed. Again, we can see rows of closely space satellites corresponding to 'recent' mass launches. There is also a persistent band along the equator, since we included geostationary satellites in the group required to reach the number of more than 6000 for this illustration.*

Selecting 3 Satellites: So, we're only going to show a few satellites now. In fact, we're going to choose 3, with completely different types of orbits from each other.

Remember that we picked three groups of satellites to download: **Space Stations**, **Active Geosynchronous** and **Earth and Space Science**. Well, there was a reason for those choices, so if you downloaded something different, make sure you get these 3 sets as well.

Next, go to the next tab along, the **Satellites** tab, Fig. 9. In the middle is a list of satellites with their names and identifying numbers. There's also a column marked *Epoch*, which is the date and time of the calculation of the satellite's orbit data. The more recent it is, the more accurate the track will be. For that reason, they are colour coded according to age, using the colour scale on the left-hand side. This is all explained in more detail in Section 7.2.
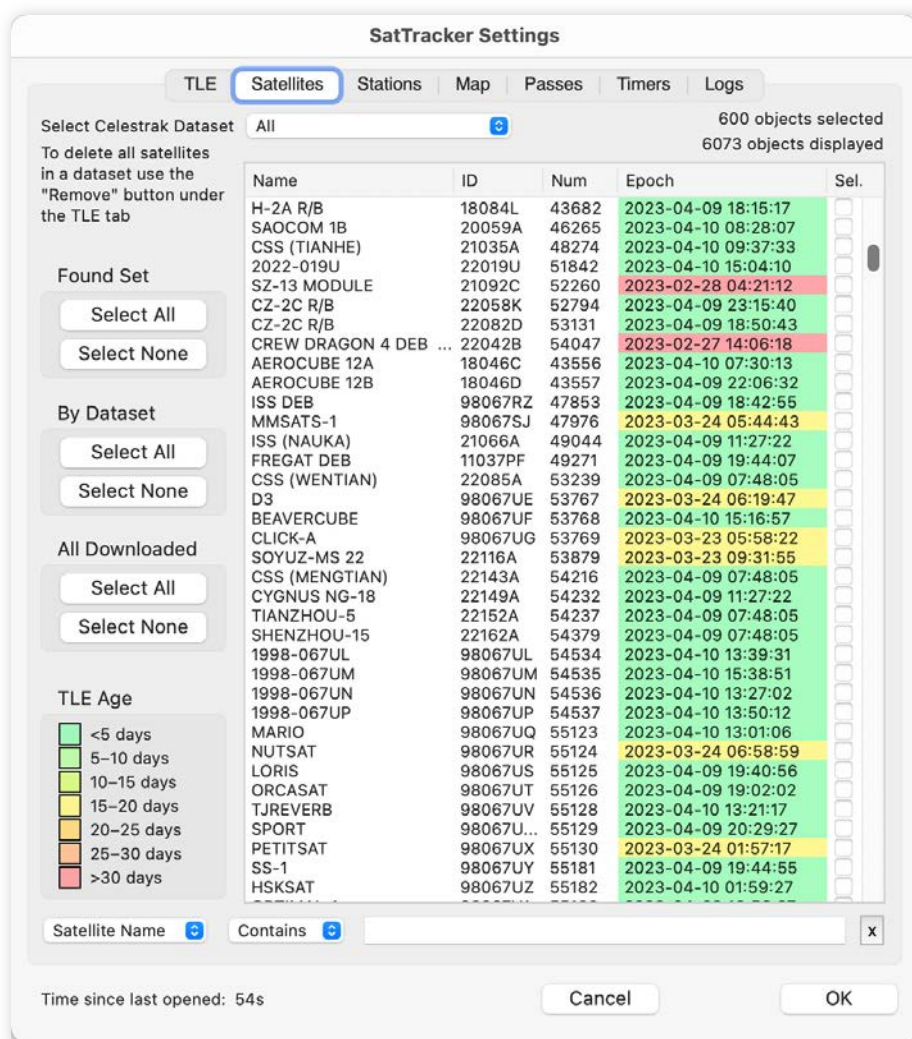
Figure 9. *Satellites tab of Settings window, with various epoch ages shown in different colours.*

For now, we are just going to pick our three example satellites.

The first is the International Space Station itself, called ISS, or sometimes *Zarya*, which is the name of the first piece put in orbit – it's a big power module built by Khrunichev in Moscow.

If you had downloaded other datasets as well it may not be immediately visible. But it can be found instantly, by typing any of the letters in its name into the search box at the bottom of the window. There it is, (in Fig. 10) at the top of the list.

Select it, by clicking in the checkbox to the right of the coloured Epoch column in the list of satellites.
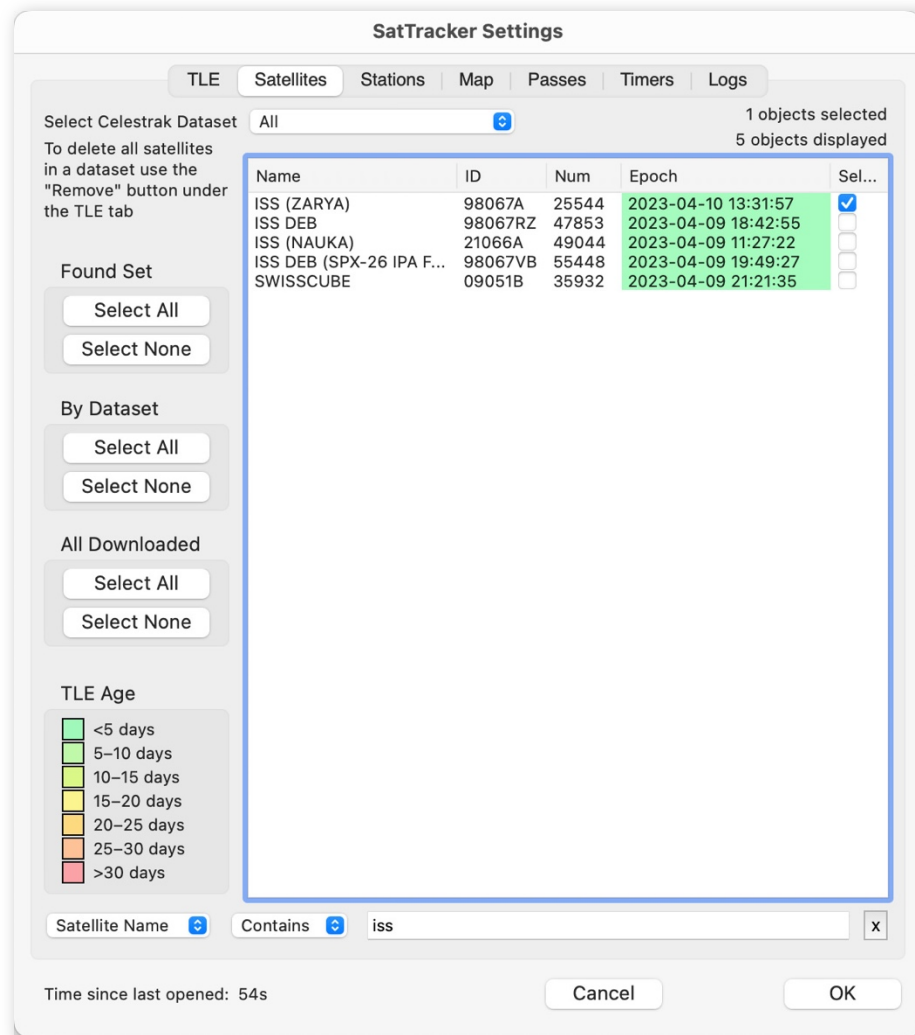
Figure 10. *Satellites tab of Settings window, with the ISS selected.*

Then do the same for MeteoSat-9 (MSG-2)[4] and XMM-Newton.

Now close the Settings window by clicking **OK**, not **Cancel**. Otherwise, the selected satellites will not be transferred to the main window.

The three satellites now appear on the map as three pale blue spots with the names nearby, as we can see in Fig. 11. Of course, they will be in a different position from what we see here when you do this, as satellites are moving all the time.

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[4] There are now 3 generations of MeteoSat in orbit. The first generation, MeteoSat-1 to -7, have all been retired, but being at geostationary altitude will remain in orbit for the foreseeable future. This generation had an 'Apogee Kick Motor', AKM, which was jettisoned after arriving on station, and these AKMs are also tracked in the CelesTrak catalog as separate objects. MSG-2, here, is one of the four MeteoSat Second Generation satellites. The first of the MeteoSat Third Generation (MTG) was launched on 13 Dec 2022.
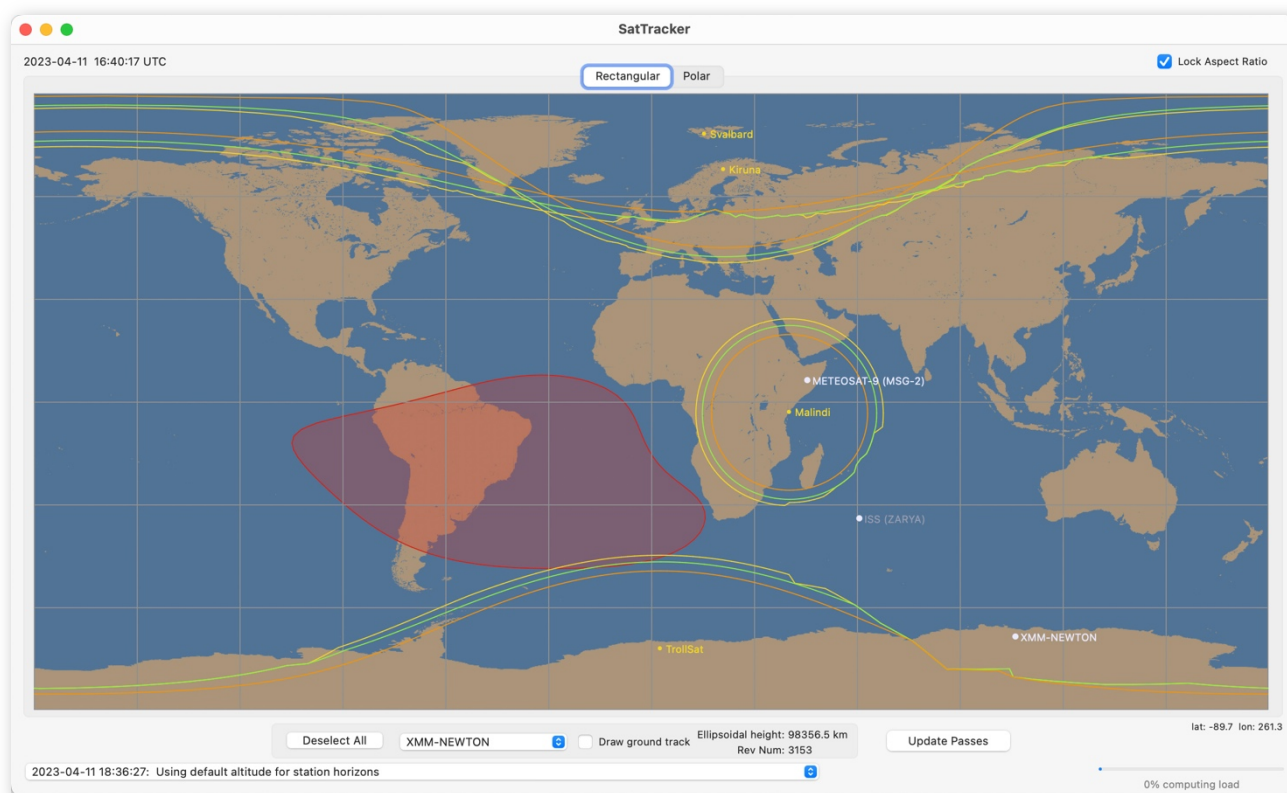
Figure 11. *The main window, with three satellites selected.*

Adding Ground Tracks: Next, go to the drop-down menu just below the map: the one with the satellite names in it. Just to its right is a checkbox. Choose each of the three satellites in turn and for each, click the checkbox.

For each one, the ground track will be drawn, covering one orbit, as shown in Fig. 12.

Now we can see the three different orbit types. The ISS is in a nice steady curving orbit, sweeping north and south as it travels around the Earth from west to east. MeteoSat-9 is a geostationary weather satellite, so it is fixed at the same place over the equator. But this satellite is quite old and, although it has the correct altitude for geosynchronism (and so maintains its position in longitude), it has acquired an orbital inclination of about 6.5°. We assume this is due to a trade-off in the remaining fuel budget between maintaining longitude and maintaining inclination. So, its orbit has a bit of tilt, and we can see it making a small looping orbit over the western Indian Ocean.

You may be wondering why some parts of the orbit track are drawn in a darker colour. These are the parts of the orbit where the satellite is not in sunlight. For a satellite engineer this means the solar array is not generating power so the satellite must rely on its batteries. For the rest of us, it means that the satellite is invisible in the night sky.
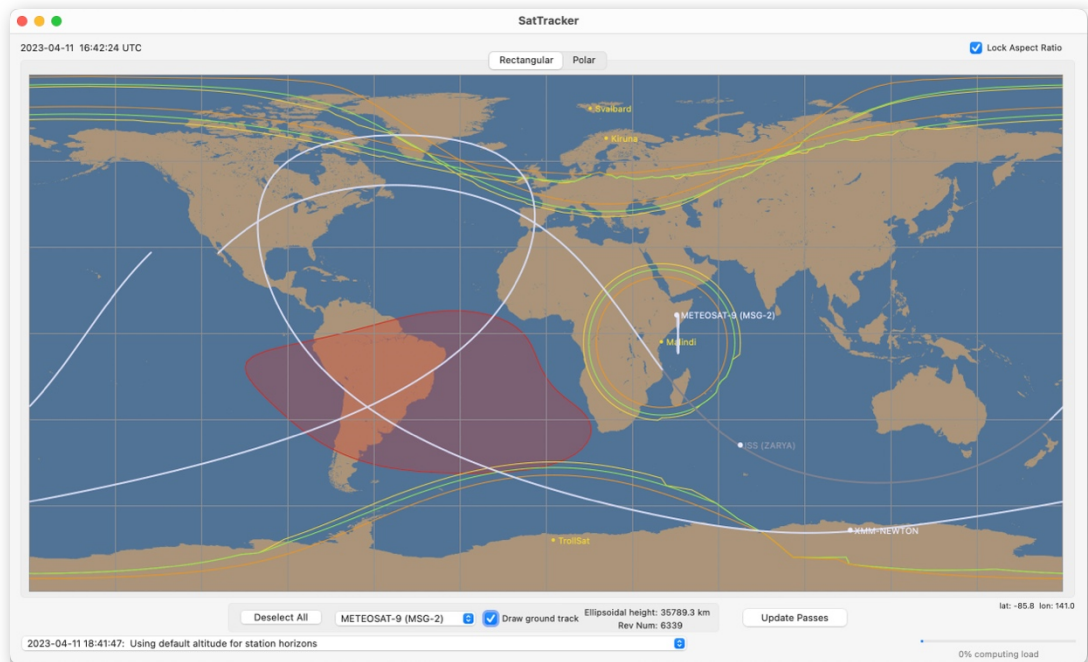
Figure 12. *The main window, with three satellites selected and ground tracks enabled for all three.*

XMM-Newton is a European X-ray telescope launched on 10 Dec 1999. It has an unusual orbit with a high apogee in the Southern hemisphere designed to keep it out of the *van Allen* radiation belts for as long as possible. If we look at the **Polar** view (using the tab at the top) we can see it make its long circuit of the south pole before its quick journey north and short eclipse passage.
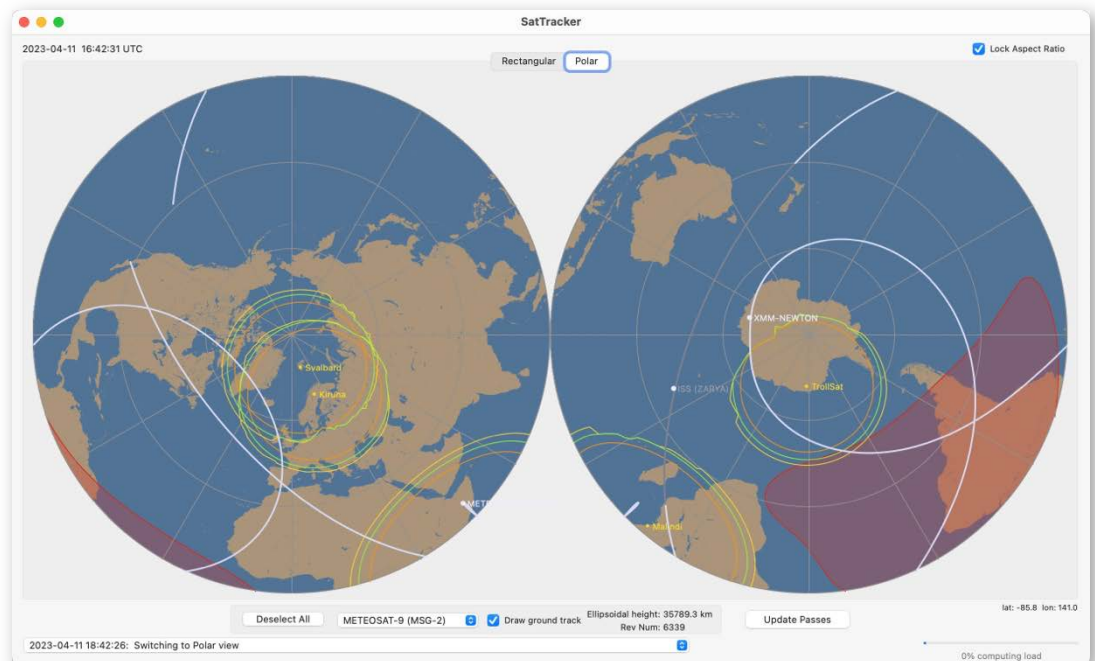
Figure 13. *The main window, with three satellites selected and ground tracks enabled for all three. Now the polar view is chosen with the Polar tab.*

Changing Ground Stations: Now let's try changing the ground stations: we'll go back to the Settings window, and this time to the **Stations** tab.

This tab is more complicated that the **Satellites** tab, but the central idea is the same. We'll be describing the full details in the Reference, Chapter 6, so now let's just look at the list of stations. At the top of the list is one station already selected, Kiruna[5]. The other preselected stations can be found by scrolling down. We are going to start by deselecting all of them, and this is most easily done by clicking **Select None**.
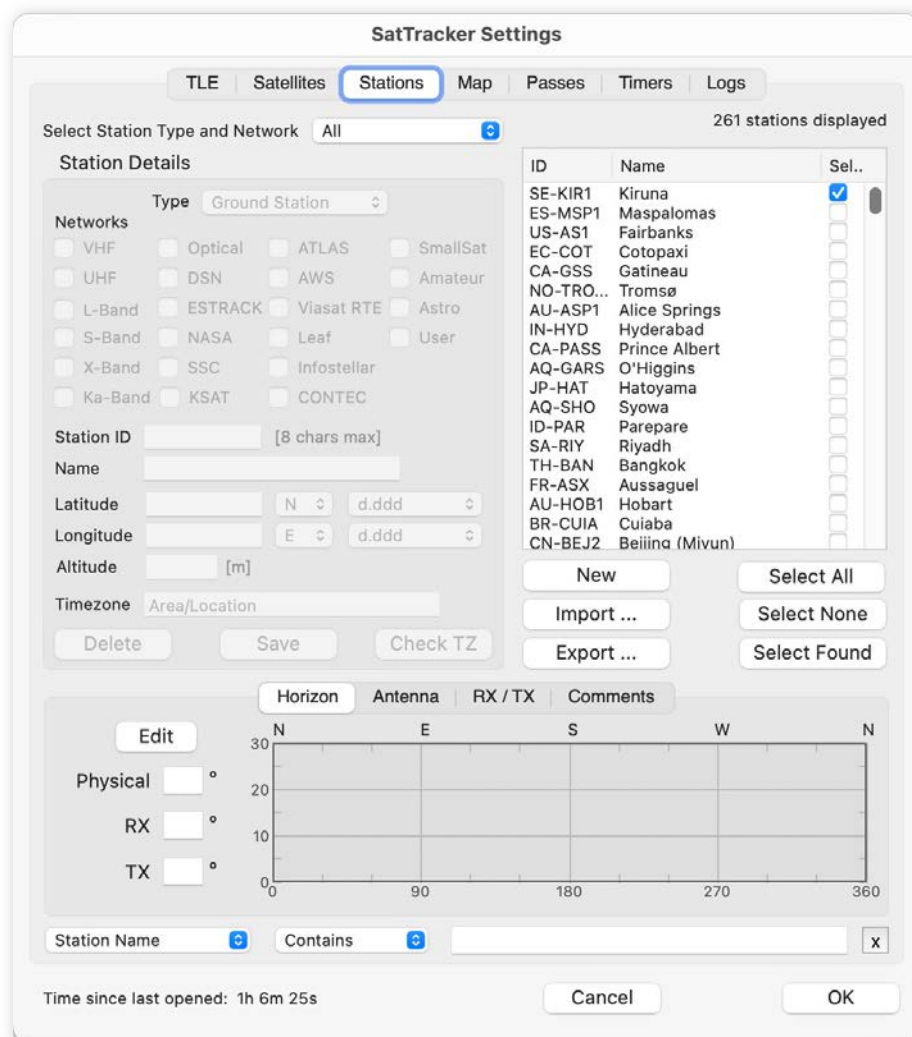
Figure 14. The Settings window, with the Stations tab selected.

It's quite likely that you'll want to add your own home, and if so, it's easily done (so long as you know where you live!). But we must wait until we cover that in Section 7.3.8.

For now, we'll take the easy way and use some of the ground stations already in the database. By the way, this database is a collection of real, operational satellite ground

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[5] Being top of the list is no coincidence: we described in Chapter 2 that *SatTracker* was developed from the experience of CryoSat-2, and Kiruna is the primary ground station used with this satellite. The default ordering for this list is the order in which the stations were first entered, and Kiruna was the first one.

stations, as well as other types of installation which interact with satellites, such as laser-ranging systems.

So, let's imagine that you want to use some stations which are part of ESA's *ESTRACK* network. Of course, this is a major institutional network, but then we are using major institutional satellites as examples.

Select ESTRACK from the menu at the top, just below the tab bar. The one labelled **Select Station Type and Network**.
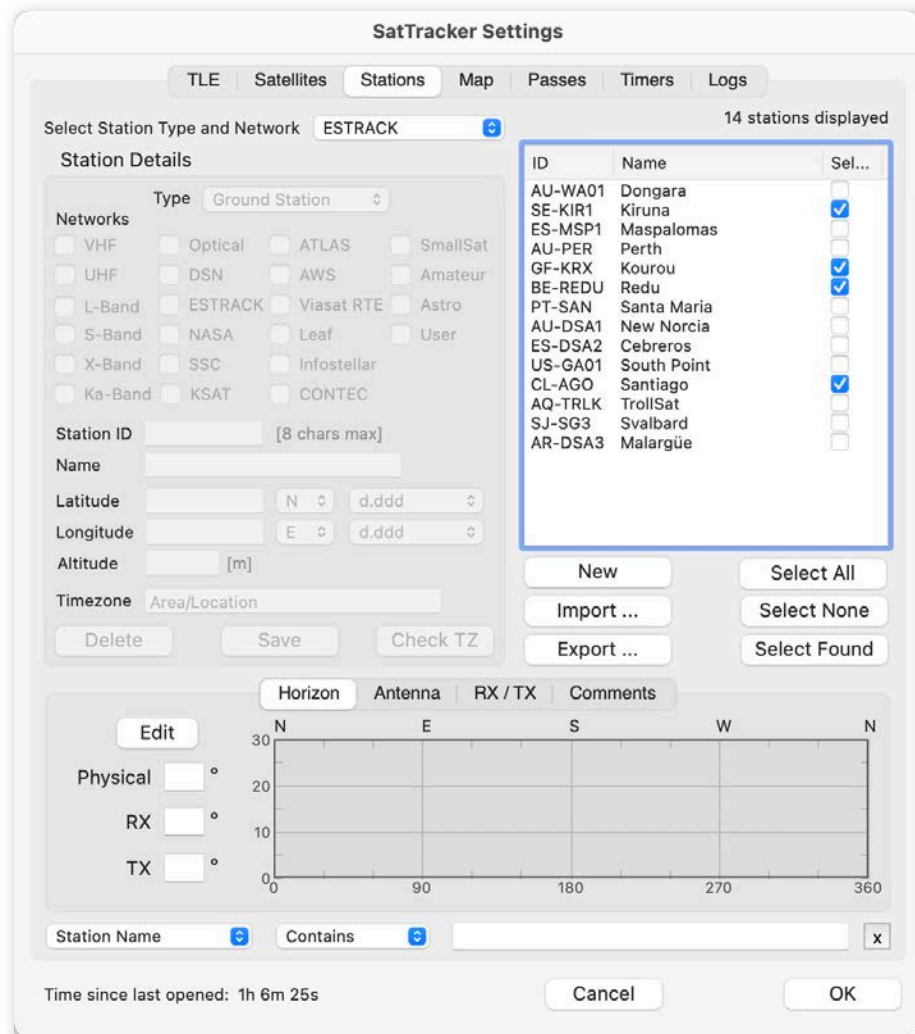
Figure 15. *The Settings window, Stations tab, with ESTRACK selected.*

Let's choose a few stations. In Fig. 15 we've selected stations in Chile, Australia, Belgium and Guyane. Now, when we go back to the main window (always clicking OK) we'll see our selected stations and their horizons on the map, as shown in Fig. 16.
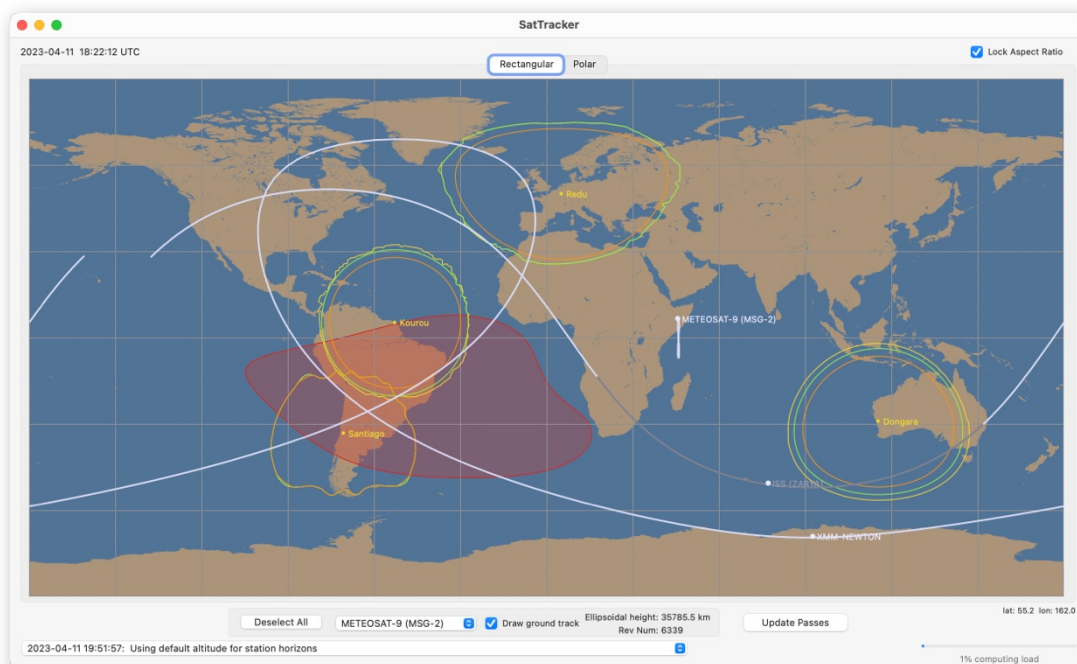
Figure 16. *The main window, with three satellites and four ESTRACK stations selected.*

Changing the Map: The final thing we're going to do in this section, before we look at the software in more detail, is to make the map look at bit more interesting. So, again, we go back to Settings. This time to the **Map** tab. This is shown in Fig. 17.

Firstly, using the panel in the middle, at the bottom, we'll change the background image for the **Rectangular** plot from **Plain** to **NASA Blue Marble NG**, using the drop-down menu, but we'll leave it as **Plain** for the **Polar** plot.

This NASA Blue Marble NG (Next Generation) image[6] has been produced by NASA's *Visible Earth* project, and is available for use in applications like *SatTracker*, so long as its ownership by NASA is acknowledged, in accordance with NASA's terms of use.

When this image is selected, its companion Black Marble[7] image of the Earth at night is used as well, while for the Plain map, a darkened version of that Plain map is used.

On the left hand-side we'll check the boxes for **Show day/night** and **Show sun/moon**. And we'll make the symbols a bit larger than the default, using the **Symbol size** slider.

We'll select **Nautical** twilight in the panel just above this, and in the panel below we *may* choose to **Show clouds**.

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[6] Actually, NASA produced Blue Marble images for each month of the year 2004. We have decided to use the image for October 2004.

[7] Updated to the 2016 version

Figure 17. *The Settings window, Map tab selected.*

The option to show clouds was originally introduced as an aid to the visual observation of satellites. For radio-frequency communication it has no added value, but for anybody hoping to make a visual observation, it does have some purpose.

SatTracker uses an on-line repository for cloud images. This is necessary to keep them up-to-date!

When *SatTracker* was first released it was possible to download a free image daily from the relevant server. However, that source is no longer maintained. A commercial source exists but is no longer free. On the other hand, the images are now updated every hour and seem to be of higher quality in polar regions.

This commercial service has absolutely no connection to *SatTracker*!

Details of the service are provided if you press the **Edit** button, where you will find the link if you want to subscribe to it. It's important to note that *SatTracker* does *not* need this, and it works perfectly well with no cloud display.

If you do choose to subscribe, you can enter your subscription details into the fields in the **Edit** box and they will be automatically used by *SatTracker* (and kept private on your computer only). See Section 7.4.2 for more information.

If you have subscribed, press the **Download Now** button.

With these changes we can go back (always clicking **OK)** to admire the main window.
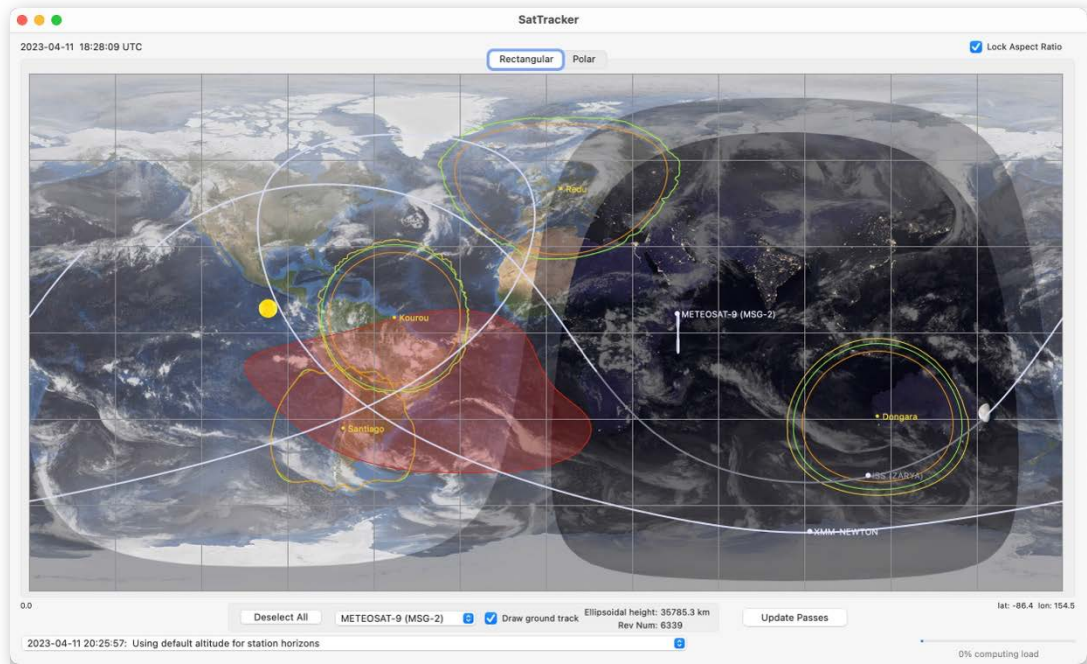
Figure 18. The main window, with NASA Blue Marble and clouds.

Have a look at the Polar tab too. With that in place, you can either go on experimenting, or read the rest of this manual.
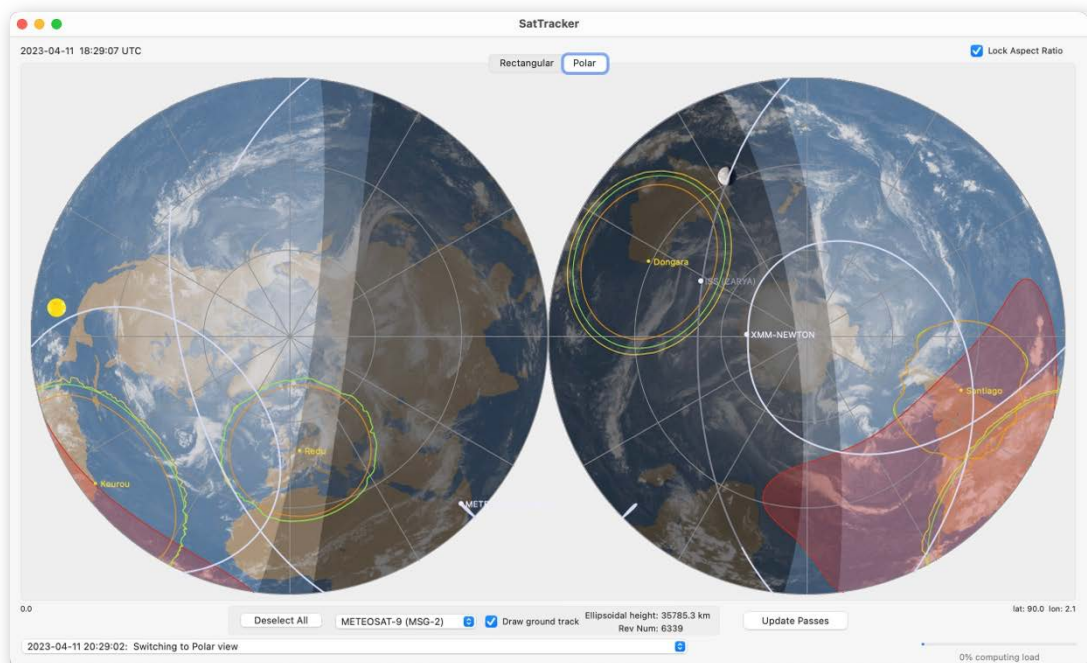
Figure 19. The main window, polar view with a plain map and clouds.

5.   Quick Start: Other Windows

Now it's time to explore some of the new features of v. 2.0. The main menu bar shows some new items, especially under the menu **Window**.
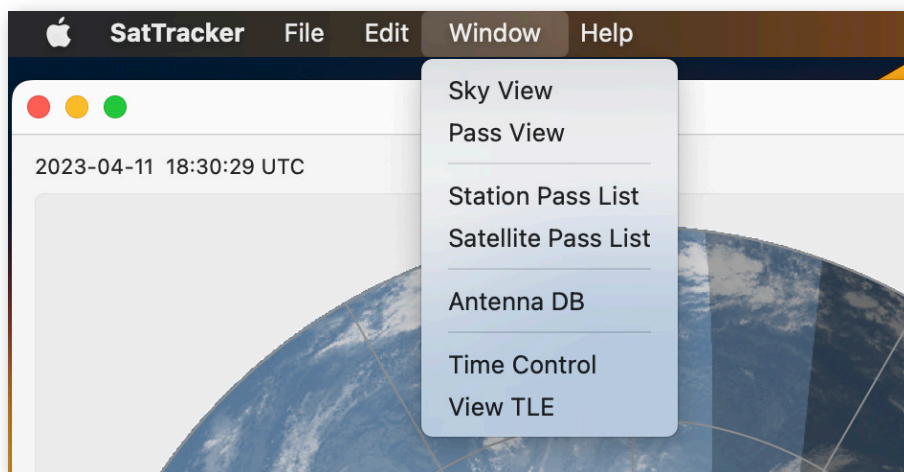
Figure 20. *The menu bar, showing the contents of the Window menu.*

5.1.   Sky View

Let's start with the first entry, **Sky View**. The new window will open with a view of the sky from the first ground station in the list; assuming you have kept the same set of stations from the previous Chapter, that will be Kourou. We can see it in Fig. 21 on the next page.

The main feature of the window is a large circular image, together with two information panels above it.

The circular image is a representation of the sky as seen from the ground station. Anybody who has used a planisphere-style astronomy app (or even studied the astronomy reports in some newspapers) should be familiar with it. For those who have not, the periphery of the circle represents the station's horizon; the four points of the compass (N, W, S and E) are marked. At the bottom is the point due South on the horizon, and the centre is the zenith, vertically overhead. Moving around the circumference from the South point, anti-clockwise (or to the right if you were actually looking at the horizon), you come to the West point. And so on.

There are some grid lines on the plot, normally every 15°, with everything centred at the zenith.

The three horizon lines, by default and in their default colours yellow, green and orange, show the horizon limits projected into the sky. If you were really at the ground station you would find the yellow line, marking the physical horizon, coincides with physical obstructions such as distant mountains. The horizon

contours are plotted in accordance with the settings described in Reference Section 7.4.5.
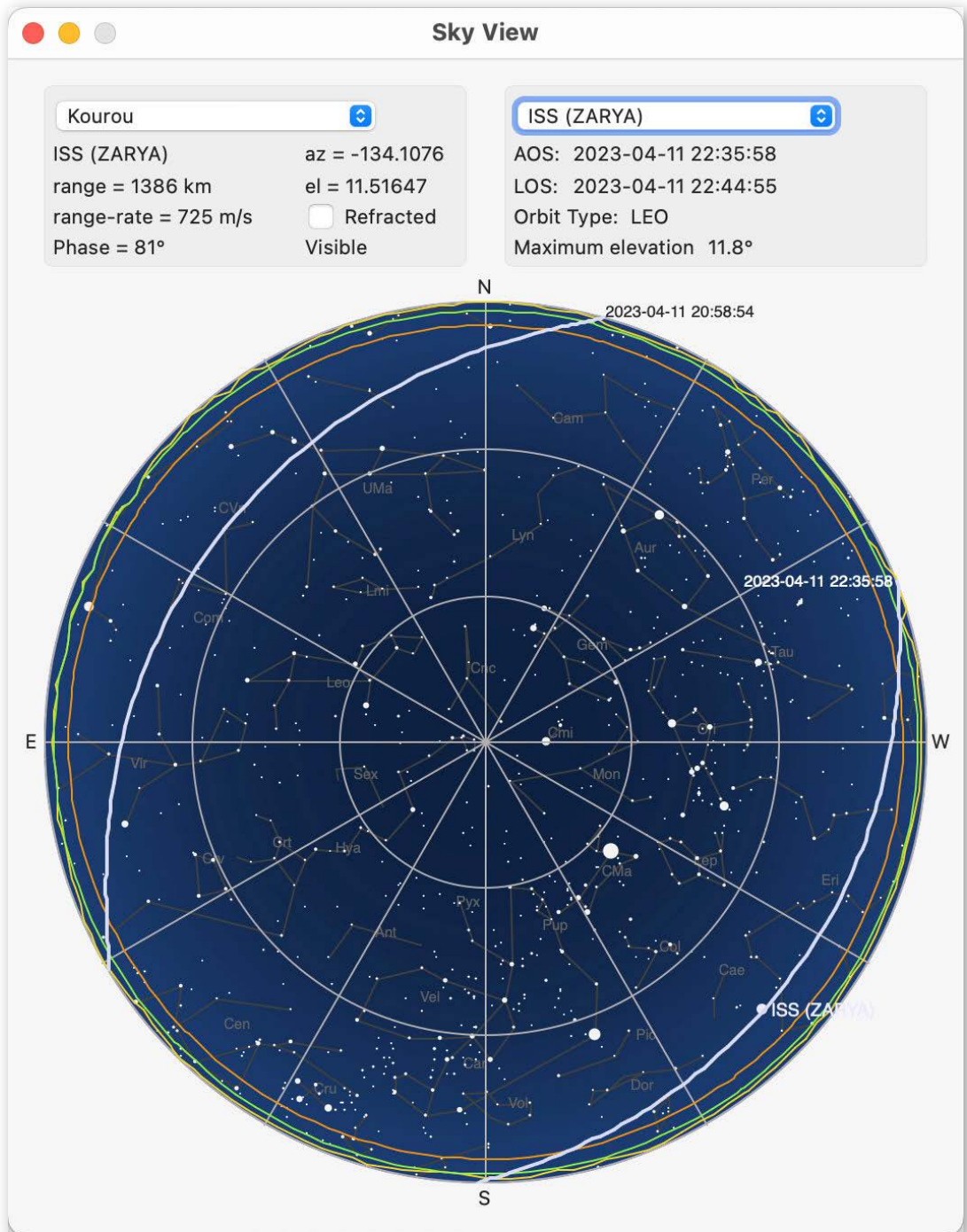
Figure 21*. Sky View from the Kourou ground station. The local time is during nautical twilight.*

This window is resizable, and while resizing it always keeps the central image circular.

Depending on the time of day, the view of the sky will be coloured differently. That's because it adopts a colour scheme in accordance with the current conditions at the station: daytime, civil twilight, nautical twilight, astronomical twilight, or night. You

may also see representations of the Sun and/or the Moon and, if it's dark, stars, constellation lines and names. These are all configurable, as we'll see in the Reference sections, and in particular, Section 7.5.

Of course, the purpose of this window is to show satellites and their tracks across the sky. Any satellite visible from the station will show up as a marked point in the sky.

Important: only satellites selected in Settings will be shown!

To see the track, choose the satellite from the drop-down list in the top-right panel. This will show all passes of the chosen satellite over this ground station, even if they are not currently visible. At the point where the track rises above the 0° horizon, the 'theoretical' horizon, a small line of text appears. It is the date and time of this appearance (in UTC), sometimes called 'Acquisition of Signal', AOS. Although not strictly accurate for this case, we will be using this terminology in the interest of brevity. The corresponding point, where the satellite sets below the horizon, is known as 'Loss of Signal', LOS.

The top-right panel gives some geometrical information about the satellite currently visible (if there are more than one, it chooses the earlier one in the selected list). Principally the information consists of the bearings, range and range-rate (which determines any doppler shift on radio signals).

Note that the elevation value may be optionally corrected for atmospheric refraction by ticking the relevant box. This only affects the read-out, and not the plotted position. The correction is optional because it is only computed for the optical case – the correction is wavelength-dependent and very small for radio frequencies. Our correction is actually calculated for yellow light.

Assuming you still have the three satellites selected, we can make a few observations.

Firstly, the XMM-Newton track is visible from all stations. See Fig. 22 which shows the **Sky View** from Redu in Belgium: the XMM-Newton track looks thickened, and the writing blurred, because the orbit almost repeats after 2 days, so we are seeing many tracks almost, but not quite, overlapping.

MeteoSat-9 (MSG-2) appears in the sky at both Redu and Dongara. It does move a bit, but not much, as it is almost, but not quite, geostationary. Although it doesn't seem to move much, the last few digits of the azimuth and elevation are constantly changing. No pass track has been computed because it does not have any event marking the start of a pass: AOS as it appears over the horizon. *SatTracker* uses such AOS events to signal that it should start calculating the pass data.

The ISS tracks, for those stations which are not in daylight, use shading of the track to show where those tracks will be in sunlight and in eclipse (and so not visible).
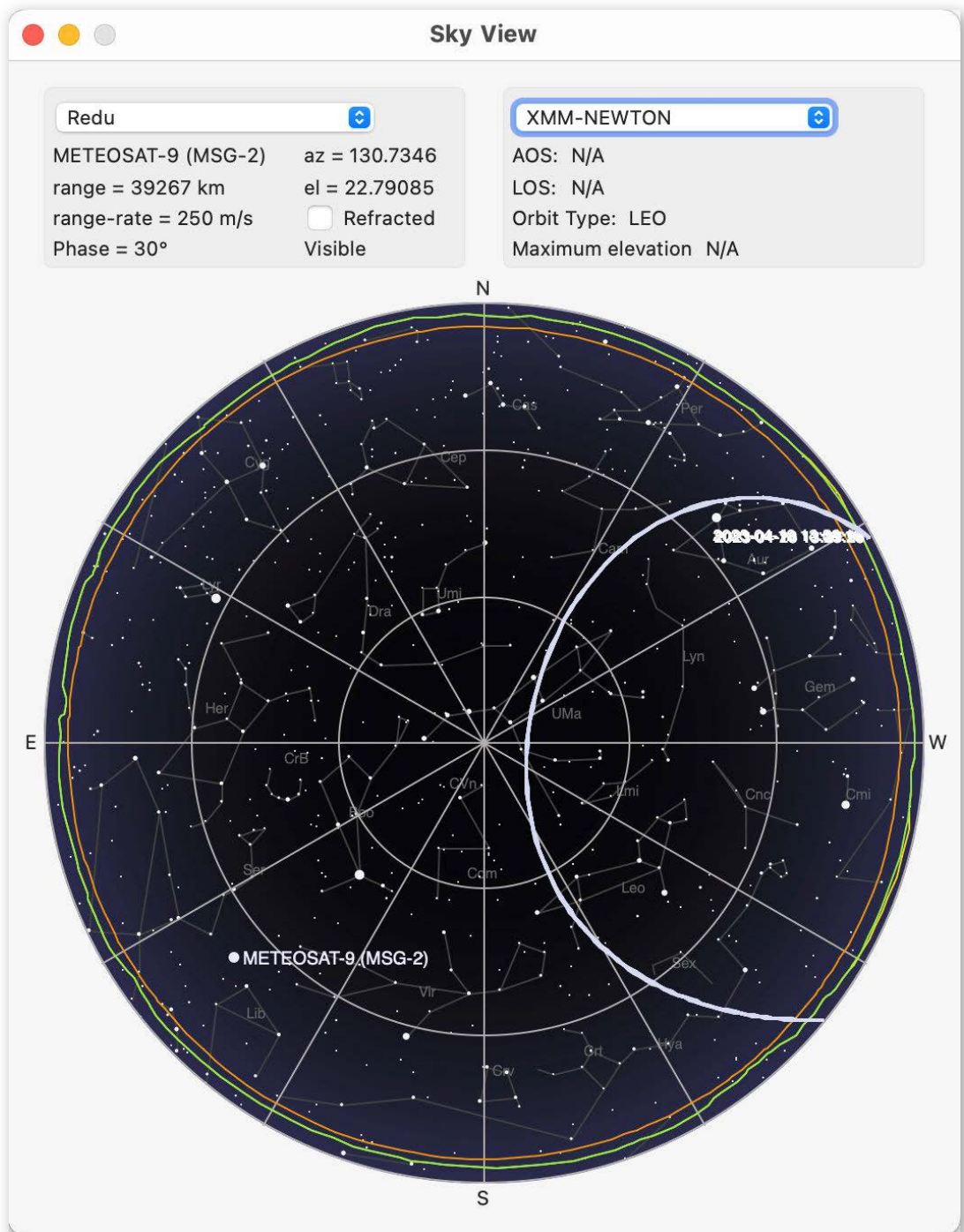
Figure 22. *Sky View from the Redu ground station. Meteosat-9 has no track because it neither rises nor sets at Redu. XMM has many almost-overlapping tracks.*

5.2. Pass View

Now let's look at the next item in the menu: **Window > Pass View**. This window is going to need a bit of explanation!
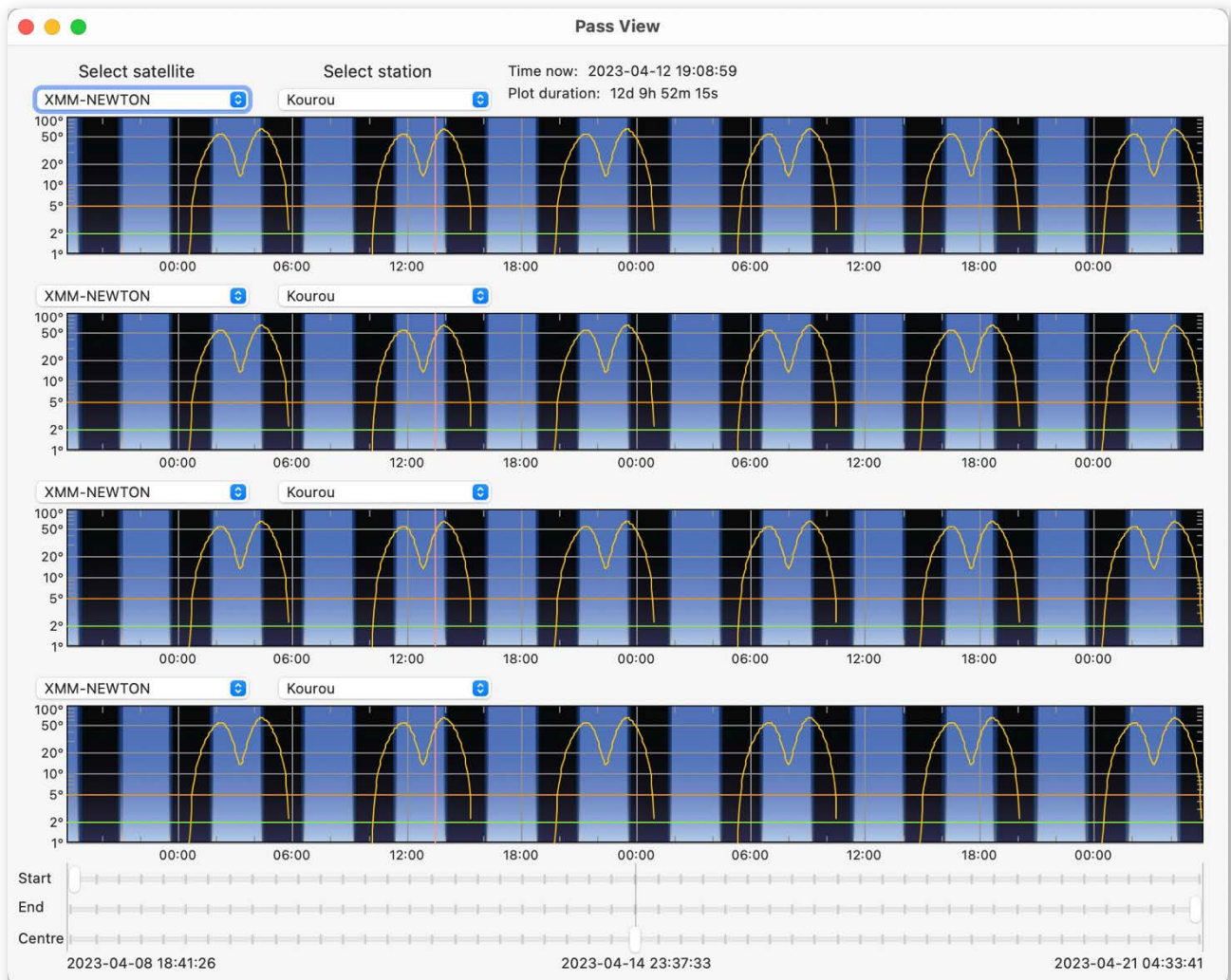
Figure 23. *The Pass View window when it first opens.*

The dominant feature is four identical, coloured graphs, with black vertical bands. These show time along the horizontal axis and elevation in the sky as the vertical one. There are coloured traces which mark satellite elevation as time passes.

SatTracker pre-computes the data for these passes, and it does so for 6 passes per satellite. Since XMM-Newton has an orbit which takes 2 days, the plot covers about 12 days, which is why there are so many black stripes – these are local night at the selected ground station.

The selected ground station and satellite can be chosen from the drop-down menus above each graph, which is why there are four of them: it allows you to see the passes of the same satellite at four stations, or for a single station, passes of four satellites.

Let's try it: make sure XMM-Newton is selected as the satellite in each of the 4 panels and select the four stations Kourou, Santiago, Dongara and Redu.
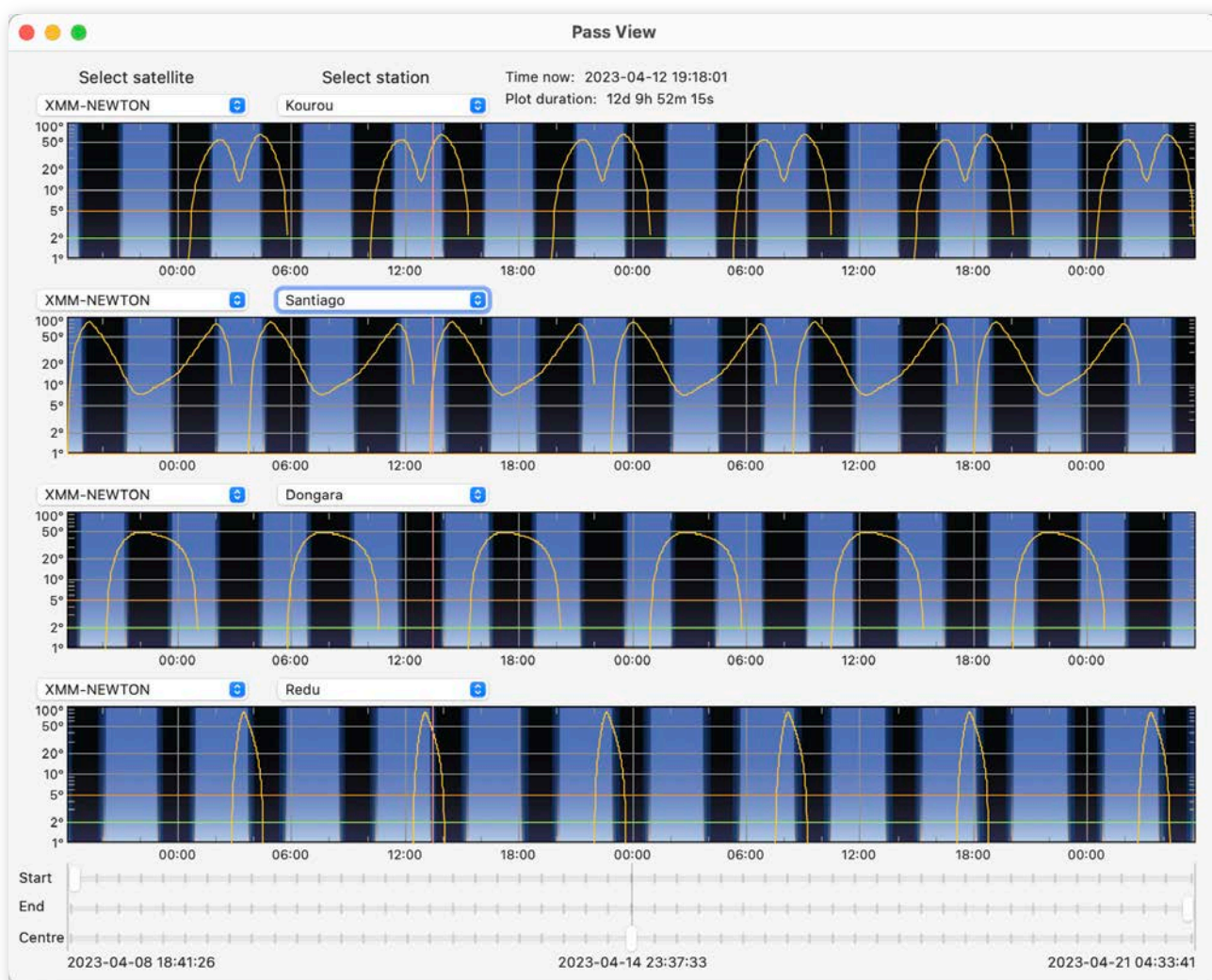
***Figure 24.** The Pass View window with one satellite and four different ground stations selected.*

The time axis, in UTC, is common to all of the stations so now we see that the first two (Kourou and Santiago), which have a similar longitude, have day and night at about the same time. Dongara, being in Australia, is more or less the opposite, with night during Kourou's daytime. Redu, in Europe, is somewhere in-between.

The night-time band is wider for Santiago and Dongara, in the southern hemisphere, than for Redu, in the northern hemisphere, because the date is in mid-April, with the Sun being north of the equator.

The line tracing out the elevation of XMM-Newton has a different shape for each station, but at a given station, each is the same. This is a consequence of the orbital period being almost exactly 2 days, so it repeats its track.

Other features to note here are some reference lines. In addition to the grid lines of the graph there is a vertical pink line, somewhere on the left part of the graph. This marks the current time: see if you can find it! The current time is also written at the top of the window; the duration of the plot is given too.

There are also two horizontal lines, in the same colours as the RX and TX horizons, and that is exactly what they are, so that you can see which portion of the trace is above those limits.

By default, the graph uses a log scale for elevation, so more detail is visible at lower elevations. If you want to switch to a linear scale, that's one of the settings described in Section 7.5.

Now change the satellite in each graph to ISS (Zarya). The graphs still cover the full 12 or so days but only 6 ISS passes have been computed: they are all squashed up around the pink line marking the current time (Fig. 25). We need to zoom in.
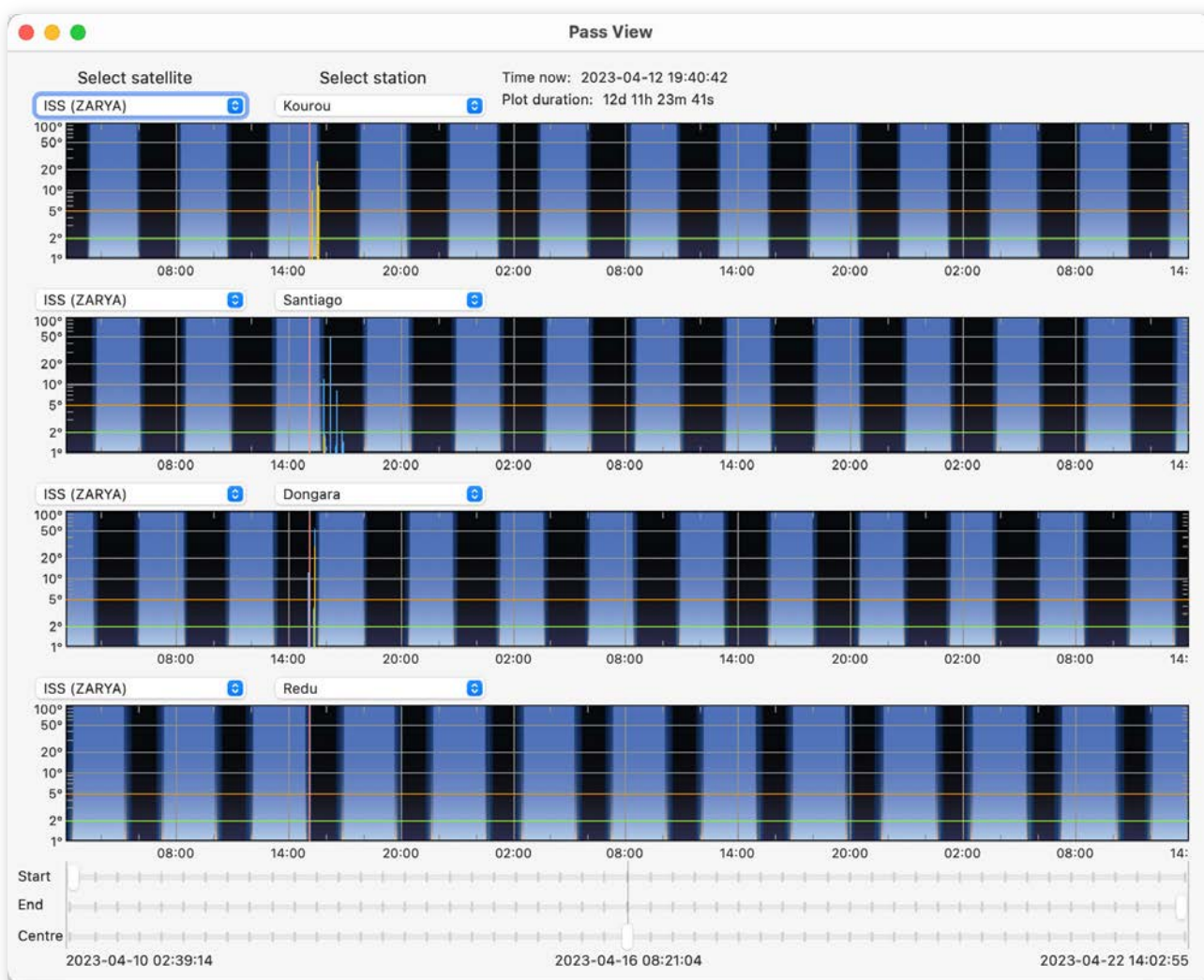
Figure 25. The Pass View window with the ISS and four different ground stations selected.

Zooming can be done with the sliders at the bottom of the window, which affect all the graphs in the same way. Unfortunately zooming can be a bit jerky: there is a lot of work going on the in background. The top slider controls the start of the graph and the middle one controls the end. Moving these towards each other will reduce the overall time span covered by the graph. At the very bottom of the window the

data and time of the start and finish, corresponding to the two faint vertical lines at each end of the sliders, is written – this may be helpful. Having reduced the span of the graph, it can be moved around by changing the central time, using the bottom slider. Again, its time, corresponding to the central vertical line across the sliders, is written at the bottom centre of the window.
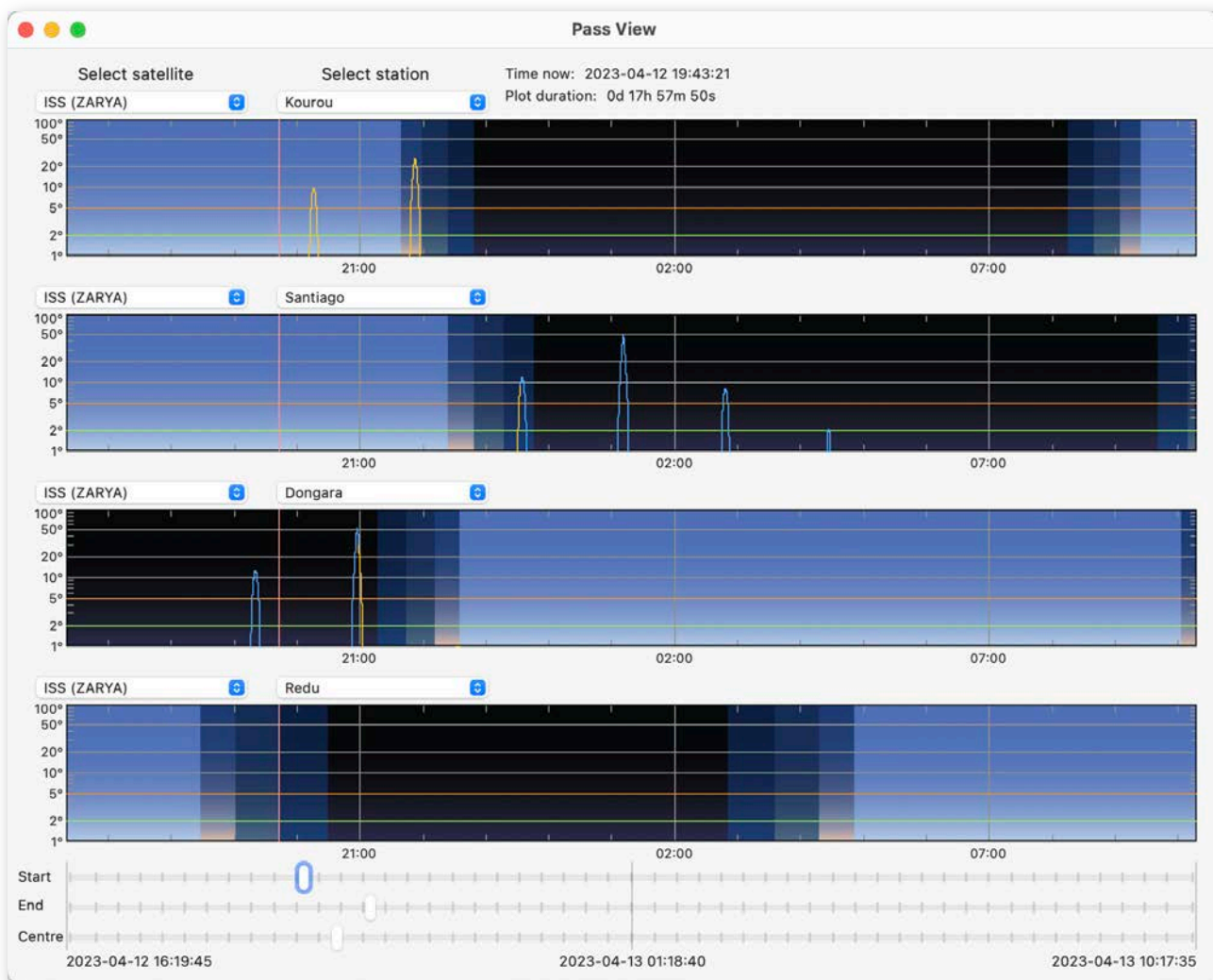
Figure 26. *In the Pass View window, the slider controls at the bottom of the window have been used to zoom in to the section of interest, where the ISS passes appear.*

Of course, if we are not so interested in XMM-Newton's passes we could just eliminate it (and MeteoSat-9 for that matter, which has no computed passes anyway). We do that by returning to Settings and deselecting them. Our **Pass View** window will now change as it adapts to the much shorter timescale without the presence of XMM-Newton, bearing in mind that it is still zoomed. We can zoom out again by moving the Start and End sliders back to their positions at the far left and right, respectively.

With the smaller time extent (the full graph now covers about half a day) we can see that it's not just day and night which are shown: the three variants of twilight (civil, nautical and astronomical) are shown too.

The satellite elevation traces are coloured orange during the day and either blue or part orange and part blue during twilight and night. Orange means the satellite is in sunlight and can be seen visibly (depending how bright it is), while blue means it is in eclipse, in the Earth's shadow, and so cannot.
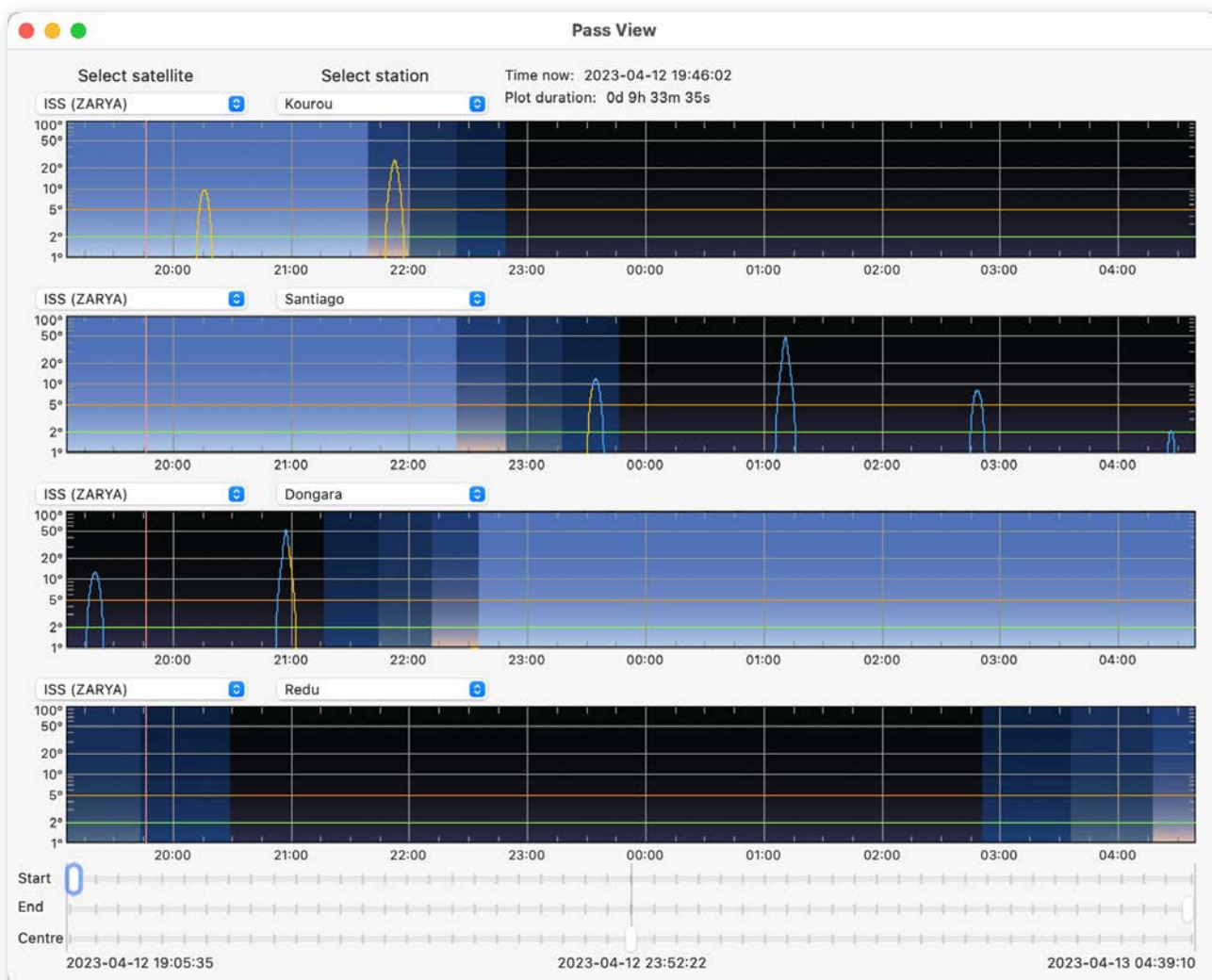
Figure 27. *This Pass View window, similar to that shown in Figure 26, shows all of the available ISS passes without the need for zooming.*

5.3.   Pass Lists

There are two types of **Pass List** available, the **Station Pass List** and the **Satellite Pass List**. We'll first describe the **Station Pass List** and then look only at the differences in the **Satellite Pass List**. Both are quite simple.

Before proceeding, we should make sure we have some relatively bright satellites selected, which means downloading the set called **100 (or so) brightest**. If you've

forgotten how to do this, check back to the beginning of Chapter 4, where we describe 'Choosing Families of Satellites'. We will use the **Satellites** tab of the **Settings** window.

We are going to choose a set of related satellites launched over a period of more than 20 years, which were all ground-breaking in their time, and which are all quite large and easily visible.

The first one to select is SeaSat 1[8]. This is a large satellite, a NASA mission[9], launched in 1978 which only lasted about 100 days in orbit before a major failure disabled it[10]. SeaSat carried a full suite of instruments designed to measure detailed characteristics of the ocean surface, three of them being microwave radars of different types (an altimeter, a scatterometer and an imaging Synthetic Aperture Radar, SAR). There was also a scanning microwave radiometer (the same design as one flown on Nimbus-7) and a visible/infra-red radiometric imager.

SeaSat was so influential, despite its short life (and limited real-time data coverage), that European scientists demanded that ESA develop a replacement (though, to be fair, ESA had already been studying similar microwave payloads for a long time before SeaSat's launch). This replacement was to be ERS-1 and naturally, being launched 13 years later, the instruments were more sophisticated, and it had a longer lifetime. It failed in 2000 after almost 11 years, though by this time it was in poor shape with many failures in on-board equipment.

ERS-1 is also large and visible, so we'll select that too, as well as its successor, ERS-2, which was launched in 1995 with additional payload instruments, and had a 16-year lifetime before being decommissioned (rather than failing).

Finally, we'll select the biggest of them all, EnviSat, which was the super-sized (at 8 tonnes) successor to ERS-1 and ERS-2 and carried a huge payload of 10 Earth observation instruments spanning much of the electromagnetic spectrum. EnviSat was launched on 1 Mar 2002 and failed just over 10 years later. A definitive root cause was never found since several overlapping failures would have been required to explain the observations of the failure.

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[8] It's called SeaSat-1 (SeaSat-A before it was launched) because the original idea was to have a series of them, as there were for the LandSat satellites. But there never was a SeaSat-2.

[9] Though a NASA mission, several other US agencies were involved in the ground segment and data processing. The SAR instrument could only be used with a real-time downlink and by the time of the mission failure there were only 5 ground stations in the network: 3 in the US (Fairbanks, Goldstone and Merritt Island), one in Canada (Shoe Cove) and only one outside the north American continent, at the UK Ministry of Defence ground station at RAF Oakhanger.

[10] The slip-rings, which transferred power from the rotating solar arrays to the spacecraft bus, suffered a massive short circuit which destroyed the whole power system.

5.3.1. Station Pass List
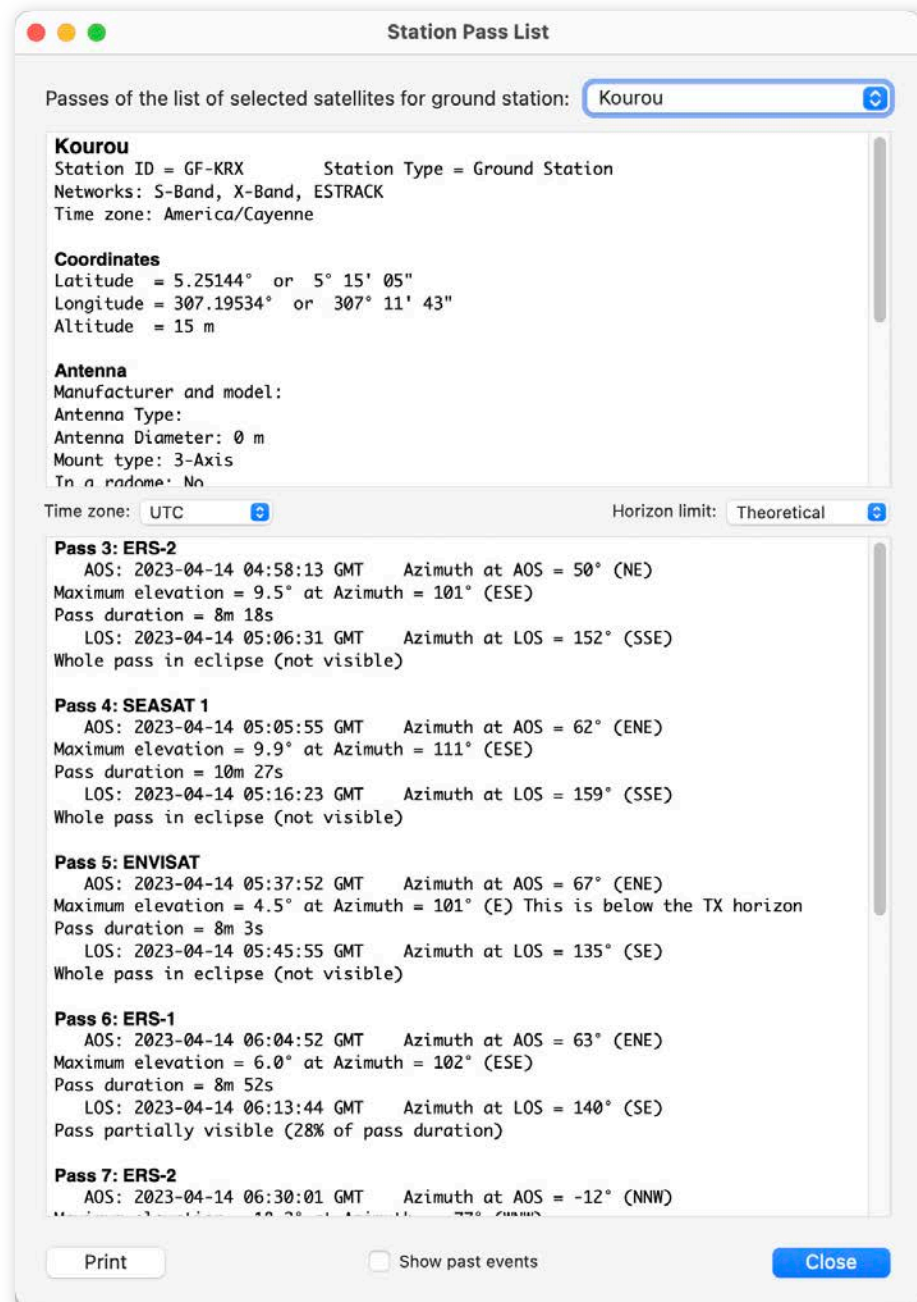
Figure 28. *The Station Pass List. Passes start at number 3 (in this case) because we are not showing past events (according to the checkbox at the bottom centre).*

The **Station Pass List** gives a textual listing of the passes (for all the selected satellites) at a given ground station. The station concerned is selected using the drop-down menu at the top-right of the window.

The first panel, which is scrollable, provides the full set of information known about the station from the Station database.

The lower panel provides the actual pass data. It lists, in chronological order, the set of passes at the ground station for all the selected satellites. For each pass it gives the

name of the satellite followed by a set of AOS times and azimuths, again in chronological order. Then there are some details about the pass itself, followed by the accompanying set of LOS details. Finally, information about the optical visibility of the pass is given.

In-between these panels are two drop-down menus.

The first, **Time zone**, has 3 entries, which control the time zone of the AOS and LOS details. Try changing them!

The other menu, **Horizon limit**, has 5 entries. It allows you to choose if you want the AOS/LOS times to refer to the theoretical, 0°, horizon, the RX or TX horizon, or some combination of them. Depending on the choice you will have more or fewer lines in the report. Again, trying it is the easiest way to understand it.

At the bottom of the window are three controls. The right-hand one, **Close**, is self-evident, while the left-hand one is one of the two places where we have provided a dedicated printing function in *SatTracker* (it being useful to have a printout of these pass lists).

The central checkbox allows you to also look at (a limited number) of past events. Usually, you will be more interested in upcoming passes than ones already missed, which is why it's disabled by default.

5.3.2. Satellite Pass List

As we said, the **Satellite Pass List** (see Fig. 29 on the next page) is very similar to the **Station Pass List**.

We will choose the satellite in the drop-down menu at the top-right. The first panel is different of course, because now it provides details of the satellite instead of the ground station. There are several blank fields here (Launch date, etc.), which are planned to be populated in future versions of *SatTracker*.

They are not populated yet because these data are not contained in the TLEs – they will need an extra, new database with satellite information to cross-reference to the TLE identifier. This is perfectly feasible for satellites currently in orbit, but keeping this hypothetical database up to date is tricky, and may not even be possible for recent launches. The huge number of debris items resulting from satellite break-ups is another difficulty.

These are problems for the future version!

The second panel, with pass details, now lists a set of ground station passes, again in chronological order. All the other descriptions of the **Station Pass List** are applicable.

In the example we show here, Fig. 29, we have chosen to display All for the **Horizon limit.** So, more lines of data are presented for each pass, but as we can see in the first line, if the satellite does not rise above one of the horizons (in this case the highest one, the TX horizon) then there is a relevant message.
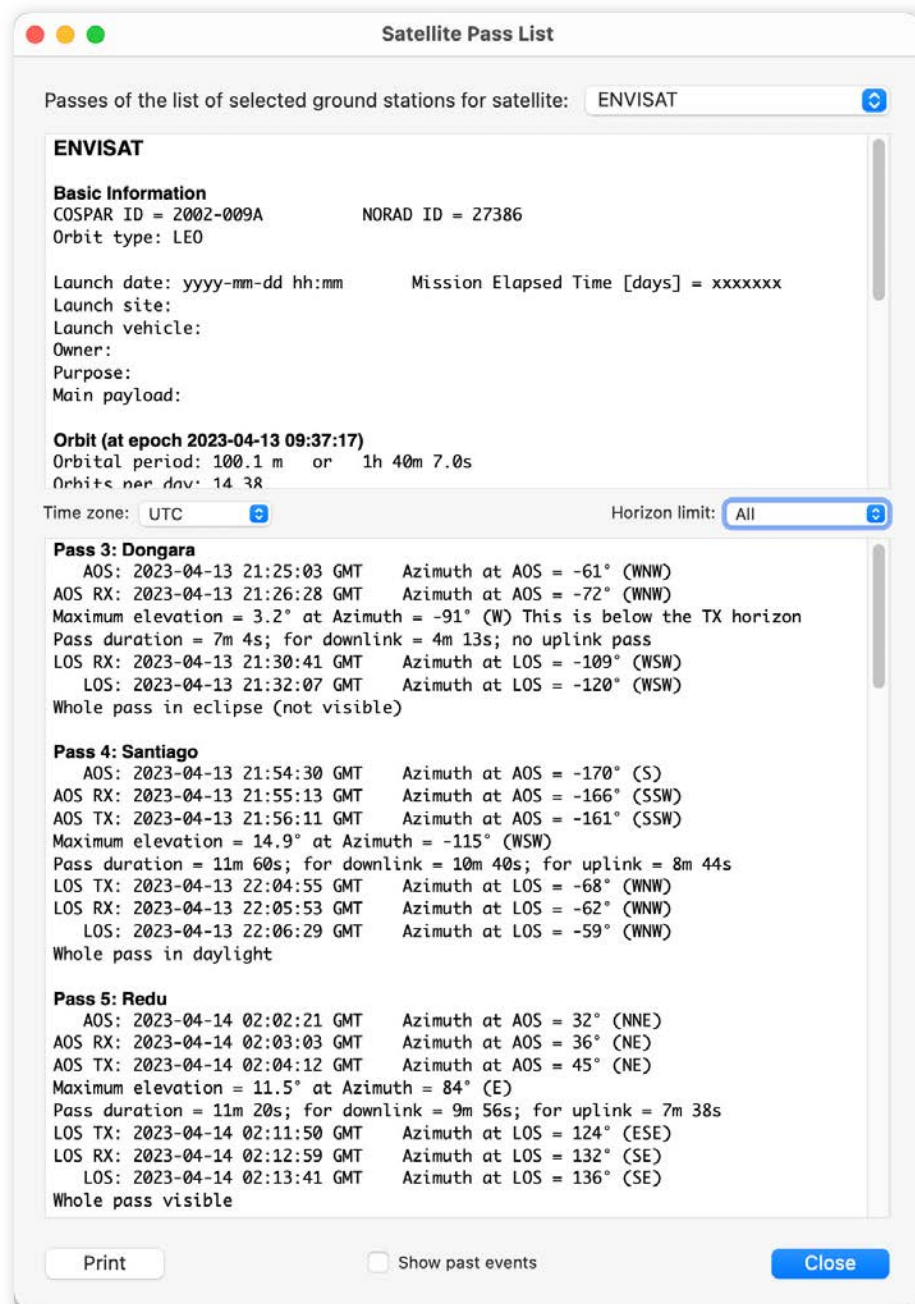
Figure 29. *The Satellite Pass List.*

5.4.   Antenna DB

This window (See Fig. 30) is of limited interest by itself. It is the interface to a new internal database of commercial ground station antennas, and, in some cases, the associated RF equipment provided with them.

This database is of main interest in defining new stations (and in limited cases, in modifying existing ones).
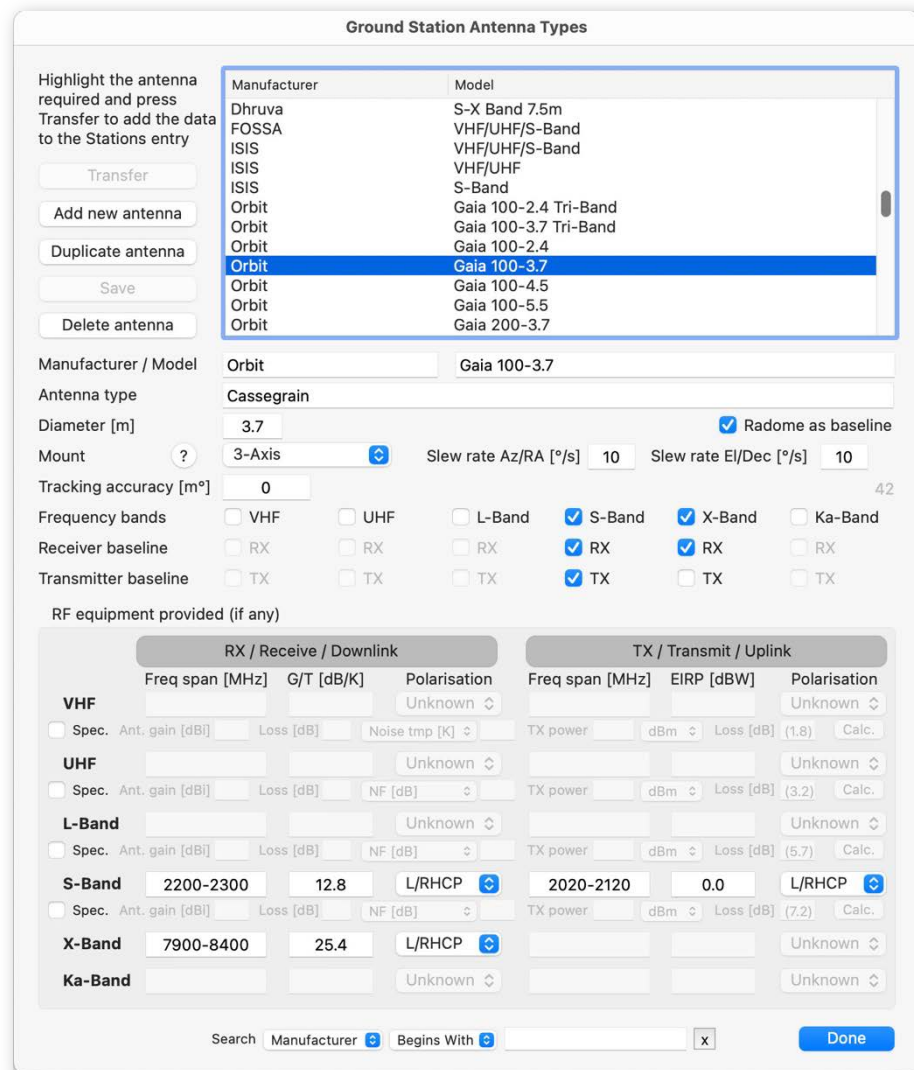
Figure 30. *The Antenna DB.*

It currently contains antenna/stations ranging from relatively low-cost VHF/UHF systems through to huge 13m diameter paraboloid dishes. Of course, it is by no means an exhaustive list!

The database can be extended by adding new antennas.

6. Reference: Main Menu Bar

*S*atTracker has a relatively sparse main Menu Bar, but it is worth going through the elements of it.
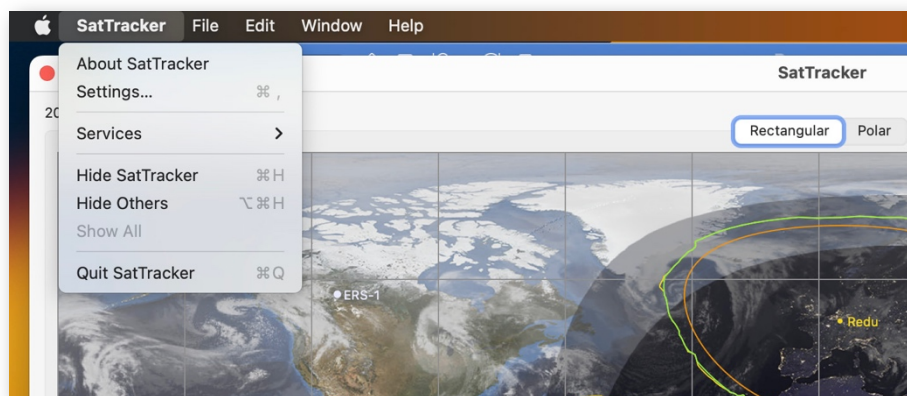
Figure 31. *The SatTracker menu.*

As usual for macOS applications the first menu, headed **SatTracker**, in bold text, contains two items: **About SatTracker** and **Settings…** (in versions of macOS before Ventura, **Settings…** is called **Preferences**).

The first item, **About SatTracker**, displays a small window with, as might be guessed, some information about *SatTracker*.

The second item, **Settings…**, is fully described in Chapter 7 below.
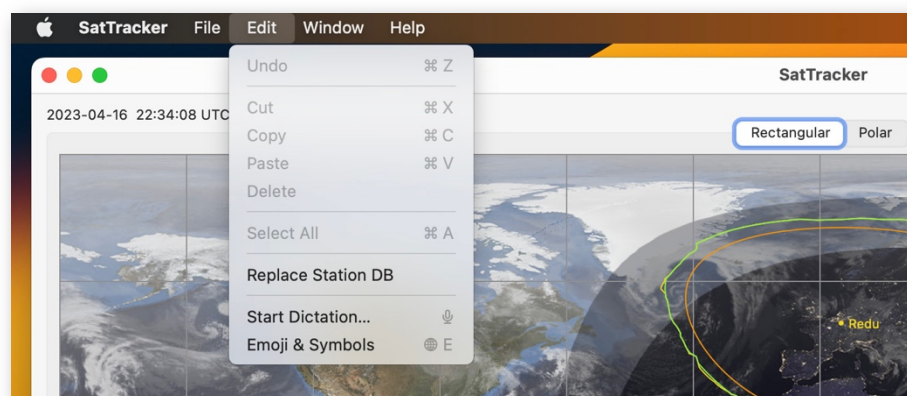
Figure 32. *The SatTracker Edit menu.*

Under the Edit menu there is a potentially useful item: **Replace Station DB** (there are also some other standard items, but they have no special function in *SatTracker*).

The option **Replace Station DB** offers the opportunity to start with a fresh version of the shipped Station database, in case you have somehow got it into a poor state. The old one will be deleted, and you will need to restart *SatTracker* so that it will make a fresh copy from its internal resources. There are several 'are you sure?' dialogs on the way!
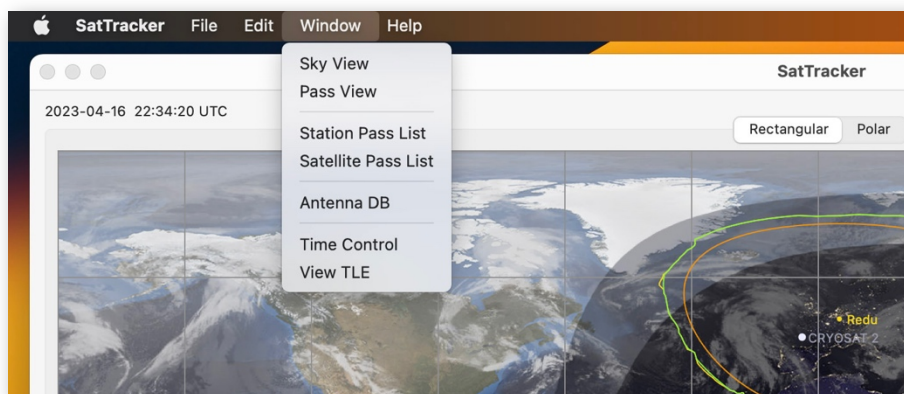
Figure 33. The SatTracker Window menu.

Under the Window menu there are several selections, fully described in later Chapters.

Sky View is described in Chapter 8.

Pass View is described in Chapter 9.

Station Pass List is described in Chapter 10.

Satellite Pass List is described in Chapter 11.

Antenna DB is described in Chapter 12.

Time Control is described in Chapter 14.

And finally **View TLE** is described in Chapter 13.
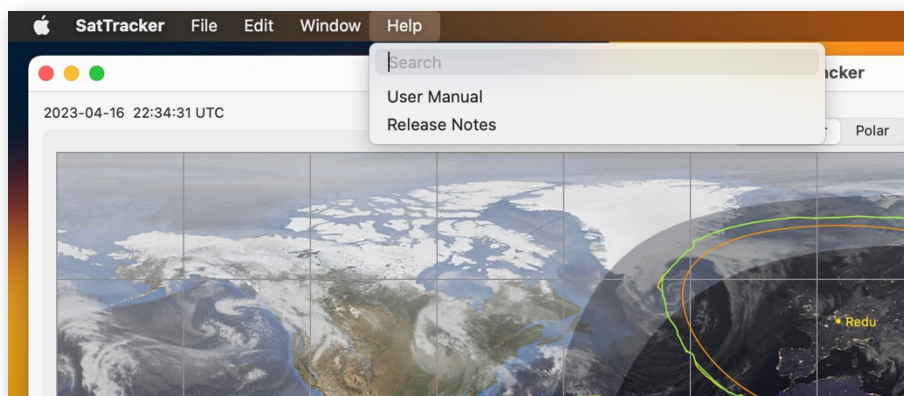
Figure 34. The SatTracker Window menu.

There are two items under the Help menu, and both open PDF files in your preferred viewer (Preview, Acrobat, etc.). They are **User Manual**, which opens this present document, and **Release Notes**, which opens a document detailing the changes from build to build during the development, up to the current build. Note that some of the early entries are a bit sparse!

7. Reference: Settings

7.1. The TLE Tab

The left-most tab in the Settings (or Preferences) window, the TLE tab, controls the download of so-called 'Two-Line Elements' or TLEs, for spacecraft, used-up rocket stages and bits and pieces of space debris. Space debris can be fragments of satellites after a breakup event or parts which were jettisoned, during the time before space debris became recognised as a major problem[11]. For now, we'll simply call all these things Satellites.
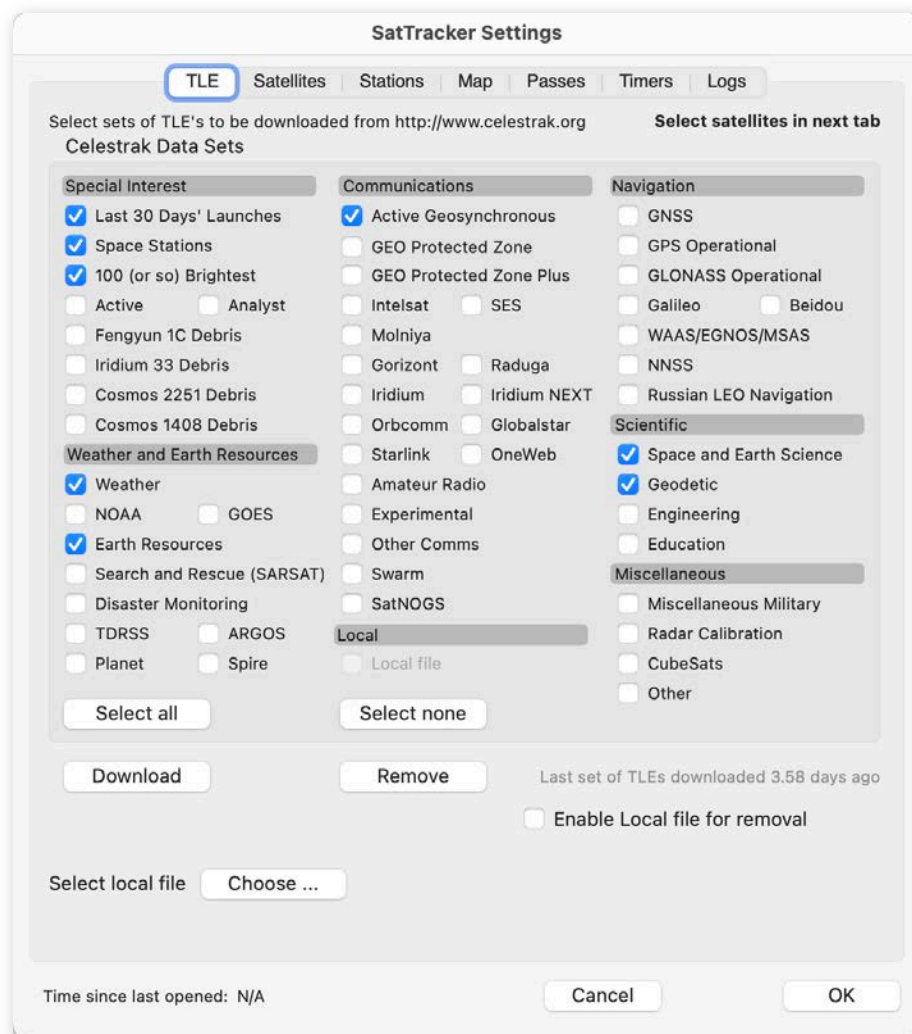
Figure 35. *The SatTracker Settings window with the first tab, TLE, showing with several families of satellites selected.*

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[11] Space debris includes small items like chips of paint, but publicly available TLEs only contain items larger then about 10 cm.

The orbits of satellites are described by a small set of numbers and these sets are known as *orbital elements*[12]. The elements define the size and shape of the orbit as well as its orientation in space. They also say where the satellite actually is along its orbital path at a given time.

There are different ways of defining these elements, but the type we will be using are called two-line elements because all the information is coded into two lines of numbers. The formatting is very specific and, if you are interested, open the **Window > View TLE** window, as described in Chapter 13, to see the format and its interpretation for whichever satellite you choose.

Sets of TLEs are very commonly used as a means of disseminating information about satellites for general use. They have drawbacks (such as not providing any information on uncertainty in the numbers) but are commonly available. They are also tuned to the SGP4 algorithms used in *SatTracker* for orbital calculations. The source used by *SatTracker* to obtain TLEs is CelesTrak, probably the most commonly used source in the world.

CelesTrak groups satellites into families, and within each family it has separate files with individual TLEs for many satellites. Some satellites appear in more than one file. This structure is shown in the area called **Celestrak Data Sets** in this TLE tab. In total the number of satellites in these files number many thousands (although over 4000 of these are literally pieces of debris resulting from the high-speed collision of Iridium 33 and Cosmos 2251 on 10 Feb 2009, and from the deliberate destruction of Fengyun 1C on 11 Jan 2007 – these are in the appropriately named files).

To use *SatTracker* to show satellite orbits it's first necessary to download some of these files of TLEs. Tick one or more checkboxes in the categories you're interested in and press the **Download** button. The files will be downloaded, unpacked and the TLEs stored in *SatTracker's* internal database.

You can select or deselect the checkboxes in bulk with the **Select All** and **Select None** buttons.

Sometimes you may want to clear out satellites from the database. For example, the category **Last 30 Days' Launches** will often contain satellites in a category you are not interested in. After a month or so, the TLEs will no longer be in the **Last 30 Days' Launches** category, and you would need to find the appropriate file (maybe **CubeSats**) in order to keep the TLEs up-to-date. The way out is to clear out the **Last 30 Days' Launches** category. To do this, select the checkbox of one or more categories to be removed and press the **Remove** button.

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[12] We have a lot more to say about this in Chapter 13. But, for now, we can say that a Satellite's 'state' can be defined by a *state vector*, consisting of the 3 components of position and 3 components of velocity, at a given time: 6 numbers, or pieces of information, and a time. But there are many ways to define and orbit and the '6 parameters and time' can be adapted in many ways. One is the version of the mean Keplerian orbital elements encoded in TLEs (which are sometimes called 'keps', after *Johannes Kepler* who deduced the laws of orbital mechanics from a painstaking analysis of decades of positional measurements of the planet Mars made by *Tycho Brahe* in the 16th century. Neither of them had any modern aid: just a sharp eye and a large mural quadrant for Tycho and quill, paper and a sharp mind for Kepler).

It's also possible to include your own TLE data. Obviously, this is mostly of interest to those who are building their own satellites! Usually, in the days before launch, the satellite control centre will have predicted TLEs available[13].

Another usage is during the simulations campaign in the months prior to the actual launch, where a simulated TLE, together with the Time Control window can be used to simulate separation following the simulated launch, and early orbits.

If you fall into this group, or maybe because you just want to play around, the idea is that you need a file with a single satellite defined in the TLE format. It should not have the same ID or name as any real satellite of course. Then, using the **Choose ...** button, select the file, and make sure the **Local > local file** option is ticked in the TLE import window. Note that you cannot tick this unless a file has been specified.

If you find that you need to remove this TLE later, then select the **Local > local file**, having first ticked the box **Enable Local file for removal** in the lower part of the panel, and then click **Remove**.

7.2. The Satellites Tab

The **Satellites** tab is where individual satellites are selected (Fig. 36). We have already seen its use back in Chapter 4.

The internal databases used for satellites and ground stations are very efficient and fast, and this shows in the effectiveness of organising and finding satellites in this tab.

7.2.1. Satellite List

The main part of the window is taken up by a list of satellites. This shows a few key pieces of information for each one, taken from the files downloaded from CelesTrak. It might be interesting to have more information too, such as where the satellite was launched from, but unfortunately this is not in the files.

The columns can be reordered by clicking in the header row, for each column, and the column widths can be modified by dragging the dividing lines in the header.

The meaning of the columns is described here:

▸ *Name:* this is the name given in the TLE itself. It is usually the same as, or very similar to, the common name, although there are exceptions. We mentioned earlier that some satellites appear in more than one of CelesTrak's files, and in some cases these different appearances will have variations on the name! There are a couple of abbreviations to be aware of: R/B means Rocket Body – in very many cases the upper stage of the rocket used to launch a satellite remained in orbit too. In recent times the hazards of space debris have become better understood and efforts are made to bring such upper stages back to Earth

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[13] In the roadmap of future development for *SatTracker*, we plan to eventually include a means to generate such synthetic TLE's.

afterwards. And in this vein, DEB means a piece of debris, and there are very many of them.
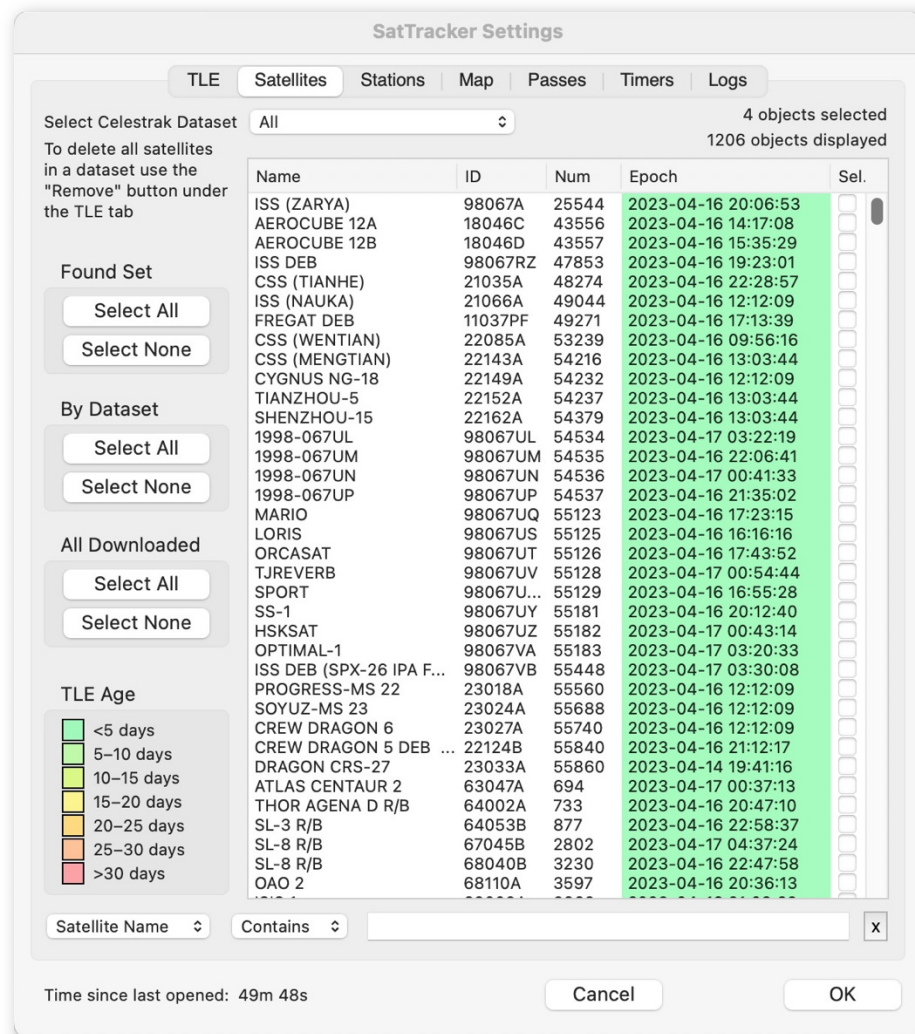
Figure 36. *The SatTracker Settings window with the Satellites tab selected.*

▸ *ID:* this is the International Designator, and it gives some useful information. The first two characters give the year of the launch (the last 2 numbers only: Sputnik 1, the first satellite, was launched in 1957 so there's still some time to go before we have an ambiguity with this). The next 3 characters are numbers indicating the launch number starting at the beginning of the year. So, looking at the top of the list above, we can see that the ISS was the 67th launch of 1998. Up to 3 more characters, letters this time, finish the International Designator. These indicate the piece of the launch. Usually, A is the main payload. This identifier is unique.

▸ *Num:* this is the Satellite Catalogue Number, allocated by the NORAD (which is the original source of these TLEs). It is a sequential number, assigned as objects are catalogued. This unique number is also an unambiguous way of referring to satellites.

▸ *Epoch:* The numbers in the TLE define an orbit in space, which is a closed curved path, but they also define a position on that path and the time when the satellite is

in that position. This time is the epoch. Each time a set of TLEs is generated (normally once per day) this epoch is set to a time close to the satellite's *ascending node*. For long-period orbits like XMM, this may be in the future! As well as providing critical part of the satellites orbit definition the epoch can be used to judge how recent the TLE is. It goes without saying, we hope, that up-to-date TLEs are the most accurate. Satellites sometimes make orbital manoeuvres which can mean that TLEs dating from before the manoeuvre are very inaccurate. To give an immediate indication of the age of TLEs the epoch field is colour-coded, and the code for this is given on the left, in the box TLE Age.

▸ *Select:* this column holds a checkbox. If ticked it means that the satellite will be included in the list of objects plotted on the main map.

7.2.2.   Selecting Satellites

How you select satellites depends partly on what you're trying to do. If you're looking for a specific satellite (as we were in the previous Chapter) it's much easier to make a direct search for it. Make sure that the drop-down menu above the satellite list, **Select Celestrak Dataset**, is showing All. Then go to the search area at the foot of the window (with the two drop-down menus and a text-entry field). Usually, you will search by the satellite's name, and that is the default menu choice. But, if the name isn't obvious, you can also search by the International Designator (Intl. Designator) or Catalogue Number (Catalogue Num.).

The first drop-down menu sets the field which will be searched. The second defines the nature of the search, using the usual database options (exactly equals, contains, etc.). The text field is the place to type what we're going to search for. Less obvious is the little button with a X at the right hand side. That clears the text field.

An interesting example is shown in Fig. 37 on the next page. A search on the International Designator, with the filtering for values beginning with 6 provides a list of satellites launched in the 1960's. Seventy show up – there were more launched than this of course, but we have not downloaded all of the groups which could contain old satellites [14], and many will have re-entered the atmosphere in the meantime. Interestingly 23 of these objects are space debris, labelled 'TITAN 3C TRANSTAGE DEB' and there are two satellites with the same numerical part of the International Designator: OV2-5 and LES-6. These are both US Air Force satellites and were part of a multi-satellite payload for the Titan-3C launch on 26 Sep 1968. The Transtage was a flexible upper stage which could be used for apogee boost manoeuvres amongst other things. They were left in the geostationary orbit after injecting the various satellites into their intended orbits.

This one broke up on 21 Feb 1992, some 24 years after it was launched. The Titan 3C Transtage used hypergolic propellants, which means they ignite on contact. This type of breakup event is why one of space debris mitigation rules now is that all propellant tanks must be vented at the end of mission.

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[14] Note that to find 70 satellites we also downloaded 2 more families compared to those shown in Fig. 35: GEO Protected Zone Plus and Radar Calibration.
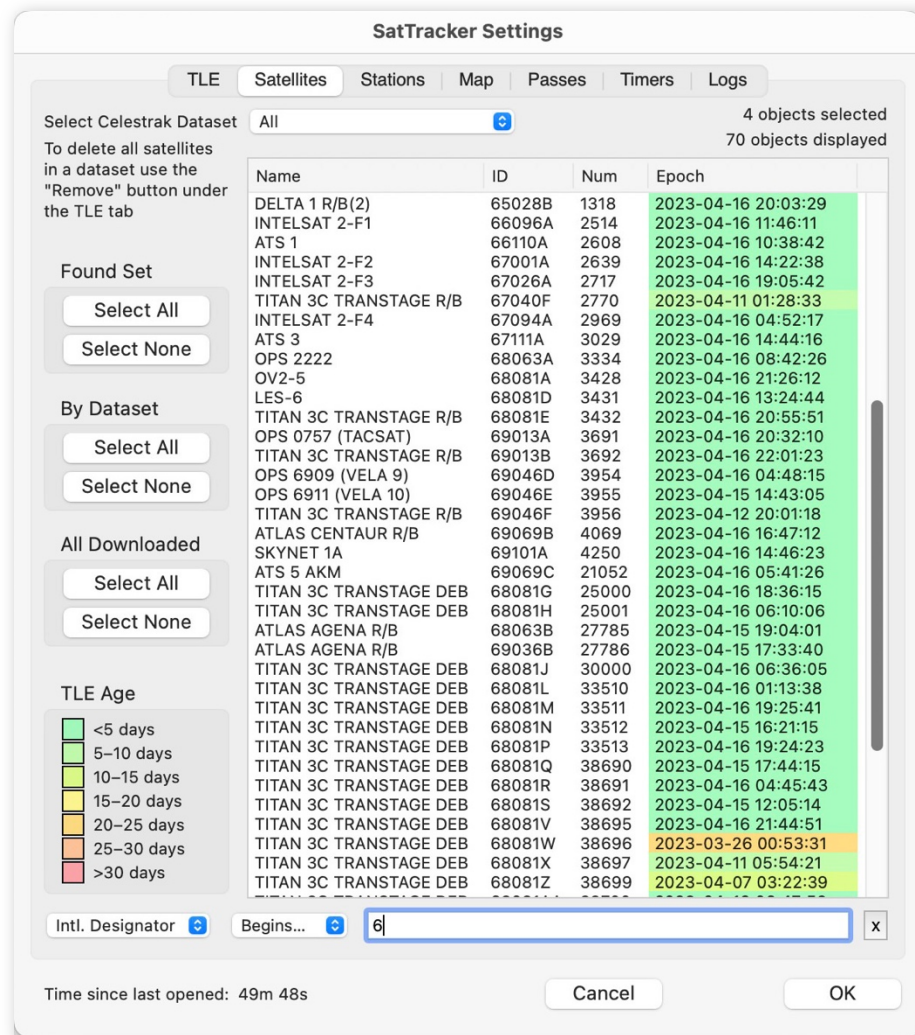
Figure 37. Finding satellites launched in the 1960's (from among the satellites downloaded).

Another search approach is to look for all satellites in a given family or group. Here we make use of the fact that the CelesTrak files are organised in groups, as we saw with the **TLE** tab. Selecting a CelesTrak dataset, using the drop-down menu at the top, will immediately give a list of related satellites (or the many pieces of debris resulting from one satellite, in the case of a few of the groups).

The remaining controls here are concerned with the selection of the satellites to display on the map. We are now going to talk about the panels on the left side, and we'll start with the third one down.

All Downloaded

This provides an all-or-nothing capability to select (or deselect) the entire set of downloaded satellites.

By Dataset

Using this middle box you can select all of the objects in the displayed dataset (chosen with the **Select Celestrak Dataset** dropdown menu), or none of them.

Both of these should be treated with caution: it is very easy to select many thousands of satellites; computing the orbits for all of them is a major task which can easily exceed the time between screen updates. If this begins to happen, *SatTracker* will automatically extend the time between screen updates. There will be a message saying so at the bottom of the main window, but the app may appear unresponsive. Quitting and then restarting will not restore the situation as the database and its selections are preserved between sessions.

A warning dialog about this risk appears if you select a lot of satellites. If you decide to press ahead and do enter this condition, with *SatTracker* seemingly unresponsive then there is a remedy on the next start-up. *SatTracker* will check the database and if many satellites have been selected it will offer the option to revert to the default, a sparse satellite database with nothing selected. If this option is taken, then the app will quit and the next startup will have the default satellite database. The last selected TLE sets are memorised so re-downloading the TLEs should be painless.

Found Set

This upper box presents a very useful way to select satellites.

Imagine you want to display all the satellites from the latest Starlink launch, but not the other Starlink satellites. This can be interesting because in the days after launch they form a closely spaced row along the orbit, while the whole dataset of many thousands of them is not only a heavy computational load but also clutters up the view. You can easily achieve this selection with panel **Found Set**.

Recall that the field labelled *ID* (short for *International Designator*) is composed of 2 digits for the year of launch followed by 3 digits for the consecutive number of the launch, and then letters for individual objects which were on that launch. So, use the **Select Celestrak Dataset** drop-down menu to choose 'Starlink' and all the thousands of Starlink satellites will be listed in the window (assuming you have downloaded the TLEs on the **TLE** tab, of course!). Click the column heading **ID** and the results will be ordered by that field. Scrolling to the bottom we can see the most recent launch; in the case shown here it was the group of satellites with the ID 23037*nn*, where *nn* are one or 2 letters indicating the individual satellite on that launcher.

Now we'll use the search tools at the bottom of the tab. First use the leftmost drop-down menu to choose **Intl. Designator** as the field to search, and with the next drop-down menu choose **Contains** or **Begins With**. Finally in the search field itself type '23037' or whatever is the common part of the ID that you want.

In our case, as we see at the top of the display, there are 52 satellites, and it would be rather tedious to click **Select** for each of them. By pressing **Select All** in the **Found Set** panel, this is accomplished with one click.

If at some future time you want to deselect these, there are two possibilities. Pressing **Select None** in the **By Dataset** panel will deselect all selected Starlink satellites (assuming Starlink remains the selected dataset). Alternatively perform the same find again, and press **Select None** in the **Found Set** panel.
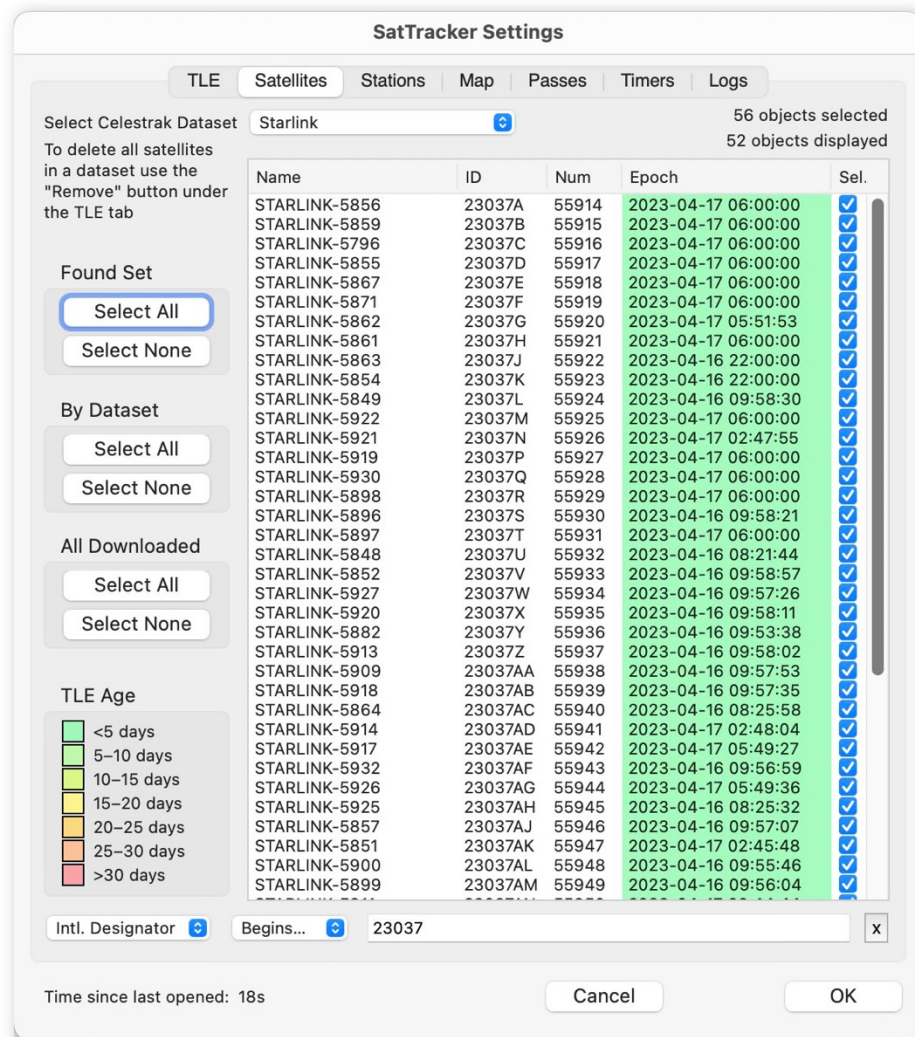
Figure 38. *Finding and selecting satellites in the most recent Starlink launch.*

Important:

Despite the satellites being marked selected in the **Satellites** tab, the actual selection is only done when pressing the **OK** button to exit Settings/Preferences. Do not use **Cancel**.

7.3.   The Stations Tab

7.3.1.   Station List

The **Stations** tab has many features in common with the **Satellites** tab we just looked at. In particular, the list of stations acts in the same way as the satellites list, and so do the search features at the bottom of the window.

We need to say a few words about the types of stations which can be selected. Let's look at Fig. 39 below, and the drop-down menu at the top: Select Station Type or Network.

The first 5 entries (after All) are Ground Station, Laser, DORIS, Special and Other. These describe the types of station and are probably mostly of interest to satellite professionals. Below the separator are the remaining entries, which are Networks; we'll come to these soon, when we look at the first entry, Ground Station.
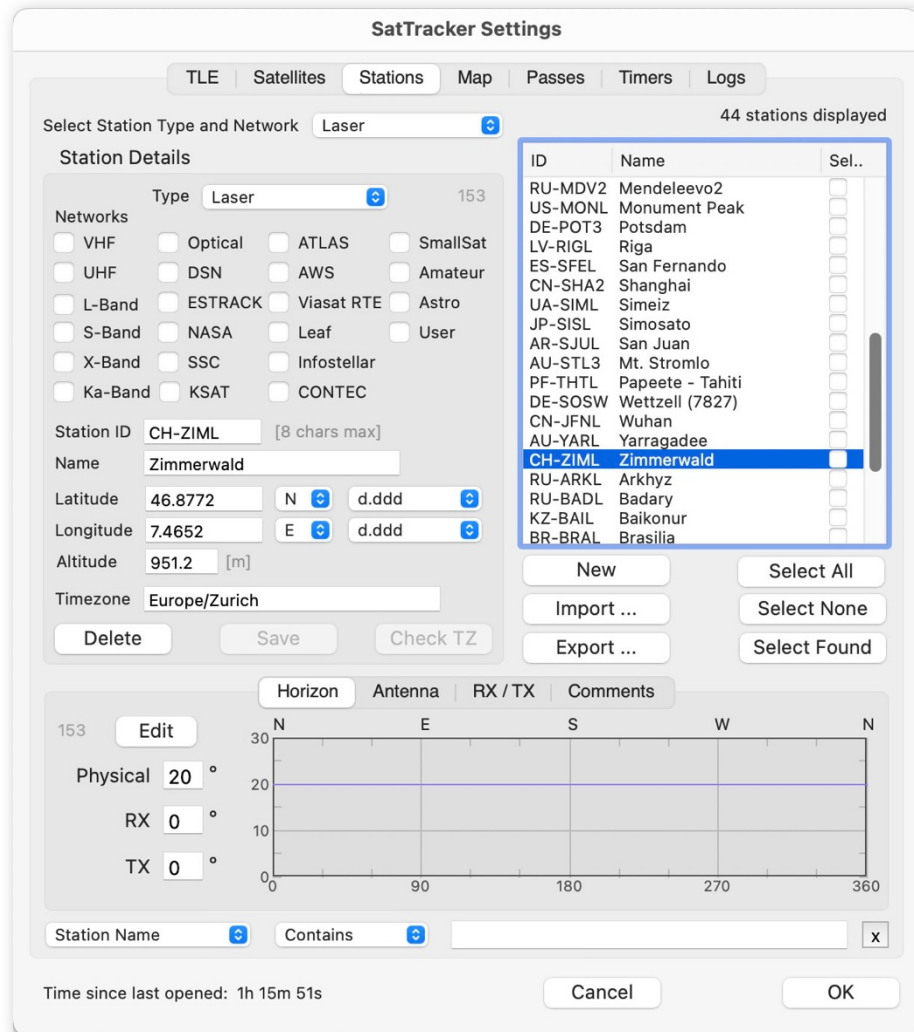
Figure 39. *Stations tab, with the station type filter chosen to be 'Laser'.*

Laser stations are facilities equipped with short-pulse lasers, telescopes and high-speed receivers. They can measure the range to satellites with astonishing accuracy. DORIS stations are globally distributed high precision radio beacons whose signals are received on satellites and used to measure the speed relative to the beacon. Both of these types are used to make measurements enabling the most highly precise orbit determination (good to about a centimetre!).

The categories Special and Other may be used for whatever purposes you want. By default, there are two entries under Special (a temporary facility in Oman used to support some rocket launches from Baikonur, and Silo 109 at the Baikonur launch

complex, from where CryoSat-2 was launched). Other, in the default database, includes a few installations which do not fit into the other categories. They are special-purpose facilities which return the signal from radar altimeter instruments carried by some satellites (for example, Sentinel 3A, 3B, Sentinel 6, CryoSat-2 and Jason-3) for calibration purposes. They are either active transponders (identified as TR) or corner reflectors (CR). They have a horizon just a few degrees from the zenith.

Stations can be imported and exported from/to the database (see Section 7.3.9). Imported stations labelled as Radio Amateur or Astro will be assigned to the type Special. Stations labelled as User, or which can't be identified, will be assigned to type Other. Of course, you can use both the Special and Other types for anything you want.

As with the Satellites tab, all the stations in a category can be selected by using the Select All (or the Select None) button. Similarly, the Select Found button works in the same way as it does in the Satellites tab.

Now let's look at the general category of Ground Stations. In the Fig. 40 we have selected a station called Mojave, with ID US-MOJA (note that there are 2 stations called Mojave), in the United States.
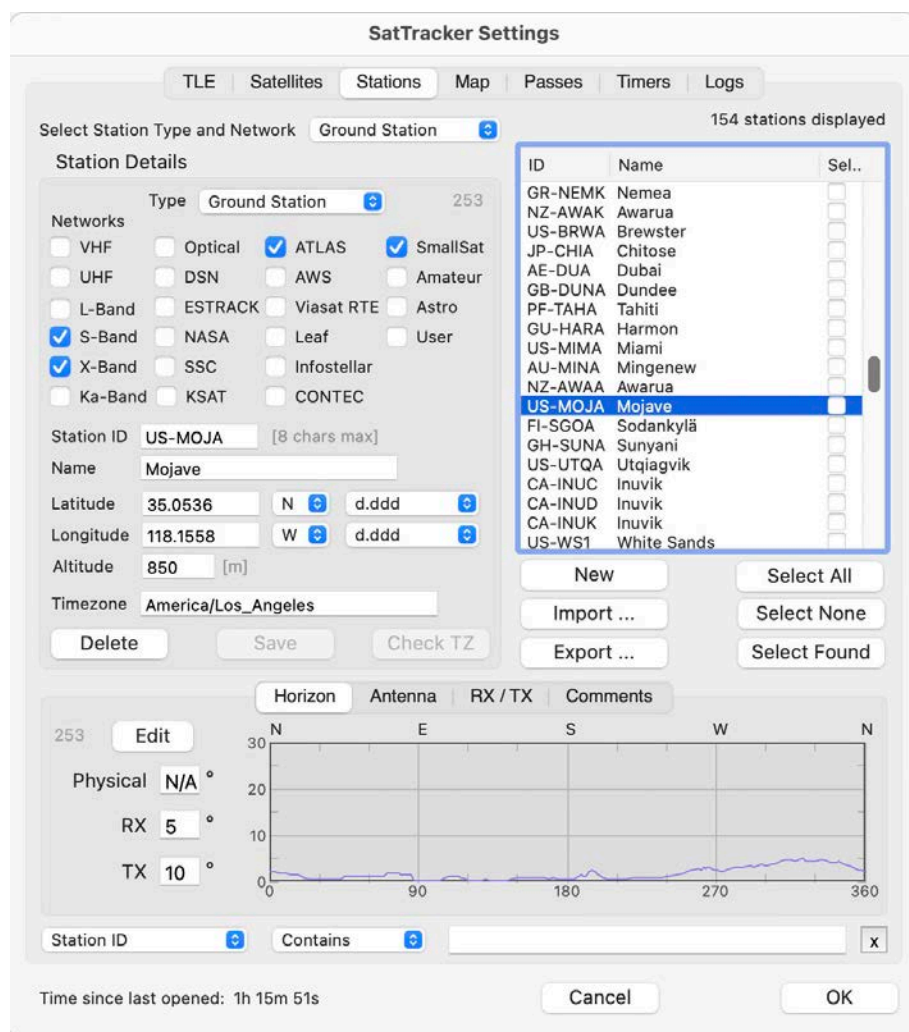
Figure 40. *Stations tab, with Mojave, US-MOJA, highlighted.*

7.3.2. Station Details

The panel on the left, **Station Details**, has become active. The pale number at the top right of the box (253 in this case), is a unique number identifying the station in the database. It has no significance for the user.

The various items in this panel are all editable (which is particularly important when we create a new entry). When we are working with an existing station (and the existence of the identifying number, described just a moment ago, is a fool-proof indication of this) any change we make will change the existing database entry. Starting from the top, we can see that Mojave is a Ground Station. This can be modified in the drop-down menu **Type**.

Tip: you can change any item here but, assuming you are experimenting, do not press **Save** *(nor respond when the dialog box pops up warning that you did not save). If you* ***do*** *press* **Save** *then your changes will be committed to the database and there is no undo function for that.*

In the next group down (the set of checkboxes called **Networks**) we can see that Mojave is an *S-Band* and an *X-Band* station (we will see more details about this later in this sub-section). It is also a member of the *Atlas* network.

This Networks section has been greatly expanded from earlier versions and now includes many commercial networks of ground stations (though not all of them, in this rapidly changing market) which are of interest to operators of SmallSats[15]. Members of each of these networks can be selected with the drop-down list we mentioned earlier: **Select Station Type or Network**.

Then we come to the identifying information. The fields **Station ID** and **Name** are used in the station list and also appear on the map (under user control).

The **Station ID** is a short code which can be used on the map instead of the name, to reduce clutter. The 8 characters ID starts with the 2-letter country code and a hyphen. In this way the station list can be searched or sorted for stations in a country. The country codes used are the standard ISO set, as listed in Annex A.

The station location is defined in the next three fields, **Latitude**, **Longitude** and **Altitude**. The units of latitude and longitude can be given in many angular measures as defined in the drop-down list. The convention here is that d means degrees, m means minutes and s means seconds. Any value shown with a decimal point allows decimal parts to be used, so 63.1916 in the form d.ddd is the same as 63° 11' 30" in the form d° mm' ss". Try it! **Altitude** is always given in metres above the WGS-84 reference ellipsoid, so you will see negative values sometimes.

We then have the field **Timezone**. This is the time zone of the station according to the official TZ database. As there are almost 600 entries here, we made the decision that instead of an unwieldy drop-down menu, the user should enter the time zone name

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[15] Many of these commercial networks are generically called *Ground Station as a Service* (GSaaS), meaning that the satellite operator uses a software front-end to interface to a ground station network which performs scheduling, acquisition, telecommand uplink and other functions more-or-less transparently.

directly. Normally the definition is simple, being the region or country followed by the nearest main city: *Europe/Paris*, for example. Some widely used abbreviations, such as *GMT*, *CET* or *EST*, are also valid. In case of difficulty the 'ToolTip' gives the link to a Wikipedia page defining all the known entries. Due to the potential for error here, uniquely this field needs to be validated before the Station can be saved: use the **Check TZ** button for this.

The two remaining buttons in this box, **Delete** and **Save**, need to be handled with care. **Delete** results in a permanent removal of the ground station from the database. **Save** will change the station entry in accordance with the values entered in this box (or any of the tabs in the block below which we'll look at in a moment). Again, only press **Save** if you are sure that's what you want to do. If you haven't changed anything, **Save** cannot be clicked.

7.3.3.   Horizon

The lower part of the **Stations** tab includes another tab box with four tabs, of which the first is **Horizon** (clearly seen in Fig. 40 above). The parameters in this tab control the three horizon contours which appear on the main map window, and also, as we will see in Chapters 10 and 11, the pass characteristics listed in the **Station Pass List** and **Satellite Pass List**.

The graphic in this tab box shows a representation of the obstructions to the station's horizon, going from North, through East and South and eventually back to North. There are also some further controls: **Edit** and three data fields.

The first data-entry field, which defines the Physical horizon, may contain 'N/A' or a numerical value. The former means that the physical horizon profile is defined already by the numerical profile shown in the graphic, while a numerical value means that the physical value is, instead, represented by a constant value. This may be because it is indistinguishable from zero, or because we have been unable to establish the profile[16].

The second field defines the horizon for telemetry downlink, reception, or, more briefly, RX. As we mentioned earlier, this may be an engineering judgement of the limit of reliability of the telemetry link, or there may be a limitation in the license conditions (although this is not evidently valid for data reception).

The third field is the equivalent definition of the horizon for telecommand uplink, transmission, or TX. This may also be an engineering consideration of the uplink, but is, more often, a limitation in the transmission license.

Note: if either the **RX Horizon** or **TX Horizon** field is left blank, or is 0.0, then default values of 2° and 5° respectively will be used when drawing horizon in both the main window and in the Sky View.

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[16] In the absence of a published horizon profiles for a ground station (often provided by institutional ground station operators) we have used the invaluable resource at the website `http://www.heywhatsthat.com`. This uses a DEM to compute local horizons and more, but unfortunately it is limited in latitude to <60N and <54S.

Returning to the physical horizon, if we click the **Edit** button, we can see an expanded version of the graphic, which also gives us the opportunity to edit it (unsurprisingly).
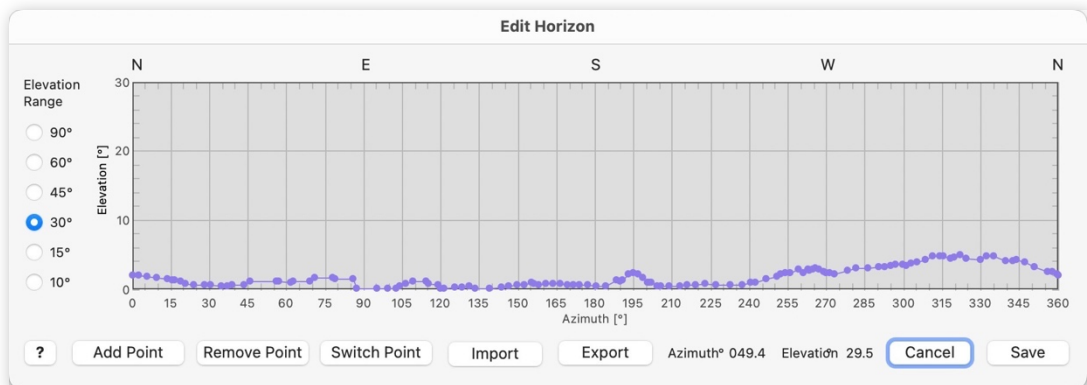
Figure 41. *The Edit Horizon window, showing the horizon for the Mojave station, US-MOJA. The vertical scale has been set to 30° to match the scale in Fig. 40.*

In this example the horizon is defined by a set of irregularly spaced points (the purple blobs). Each of these can be dragged to modify the horizon (say if somebody planted a nearby tree), and new points can be added by using the **Add Point** button.

More details about editing horizons are provided in Section 7.3.8, where we describe making a new station.

7.3.4.   Antenna
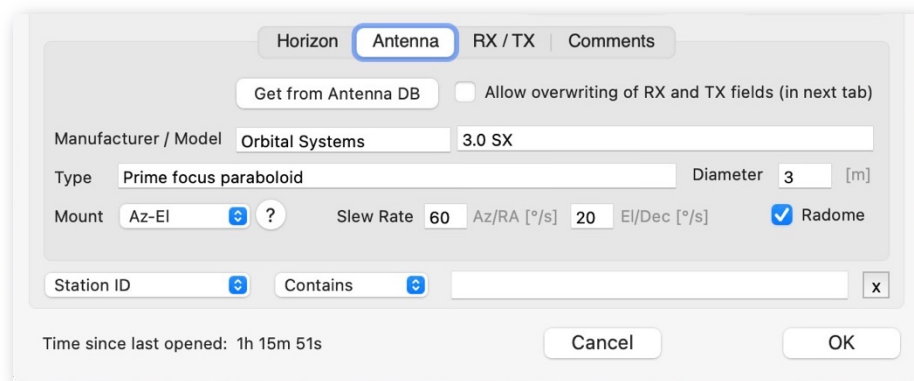
Figure 42. *The Antenna tab in the lower part of the Station tab.*

The next tab, shown in Fig. 42, in this lower part of the **Stations** tab, is named **Antenna**. It is concerned with the characteristics of the antenna installed at the ground station. In some cases, there is more than one antenna: the most extreme example is KSAT's Svalbard ground station which has more than 100 of them! We have not provided separate entries for each in these cases (though they are often noted in the **Comments** tab, see Section 7.3.6). Of course, you are free to make as many separate entries as you want for these situations.

Let's ignore the first line (**Get from Antenna DB** etc.) for a moment: we'll have more to say about this in Section 7.3.8, as well as more background in Chapter 12

The second line is concerned with the manufacturer and model description of the antenna. In some cases, antennas have been custom-built so these fields are not relevant, but mostly they will hold some useful information. The next line, **Type**, provides information about the type of the antenna. Many will be paraboloid dish antennas of some type, but low-frequency ones tend to be Yagi antennas, which consist of several parallel rods ranged along a supporting bar[17]. A single Yagi antenna has a linear polarisation so there are often two, mounted orthogonally, to make a 'crossed-Yagi'. The signals from such an antenna can be configured, in the downstream electronics, to have circular polarisation.
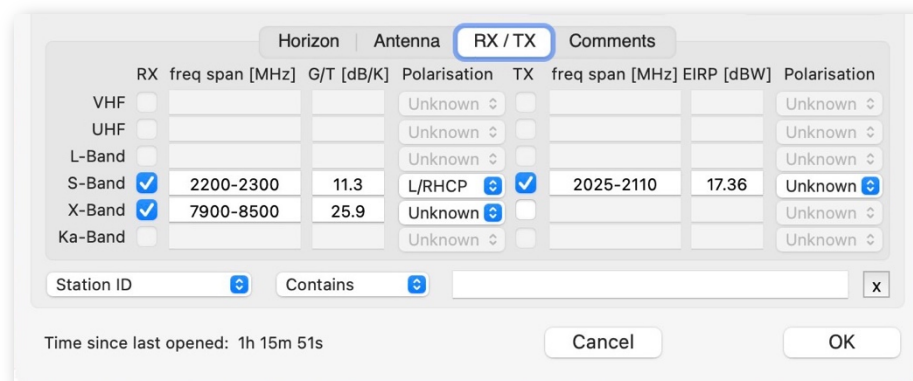
On the same line is a field for the antenna **Diameter**, in metres. This is only relevant for paraboloid antennas.

In the last line we have a drop-down menu, **Mount**, to select the type of mounting (there is help available for this by pressing the button marked **?** next to the menu).

The next fields, **Slew Rate**, are the speeds at which the antenna can turn around its axes. They expressed for either an Azimuth/Elevation pair, or a Right Ascension/Declination pair for a Polar mount. These numbers are always expressed in degrees/sec. Neither they nor the mount information are used in the current version of *SatTracker*.

The last item in this row is a checkbox called **Radome**. It indicates if the antenna is in a radome or not. A radome is a protective structure enclosing the antenna made from a material transparent to radio waves, commonly white in colour.

7.3.5.   RX / TX

Figure 43. The RX/TX tab in the lower part of the Station tab.

This tab contains information about the transmit and receive (uplink and downlink) characteristics of the ground station, across the bands in which it can operate.

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[17] While everybody can recognise a 'satellite dish' as an antenna, the Yagi is also extremely widespread, and recognisable, as a TV antenna. Often, as UHF antennas, these have multiple short elements. But the old-fashioned 'H-shaped' TV antenna is also a Yagi, with just one director, at lower frequencies. The Yagi's active element, a half-wave dipole antenna (of length half the radio-frequency wavelength) is near the back. The passive elements in front of it are called 'directors' and the passive element behind (usually there is only one) is the 'reflector'. The more directors there are the more directive the antenna, with correspondingly higher gain.

See the textbox below for some background information.

The bands listed in the **RX/TX** tab are:

VHF or *Very High Frequency* is a range of frequencies from 30 MHz to 300 MHz. Notably, the ITU has allocated the frequency range 144-146 MHz, up- and downlink, for the Amateur-Satellite Service.

UHF or *Ultra High Frequency* is the range of frequencies from 300 MHz to 3000 MHz, though beyond 1000 MHz (1 GHz) the nomenclature changes to L-Band, S-Band *etc*. There are several allocations in UHF, of which one, 435-438 MHz, up- and downlink, is for the Amateur-Satellite Service. The other notable allocation is 401-403 MHz, again with parts for both up- and downlink, allocated to the Earth Exploration and Satellite Operation Services. Some antenna vendors refer to these as the Amateur and Professional bands respectively.

Frequency allocations for all radio spectrum users, from Air Traffic Control radars to Wi-Fi, are governed by an international body, the *International Telecommunications Union*, ITU. Spectrum users are grouped into a number of 'Services' for the purpose of allocations. The relevant ones for satellites are:

- Amateur-Satellite Service (ASS);
- Earth Exploration-Satellite Service (EESS);
- Meteorological-Satellite Service (MSS);
- Space Research-Satellite Service (SRSS);
- Space Operations Service (SOS);
- Fixed-Satellite Service, Mobile-Satellite Service, Land Mobile-Satellite Service, Maritime Mobile-Satellite Service, Aeronautical Mobile-Satellite Service (all for radiocommunications involving satellites)
- Broadcasting-Satellite Service (for broadcast signals from satellites direct to end-users)
- Radiodetermination-Satellite Service, Radionavigation-Satellite Service, Maritime Radionavigation-Satellite Service, Aeronautical Radionavigation-Satellite Service, Radiolocation-Satellite Service; Standard Frequency and Time Signal-Satellite Service

L-Band (where L originally meant 'Long') is the band between 1 and 2 GHz. There are several ITU allocations in this band, but the most common usage is for direct download of meteorological and other Earth images to small terminals, in the band 1670-1710 MHz.

S-Band (where S originally meant 'Short') is the band between 2 and 4 GHz. Historically S-band has been the preferred band for *Telemetry, Tracking and Command* (TT&C), using frequencies in the range 2025-2110 MHz for uplink and 2200-2290 MHz for downlink. There is also a bi-directional allocation to the Amateur-Satellite Service at 2400-2450 MHz and another at 3400-3410 MHz.

X-Band (where the 'X' referred to cross-hairs, since the band was originally used for fire-control radars) is officially the band between 8 GHz and 12 GHz. However, the frequency range above 7 GHz, used for meteorological and deep space missions, is also normally referred to as X-band. Deep space missions (which are not handled in *SatTracker*) use the allocation 7145-7190 MHz for uplink and 8400-8500 MHz for downlink. But X-Band is mostly known for the downlink of large volumes of payload data, from earth observation and weather satellites in the Earth Exploration and Meteorological Satellite Services, where the main EESS allocation is 8025-8400 MHz.

Ka-Band (derived from 'Kurtz above,' where *Kurtz* means short in German and refers to K-Band, from 18–26.5 GHz) is the band above K-Band and covers the frequency range 26.5-40 GHz. Although more susceptible to atmospheric losses, it is increasingly used for TTC and for high data-rate download. It is also often used for telecommunications.

For each band there is a checkbox for downlink capability, marked **RX,** for 'receive', and for uplink, marked **TX**, for 'transmit'. when these are checked the corresponding data fields become enabled (conversely, if either is unchecked, the corresponding fields are not only disabled but also erased).

The fields for the downlink are **freq span [MHz]**, which is hopefully self-explanatory, **G/T [dB/K]** and **Polarisation**, which is a drop-down menu. The G/T figure is a figure-of-merit for the receiving system: it represents the gain of the antenna divided by the amount of noise in the receiver. The polarisation of the receive antenna is constrained by the drop-down menu to various descriptions, which are various linear polarisations or circular.

The uplink options, **freq span [MHz]**, **EIRP [dBW]** and **Polarisation** are similar, except that EIRP, measured in dBW, is the figure-of-merit for the transmit side, and represents the effective power in the transmitted direction.

7.3.6. Comments
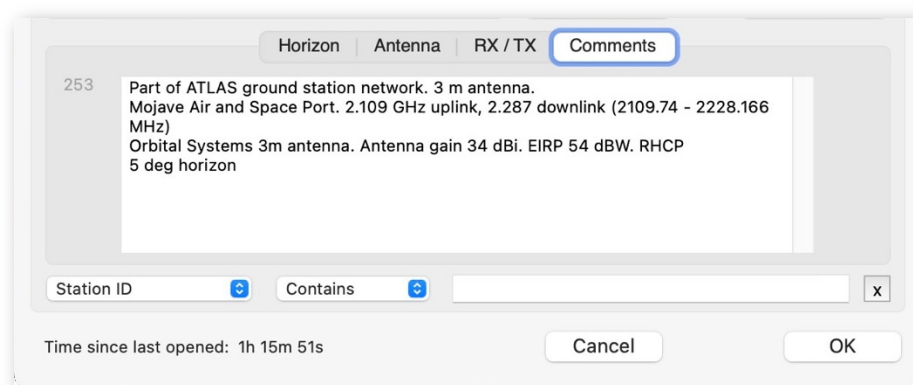
Figure 44. The Comments tab in the lower part of the Station tab.

In contrast to the other fields, this tab is very straightforward: it simply has a text area in which comments about the ground station can be entered. It is a free-text field.

Some information for each of the ground stations (but not DORIS nor Laser stations) is provided in this comments field in the default database. This includes any other networks the station is affiliated with So if you want to look at a group of stations, and there is no drop-down menu for them, you can still find them by performing a search in the **Comments** field. Similarly, you can find the stations in, or affiliated with, as an example, ISRO's ISTRAC network by searching for either ISRO or ISTRAC in this same field.

7.3.7. More about Networks

Twenty-two different types of network are identified in *SatTracker,* and this selection is rather arbitrary (there are more!). The selection of network is non-exclusive. Stations can be members of many different networks.

The first six 'networks' identify the frequency bands in which the station is capable of operating. The downlink and uplink checkboxes in the **RX/TX** tab we described

above are only active for the bands checked here. The seventh checkbox, **Optical**, is somewhat similar in that it identifies the transmission and/or reception frequencies, but it is not represented in the **RX/TX** tab.

The next group of networks, until the last four (**SmallSat**, **Amateur**, **Astro** and **User**) are networks of collaborating or commonly owned ground stations.

Optical communications with satellites has been under development for some time, including inter-satellite links to geostationary satellites. Now some ground stations, including some in the commercial networks listed here, are offering optical communications systems too.

The **Deep Space Network**, **DSN**, is represented in the ground stations database by several networks: ESA's network of three antennas, NASA's set of four, and some others. They are normally reserved for interplanetary missions and so are not normally relevant for the satellites in Earth orbit which can be displayed by *SatTracker*.

ESTRACK is a set of stations belonging to the European Space Agency (ESA) (Kourou, Kiruna, Redu and Santa Maria, plus the Deep Space antennas at Cebreros, New Norcia and Malargüe). This network also includes the former stations Perth (retired and dismantled in 2015), Villafranca and Maspalomas as well as a cooperative network of commercial operators and international partners.

SSC (now called *SSC-Connect*) is a commercial network which took over the former PrioraNet. It operates a network of ten stations worldwide and eight supplementary partner stations. SSC is based in Sweden.

KSAT is also a commercial network, with a large number of stations and associated stations. Some of these, in its *KSATlite* sub-network, are particularly suitable for so-called SmallSats (see below). KSAT is based in Norway.

ATLAS is a commercial network offering the so-called *Ground Station as a Service*, or GSaaS. In this model users have access to a network of ground station accessed through a software front-end. Atlas is based in the US.

AWS is another commercial network, Amazon Web Services. This is also a GSaaS offering but the ground stations are collocated with Amazon's data centres. They offer a combination of data-downlink, processing, storage and dissemination using Amazon's existing services. AWS is based in the US.

Viasat RTE (Real Time Earth), yet another GSaaS network, comprises a set of larger antennas than many of the other GSaaS systems. Since Viasat is a well-known manufacturer of ground station antennas (typically with X-Y mounts), most, if not all, of the antennas are Viasat ones. Viasat RTE is based in the US.

Leaf is another GSaaS provider. As well as the ubiquitous mid-sized antennas Leaf also offers services in VHF and UHF. Leaf is based in Italy.

Infostellar, like Leaf, is a GSaaS provider which also offers services in VHF and UHF. Infostellar is based in Japan.

CONTEC is another GSaaS system with a global network of, mostly, smaller stations. CONTEC is based in South Korea.

The network identified as **SmallSat** is composed of stations which are primarily suitable for small satellites, such as CubeSats. Recent years have seen the development of networks specifically aimed at SmallSats such as the networks mentioned above. They are gathered together under this SmallSat network.

The **Amateur** network is for stations operated by Radio Amateurs. There are no stations in the default database as these stations are expected to be defined by the user.

Similarly, the network called **Astro** is intended for astronomical facilities, which will make visual observations of satellites.

Finally, the network **User** is intended for user-defined facilities, for arbitrary purposes. The radar altimeter calibration facilities described in Section 7.3.1 have been assigned to this network.

7.3.8. Making a New Ground Station (My House)

Now let's make an entirely new station, which we'll call 'My House'.

Press the New button, located under the list of stations.

Now the box Station Details becomes active (it changes from a dull grey to a more lively-looking grey!) and we can start entering details. We show the state during this process in Fig. 45 on the next page.

We can start with some names. We'll fill in the Station ID as FR-HOME and the Name as 'My House'. These are used as alternative labels in the map view and for precious little else, so you can use whatever names take your fancy. You can even reuse existing names (since, as we saw, the unique, non-modifiable station number is what really identifies the station). However, many commercial or professional Ground Stations have alphanumeric identifiers which we used in this field for the default database.

We have also adopted the convention that the first 3 characters are the 2-letter ISO country code (listed in Annex A) followed by a hyphen (hence the Station ID FR-HOME rather than HOME).

Next you need to enter the latitude, longitude and altitude of the station. For the sake of demonstration, we moved the cursor around on the main map window and used the reading of latitude and longitude when it was pointing at about the right location, and then rounded the values, as this is just an example. Normally you would want to use more precise coordinates.

Of course, there are many ways of finding your position, such as using a GPS receiver (built into most smart phones), or *Google Earth* or even the old-fashioned way: with a map. However, *SatTracker* does not hold your hand here; you will have to find the location of your house by yourself.

Altitude. The altitude of the station **is** used in the calculations. but is certainly not critical. If you don't know the elevation of your house, or if you're entering the location of somewhere else, you can get a usable value from *Google Earth*. Ideally, the altitude we need is the altitude above the WGS84 reference ellipsoid (known as the

ellipsoidal height) not the height above sea-level[18]. GPS receivers work internally with ellipsoid heights and may give them as output, or there are on-line sources which can convert sea-level height to ellipsoidal height. In most cases though the difference in the results (in the pass timings reported in the pass lists) is negligible or non-existent, so using the normal height above sea-level (*geoidal height* or *orthometric height*) will be fine.
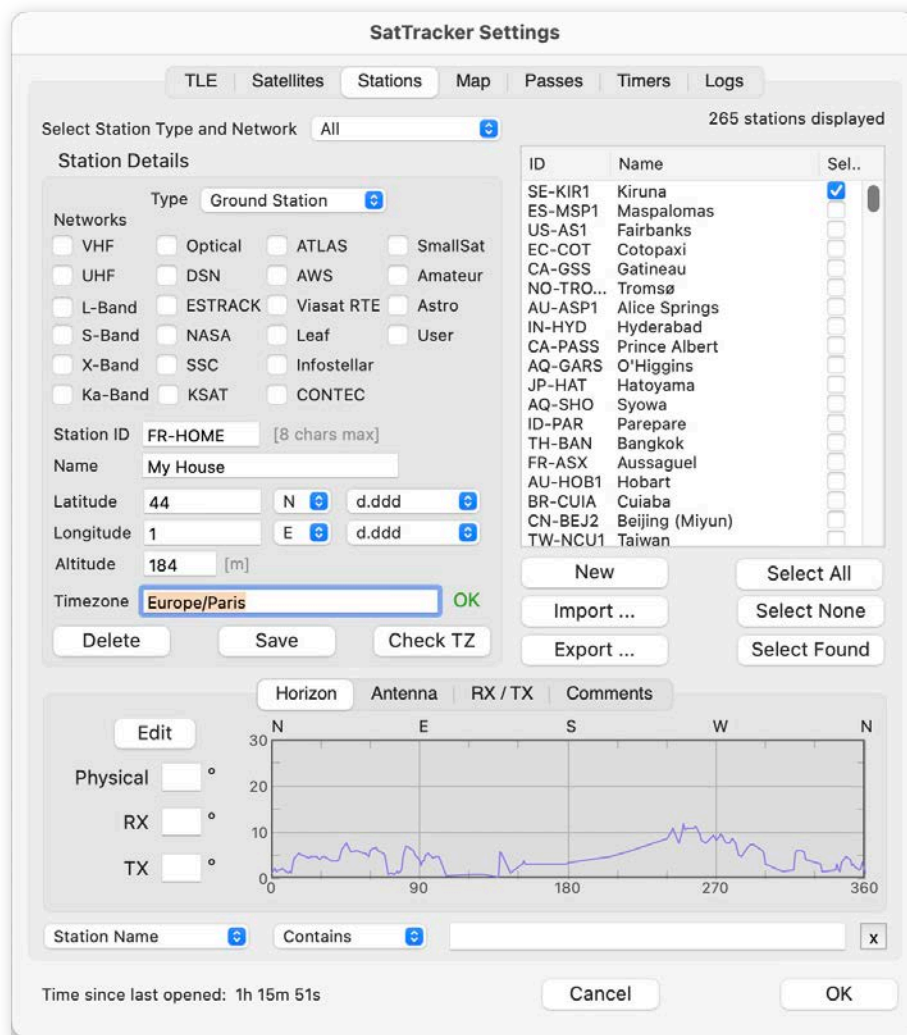
Figure 45. *Starting to enter information for a new station.*

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[18] The reference ellipsoid is a mathematically defined surface which best approximates to the overall shape of the Earth: it's in the form of an ellipse with major axis along the equator, which is rotated around its minor, polar axis. The polar flattening of this ellipse is almost one part in 300. Sea level would be coincident with this surface if the Earth were of uniform density, but it is not. As a simple illustration: imagine an underwater mountain, a seamount, which may be kilometers high. The surrounding water has a density of 1 tonne per cubic metre, while the seamount may be 3 times denser, so there is an excess of mass. Therefore, the local gravity around the seamount is higher so it pulls the water over itself – there will be a bulge of the ocean surface above the seamount (which can be measured by suitably equipped satellites). This also happens on a larger scale due to the distribution of mass inside the Earth. The resulting surface, where the gravitational force is equal (and where the sea-level should lie in the absence of other effects like wind) is called the geoid. An (exaggerated) illustration of the geoid is shown in Section 13.1.

However, we are going to do it correctly and use the ellipsoidal height. According to *Google Earth*, the altitude at our chosen position is 135m. This type of altitude, the elevation above Mean Sea Level, is also called the *orthometric height*. To convert this to the *ellipsoidal height* which we need, we must add the value of the height of the geoid at the point. There are many on-line tools to do this; we used `https://geographiclib.sourceforge.io/cgi-bin/GeoidEval`. The value, according to the latest EGM2008 model, is 49m.

So, in the altitude field we will use a value of 135m + 49m = 184m as the ellipsoidal height.

Time Zone. The last thing we need to enter in this panel is our time zone, as defined in the *Time Zone Database* (also called 'tz' or 'zoneinfo'), which is maintained by the *Internet Assigned Numbers Authority*, IANA. We considered providing a drop-down list but there are almost 600 valid time zone definitions, and the list is not fixed. Instead we adopted a less user-friendly way (not that a list with 600 entries would be user-friendly either). So, the principle is that you need to write the correct definition of your time zone into the field **Timezone**. The full database can be downloaded from `https://www.iana.org/time-zones`, and an alternative, perhaps more accessible, list can be found at `https://en.wikipedia.org/wiki/List_of_tz_database_time_zones.`

There are also many websites which specify the IANA time zone name for a given place, such as `https://time.is`. This is the method we used to enter the time zones for the hundreds of stations in the default database.

Some well-known time zone names, like GMT, CET and EST are in the Time Zone Database, so these can also be used.

Since we need to be sure that the time zone name is valid for calculations inside *SatTracker*, there is a mandatory check which must be performed before the station can be saved. So, press the button **Check TZ**. If all is well a green **OK** will show up.

All this is shown in Fig. 45.

Horizon. The last mandatory entry before we can save the station is the physical horizon. The simplest choice is to define a fixed horizon, which can be done by choosing an angle above which the horizon is clear all around (say 10°) and entering it in the box labelled **Physical**. This will immediately show up as a straight, horizontal line in the Horizon graphic, and then it will be possible to save the new ground station, using the **Save** button.

There are two other horizon boxes, for the **RX** (downlink)and **TX** (uplink) horizons. We described these back in Chapter 3 'Quick Start: Main Window'. If you don't enter any value they will be assigned default values of 2° and 5° respectively (with no check if either is below the physical horizon). That is what we will do here.

But for the physical horizon we will define one corresponding to our actual physical horizon, as we will mostly be interested in visual observations. So, we will include trees, which would not be so important for a radio-frequency ground station.

We start by pressing the **Edit** button. This brings up the horizon editing window. We will use the radio buttons on the left-hand side to expand the vertical scale, to 15° full-scale (as our maximum horizon elevation is 12°), and then use the **Add Point**

button to add a point (you need to click on the plot to actually add the point, at the position clicked).
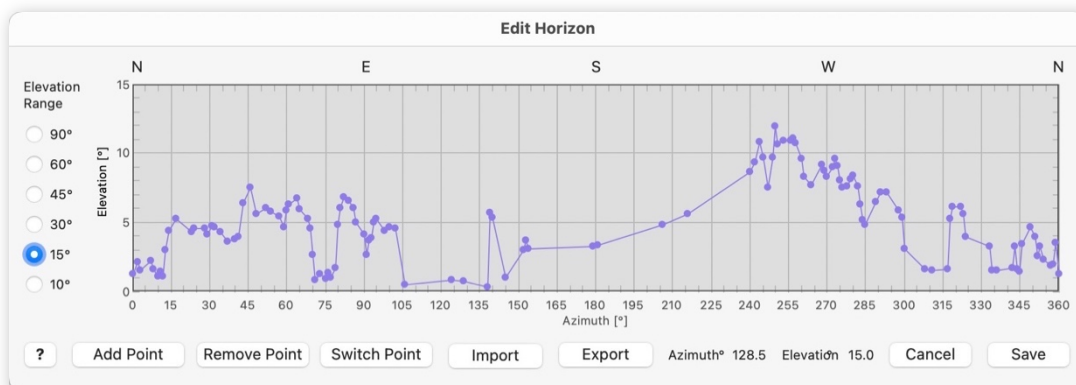
Figure 46. *The Edit Horizon window, with our new horizon picked out point-by-point.*

The azimuth and elevation values of the cursor position are always reported below the plot. Further information is available by pressing the **?** button.

Continuing, we add points corresponding to our horizon, including trees from 15° to 105°, a distant horizon and woods from there 150° to 225° azimuth, then nearby trees and buildings to about 300°, and finally occasional trees until 360°. Then we press **Save**.

There is an alternative to this point-by-point method. If you have a file which lists your local horizon in azimuth-elevation pairs, this can be imported using the **Import** button (near the centre of the bottom row of buttons). The required format is a comma-separated-value (CSV) file with each azimuth-elevation pair on its own line (See Annex B for details of the format).

There are several potential sources for such data, including the aforementioned http://www.heywhatsthat.com and many astronomy planetarium-type applications (which is what we used here: an application called *TheSkyX Pro*). This application gives data points for every degree of azimuth but this is far more resolution than necessary. All that's really needed is to capture the major obstructions to visibility of the sky.

The points do not have to be equally spaced and they will be sorted into ascending azimuth order after import.

Don't forget to press **Save** in the Edit window.

Other Tabs. If you are entering a ground station rather than a telescope as we are doing, you will want to enter something into the next tabs after the **Horizon** tab. Let's click the **Antenna** tab (see Fig. 47 on the next page).
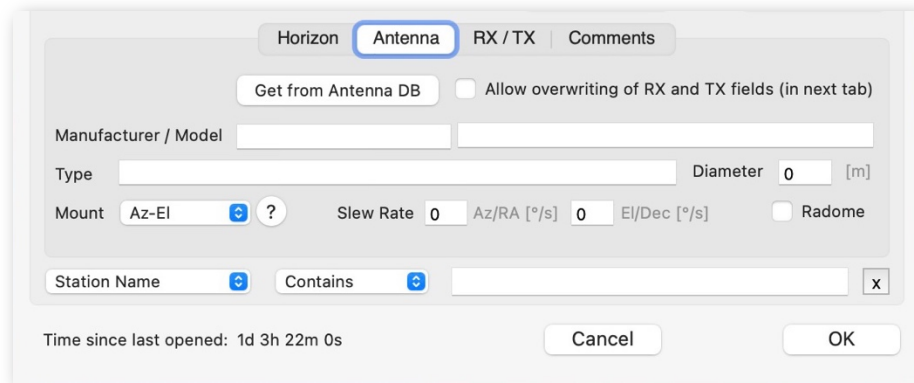
Figure 47. The (as-yet) unpopulated Antenna tab.

Imagine you have an 'Alén.Space GS-Kit' with VHF, UHF-435 and S-Band antennas. Then the easiest way to proceed is to click the button **Get from Antenna DB**. This will open another window listing many commercial ground station antenna types, as shown in Fig. 48.
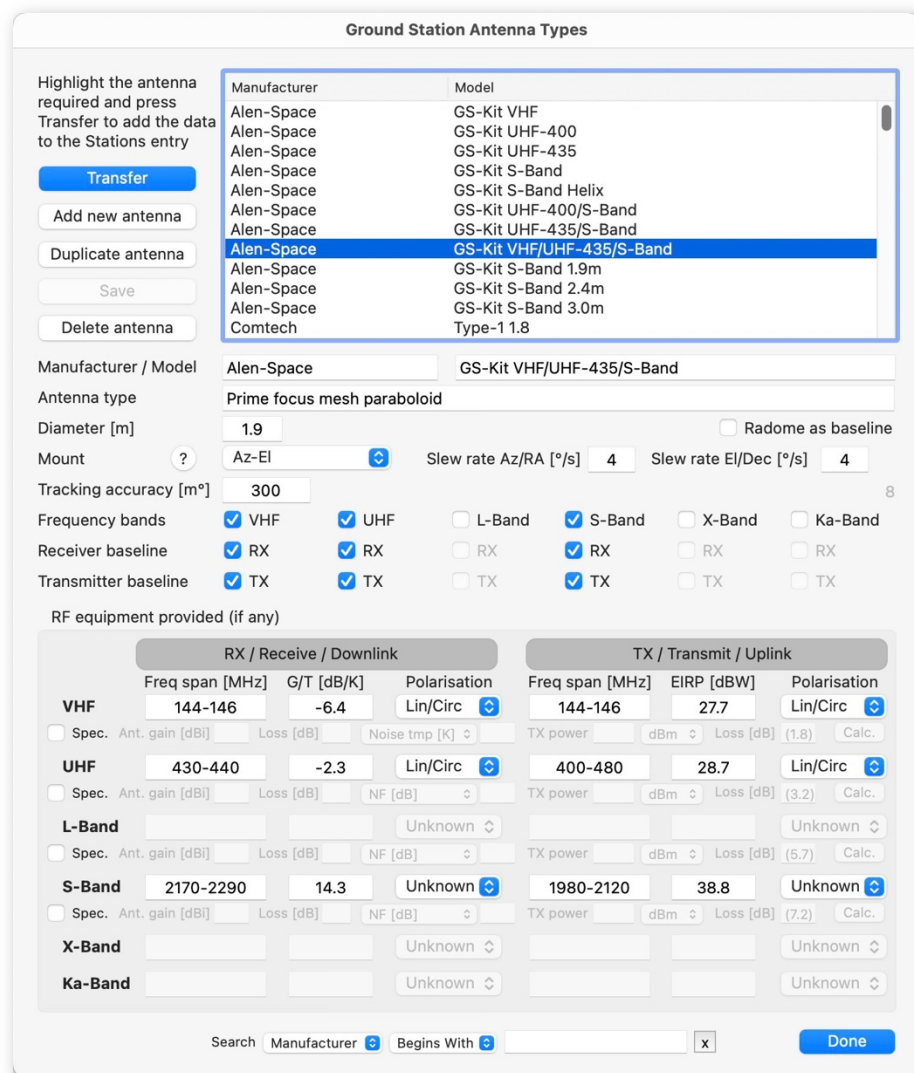
Figure 48. Selecting an antenna in the Antenna DB window.

Alén.Space is near the top and so already visible, but if you want to search for something rather than scrolling down, the normal **Search** function is available at the bottom of the window. Once you click the station you have, you will notice (in this example at least) that information about RX and TX links are also in the Antenna Database. So let's go back to the Settings window and tick the box right next to the **Get from Antenna DB** button, labelled **Allow overwriting of RX and TX fields … .**
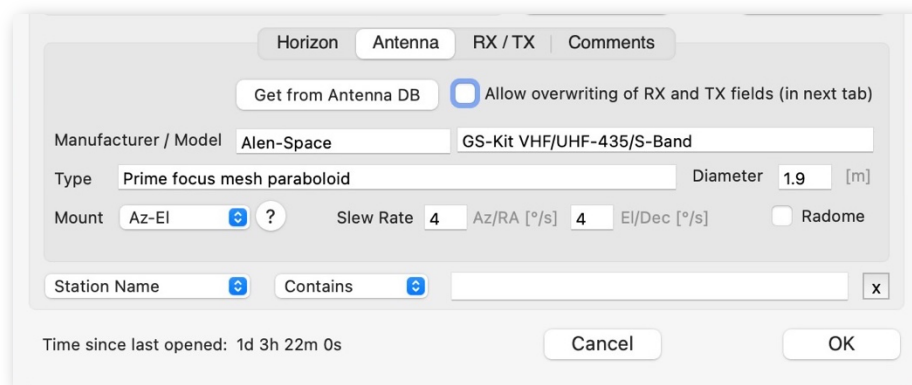
Figure 49. *The Antenna tab after transferring data from Antenna DB.*

Back in the Antenna Types window we can now press the **Transfer** button and all the relevant information will be written into the **Antenna** *and* **RX/TX** tabs, as shown in Fig. 49 above. Not only that, but the **VHF**, **UHF** and **S-Band** network checkboxes in the **Station Details** panel will be ticked as well.

About the **Slew Rate** and **Mount** fields – this version of *SatTracker* does not use any of these three pieces of information so the entries here are unimportant – for now.

Finally, we can visit the **Comments** tab and enter any text we think might be interesting or useful.

Now let's look at the overall **Stations** tab (which we are already in) and look at the **Station Details** panel again. we can add some more **Networks** for our new station, in addition to the *VHF*, *UHF* and *S-Band* ones which were already added when we transferred the antenna. Since this is our home base, we can decide that our new station will be used for amateur radio and astronomy, so we check the boxes *Amateur* and *Astro*. Amateur radio satellites are also, mostly, SmallSats, so we will tick the *SmallSat* network too.

Because this is not going to be a full-blown Ground Station we will assign it to **Special** in the drop-down menu **Type**, at the top of the **Station Details** box. This choice is useful because when we are looking for it, we can select Special from the drop-down menu **Select Station Type and Network**, right at the top of the tab.

These changes (as well as the updates to the **RX/TX** tab) are shown in Fig. 50.

Finally, we click the **Save** button (but if we forget, *SatTracker* will remind us if we try to move on to another station).

Of course, even if we hadn't put it into a small group like **Special**, we can search for our new station by entering the text 'house' in the search field and ticking the **Select** checkbox when we find it.

Finally, we click **OK** at the bottom right to save all our changes. Before closing the Settings / Preferences window let's deselect all of our previously selected satellites and select the ISS. Then we can close the Settings window.
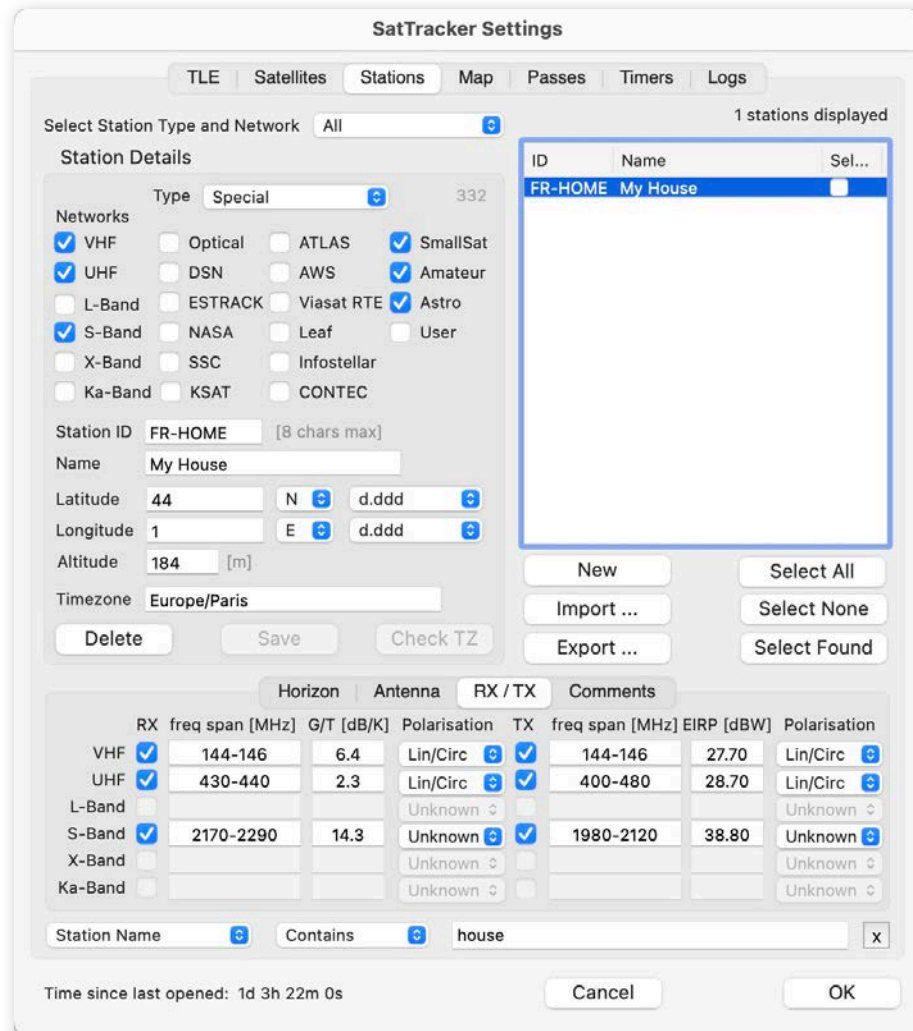
Figure 50. *The RX/TX tab after transferring data from Antenna DB and additions to the networks and the station type, as mentioned in the text.*

Now, if we click the **Select** box, we can see our new station on the map. As we could interpret from the Horizon view the visibility in most directions is not too bad, but there are some obstructions to the East and the South-West. The horizon is not very extensive though, because it is now calculated for the ISS altitude (see Section 7.4.5 for more information about this).

We can also see that the ISS is making a pass, and, since it is within our horizon, it should be visible. During the pass (now) we are at the end of twilight while the ISS is fully in sunlight (indicated by the brighter trace for the orbit track). So, as the ISS is so bright, it will be easily visible! (if there are no clouds).

By the way, these features are visible because we selected the **Show day/night** checkbox in the **Settings > Map** tab.
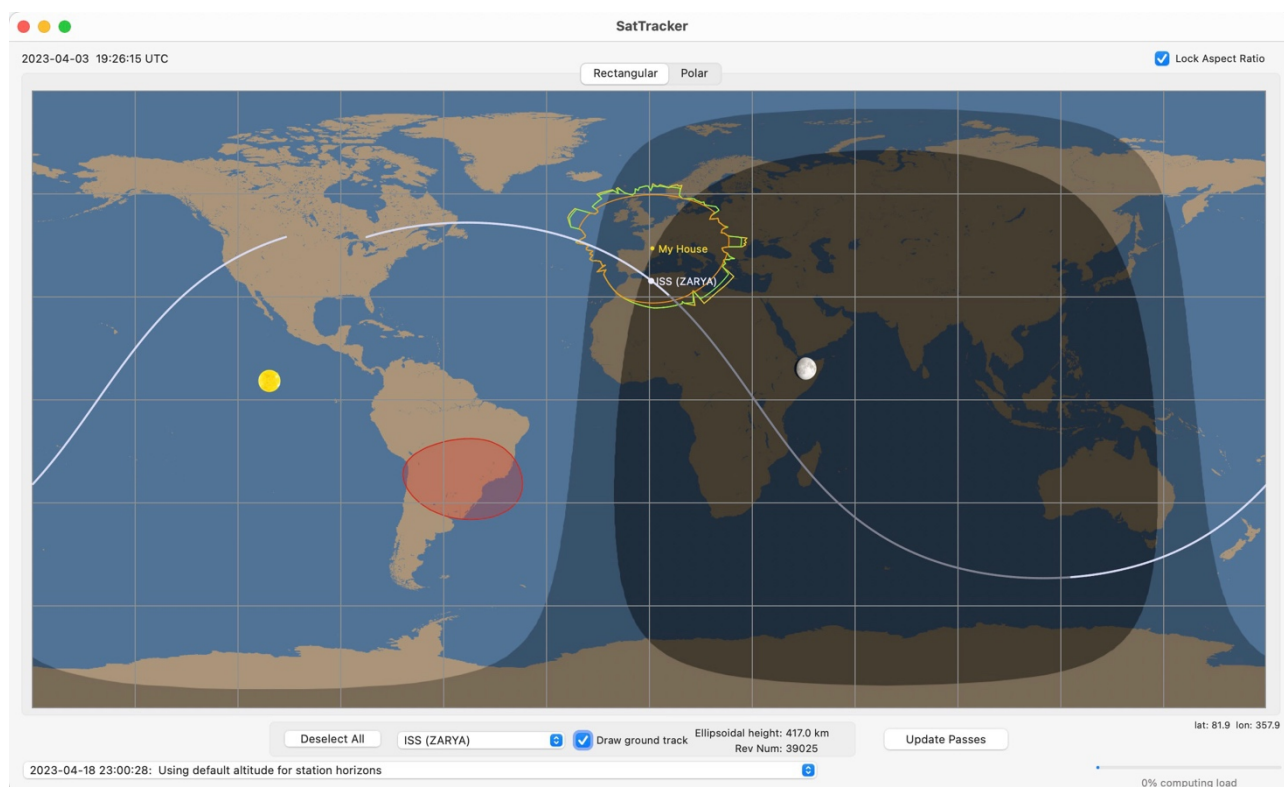
Figure 51. *Our new station, 'My House', with its horizons shown, and a visible pass of the ISS taking place.*

Spoiler: as you can see from the date/time in the top left corner, this scenario is from 3 Apr 2023, while this text is being written in mid-April 2023. We used the **Time Control** window (see Chapter 14) to adjust the time, since no ISS passes are visible in Europe at the moment.

If you have followed this example through, as a test, and now decide not to keep it, then the **Delete** button, in the **Station Details** box, will be the one you need.

7.3.9. Importing and exporting ground stations

The remaining items on the **Stations** tab are the **Import…** and **Export…** buttons. These enable the bulk import or export of ground stations.

For professional networks these are not necessarily of great use, other than for keeping *SatTracker*'s database up to date. They are of more interest for those using *SatTracker* with self-defined Ground Stations. For example, imagine you are using a satellite radio amateur station and have defined your station as we described above.

Exporting your station details will result in a single-line text file. Other stations can be defined with equivalent details so that a multi-station network could be defined in a file, which could then be imported.

The file format used is always CSV. Details are provided in Annex B for Import and Annex C for export.

Pressing the **Import …** button provides a small dialog box which is mainly concerned with selecting the file to be imported.

Now we meet the first limitation. Consider that *SatTracker* allows stations to be in an arbitrary number of networks (for example it may be a *Ground Station* supporting *S-band*, *X-band* and be part of the *ESTRACK* network, or, as we saw above, it may be a *Special* station in the *Amateur* and *Astro* networks, or it may simply be a *DORIS* station).

Therefore, to simplify the interchange file format, we have made the decision to limit the type or network to one entry. The imported file must define the Type or Network and the allocation to station network and type (*Ground Station*, *Laser*, *DORIS*, *Special* or *Other*) is made according to the rule explained in Annex B. If imported stations need to be associated to additional networks that must be done by updating them case-by-case after import.

The **Export…** button needs even more explanation. You have the choice of which stations to export. The choices are *All*, *Selected stations*, or *All the stations of a given Type or Network* (where this is supported by a drop-down menu).

In the first two cases there will inevitably be a mixture of Types and Networks, so the associated field in the export record will only contain the Type. In the last case we can infer the intent of the export (as the drop-down menu will identify a single Type or network). So, uniquely in this case, the field in the export record will record this selection.

The second limitation concerns horizons. Within the simple file format we have chosen, it is not possible to cater for both fixed and varied horizons. So, for both import and export a simple, fixed horizon is used. When exporting a station with a varied, azimuth-dependent horizon, the export process will calculate the overall average of this horizon and provide a single value.

For stations which should be passed between users there is a solution to this: the horizon edit window (described in Section 7.3.3) has both an **Export** and **Import** button, by means of which individual station horizons can be exchanged.

7.4.   The Map Tab

The **Map** tab, Fig. 51, provides control over all the elements which make up the map display on the main window. We'll describe it here as it goes, from left to right and top to bottom.

Figure 51. *The Map tab of the Settings window.*

7.4.1.   Twilight

With **Twilight** we immediately hit something which must be described out of sequence!

The **Twilight** controls are only relevant if **Show day/night**, in the next block down, is selected.

When day and night are shown, the map is divided into darker and lighter areas which correspond to the actual geographical areas where it is day or night. The darker area has two levels of darkness. The first, intermediate dark level has its boundary from the light area at the location where the sun is at the horizon (sunset or sunrise, accordingly). Between these sunrise/sunset times and the full onset of night there is a period called twilight. The twilight zone is marked in half-intensity dark, while full night is the darker area.

Everybody is familiar with the concept of twilight, but not everybody knows that there are three types of twilight, and each is exactly defined. The everyday kind of

twilight, where at the end of twilight it is pretty dark, is called Civil Twilight. This twilight is defined as the zone (or period) where the Sun is between the horizon and 6° below the horizon.

Nautical twilight is similar, except that the position of the Sun at the end of nautical twilight is 12° below the horizon, rather than 6°. The idea here is that this is the limit where a sailor could see both stars and the horizon, to be able to use his sextant.

Finally, astronomical twilight ends when the Sun is 18° below the horizon. The darkness during astronomical twilight is regarded as still insufficient to perform the full range of astronomical work, and it is necessary to wait until the Sun is a full 18° below the horizon before it is truly dark.

In the **Twilight** box, the twilight zone can be set to any of these three settings, **Civil**, **Nautical** or **Astronomical**.

The next set of controls are not grouped into a box.

The **Show day/night** checkbox shows the zone where it is night (and twilight, as we described it above) to be shown on the map.

The **Show sun/moon** checkbox displays a symbol for the Sun and for the Moon, at the map location where each is directly overhead. The Moon image, furthermore, shows a representation of the Moon's phase. The Sun image, by the way, is a coloured image derived from data from the Soho spacecraft.

The size of these images is controlled by the slider just below, marked **Symbol size**.

The next checkbox, **Invert Moon (S. hem.)** will provide an inverted version of the Moon's image, which matches the Moon's appearance in the Southern hemisphere.

7.4.2.   Clouds

SatTracker can optionally show cloud cover. This is not only aesthetic – the original purpose was to indicate whether satellites would be optically visible from ground stations during night-time passes.

The display of clouds is managed by the controls in the **Clouds** box, but first let's understand the background, which we briefly introduced towards the end of Chapter 4

The clouds shown by *SatTracker* are recent images, never more than 1 hour old. This is so that they can fulfil the objective of indicating satellite visibility. So, obviously, these up-to-date images have to be downloaded. The solution adopted in *SatTracker* is to obtain them from an on-line repository. Originally this was the one set up to supply such imagery to *Xplanet* (and it had a less timely update cycle, at 3 or 24 hours).

However, the *Xplanet* cloud image service is no longer available. A third party, *Xeric Design* (which markets its own application called *EarthDesk*) has stepped in and offers a compatible cloud-image service, but only on subscription. There is no free download option any longer. The positive side is that the update frequency is increased so that images are now updated every hour.

Subscriptions are available (at different prices) for various resolution images. The images used by *SatTracker* are the lowest resolution (and cheapest) 2048x1024 pixel images.

To be very clear: it is not necessary to have such a subscription to use *SatTracker*; it is only needed if you want to include cloud images, typically for aesthetic reasons. *SatTracker* works perfectly well without.

If you have a subscription then the checkbox **Subscription** needs to be ticked. But you also need to provide your user name and password, in the dialog box called up by **Edit**, or the subscription download will fail. *SatTracker* memorises these details in its own Settings file, and nowhere else. If you want to see this file it is stored in SatTracker's 'sandbox' and named `com.ClearAndDark.SatTrackerBasic.plist`. To find out how to access this 'sandbox' look at the image in Section 7.7 which explains how to find *SatTracker*'s log files. The above-mentioned '`.plist`' file is nearby: one folder level higher.

The checkbox **Show clouds** switches the display of clouds on and off. The lines of text below that give the details of when the image was created, when it was downloaded and how old it is (time since its creation).

The download of cloud images can be automated, occurring at fixed intervals. We will come to this in Section 7.6, where the **Timers** tab is described.

However, downloads can be performed manually too, by pressing the **Download** button. This starts a request for the download which also includes a timeout period. This is the one chosen from the drop-down menu **Timeout**. The actual time taken is recorded just above this, in the field **Download time [s]**. If this is longer than a timeout period which has previously worked, it's usually a bad sign, and is normally accompanied by a defective cloud image.

If you do find a defective image, it is usually the case that the download was interrupted by this timeout, and the normal cure is to increase the timeout and try again.

Please note that the *Xeric Design* server limits traffic by only allowing a given subscription account 5 downloads in any 3-hour period. To assist you with this, *SatTracker* checks the date of its latest downloaded image and compares it to the image available on the server. It will only request a download if the server image is more recent.

7.4.3.   Ground Station

The topmost box of the centre panel of the **Map** tab is labelled **Ground Station**. In here are controls for how ground stations will be represented. This is independent of the display of the station horizons, which is controlled in the next box. The checkbox **Show station** defines whether the station is indicated or not. If not, then there will be no indication of any ground station on the map at all (nor label nor horizon mask). If checked though, there will, at least, be a small dot on the map display, in the same colour as the Physical Horizon line.

Then there are 3 radio buttons. These control the type of label which will identify each station. The first disables any label at all, while the other two select between the **Name** and **ID**, which we saw in the **Station List** in Section 7.3.1. These are simply alternative ways of labelling, and each is equally valid. The name can be quite long, but descriptive, while the ID, by convention, is a short string (up to 8 characters).

7.4.4. South Atlantic anomaly (SAA)

The next topic is not grouped in a box. It is the checkbox **Show SAA**. The SAA, or South Atlantic Anomaly, is a region where the Earth's magnetic field is relatively weak, and this means that the *van Allen radiation belts* are a bit closer to the Earth's surface in this region. We are still talking about hundreds of kilometres up, so there is no effect at ground level, or even for high-flying aircraft. But as satellites fly through this region they experience more radiation, in the form of energetic particles, than at any other part of the orbit. This can make the electronics throw unexpected errors, and it can also cause CCD sensors (such as in imaging sensors) to show white spots where energetic particles have hit the pixels in the sensor.

The contour of the SAA is a function of altitude – if you want the details: it is taken as the contour where the Earth's magnetic field has a strength of 20 µT, using the IGRF-11 model of the Earth's magnetic field. The altitude used to compute it is the same as the altitude used for ground station horizons (see the next Section).

It is smaller at low altitudes and larger at higher ones.

The contour is filled in with the same colour used for the counter line, but it has a transparency controlled by the drop-down menu **Transparency**.

7.4.5. Ground Station Horizon

We already looked at the definition of the **Ground Station Horizon** in Chapter 3, so we are not going to describe it again.

The important point is that satellites which are higher up can be seen over a wider area on the ground. Think of seeing a mountain from far away, or, in the extreme case, how the Moon, which is in a very high orbit, can be seen over half the Earth at the same time. So, the horizon lines enclose more area for higher satellites.

Selecting the correct satellite to use as a reference is important for the horizon to correctly mark where it will be visible.

The drop-down menu in this box allows the selection to be made amongst the satellites selected.

Please note that any satellites selected just before switching to the **Map** tab will not be present in this menu, because the actual selection is only done when pressing the **OK** button to exit Settings.

The box **Default altitude [km]** is used to define an orbital altitude which can be used if for any reason there is no selected satellite. This can occur if no satellites are selected at all, or if the satellite previously selected becomes deselected.

The tick box **Use default instead of satellite** is useful when the range of satellites available is too diverse for a meaningful display: we used this to display the ground station horizons for Meteosat-9, XMM-Newton and the ISS in Chapter 4.

The checkbox **Show Physical Horizon** is used to control whether the physical horizon (as defined in the **Horizon** window of in the **Station** tab) is shown. This really gives the limit of when a satellite could possibly be observed.

The next checkbox, **Show RX Horizon** draws the horizon contour corresponding to the RX horizon is shown. For an operational ground station this indicates when telemetry from the satellite may be received.

Finally, the **Show TX Horizon** checkbox enables the display of the third horizon line, for the TX horizon, where sending telecommands to a satellite is considered reliable (or, in some cases, where the local regulator has declared transmissions may be performed, via the license).

For both the RX and TX horizon, if the physical horizon is higher in some places, then it is used instead of the pre-set value at that point.

7.4.6.   Map Image

The lowest box in this middle panel controls the image which is displayed on the maps. There are three options.

The first is a simple map where the land and ocean areas are filled with appropriate colours (one for each). The night-time image, if needed, is simply a darker version of the day-time image.

The second is an image derived from satellite imagery and made available by NASA for public use. This is called NASA Blue Marble; NASA produced an image for every month of 2004. We have selected the October 2004 image. In the case that this image is selected, the image for the night-time (assuming **Show day/night** has been ticked) is the companion NASA Black Marble image, updated with data from 2016.

The third option is a topographic map of the Earth and its bathymetry[19]. Again, the night-time image, if needed, is simply a darker version of the day-time image.

A separate selection is available for the rectangular and polar view, in case it should be necessary.

7.4.7.   Colours

The **Colours** box occupies much of the right-hand panel of the **Map** tab. It is used to control the colour of the many elements which are plotted on the map window. The names are self-explanatory. In each case, clicking the coloured square next to the name will bring up a colour picker, where it may be modified.

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[19] This map has been produced using satellite altimetry with the bathymetry having been derived from the local elevation of the sea-surface, as we explained in Footnote 18.

The one thing to note is that while the **Satellite** colour controls the colour in which both the satellite and its label (in daylight) are plotted, the **Satellite Eclipsed** colour only affects the colour of the label (and not the satellite marker) in the eclipsed portion of the orbit. This is the result of many hours of use during development where it became apparent that this was a better choice than dimming the satellite marker too, in eclipse.

If you decide that you have made an absolute mess while changing colours, and you want to return to the starting point, then press the **Default** button.

7.4.8.   Other Controls

Three more controls appear before the final box.

The first is the **Lat/long Grid** drop-down menu. This enables control of whether a grid is shown, and, if so, how dense it is. In all cases, it is a square grid, where equal divisions are made on both the latitude and longitude axes.

Then there is a drop-down menu for the number of **Horizon points**. The idea here is that, while potentially 360 points are available to define horizon contours, often fewer than this are needed to give a good on-screen representation. Exceptions can occur for high latitude stations in the rectangular projection, where sometimes ugly straight-line segments may be drawn. Increasing the number of **Horizon points** can reduce this problem. Note that the same rule is also applied to the plotting of the SAA contour.

Finally, there is a checkbox **Show satellite names**. This would normally be ticked, but as we have seen, if large numbers of satellites are displayed then it is sometimes useful to disable the display of their names.

7.4.9.   Orbit Tracks

The final item on the **Map** tab is the pair of drop-down menus controlling how many orbit tracks are displayed. The current orbit is, by convention, the first orbit 'after' (since it continues *after* the satellite's current position). This is open to discussion, but in *SatTracker* it is the convention we use.

It is possible to display up to 2 orbits before and 4 orbits after for each satellite. No distinction is made between the selected satellites – the same number of orbits before and after are plotted for each.

7.5.   The Passes Tab

The **Passes** tab has two panels, one for each of the view windows, **Sky View** and **Pass View**. See Fig. 52, below.
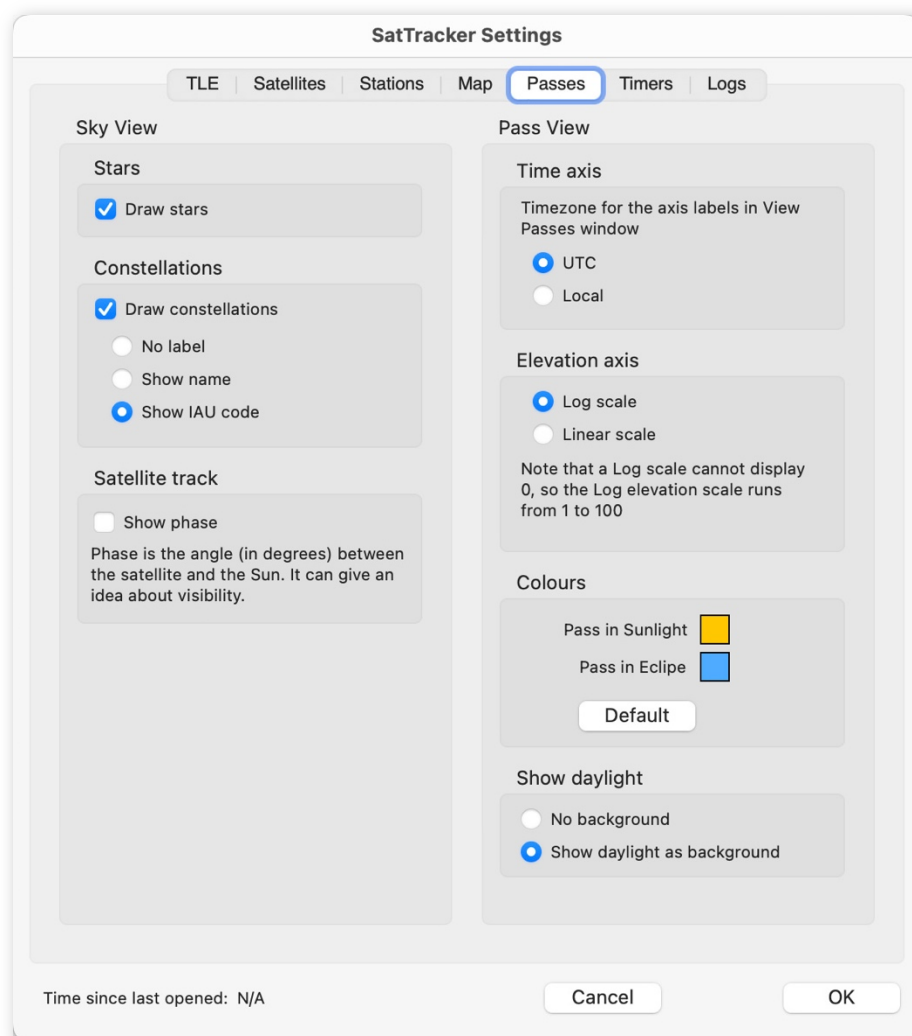
Figure 52. *The Passes tab of the Settings window.*

The left panel is devoted to the **Sky View** and is mostly intuitive.

The first two sub-panels are devoted to the way stars and constellations may be represented. For constellations, there is the option to draw the constellation figures (we use the stick-figures from *Sky and Telescope* magazine). Constellations may also be labelled, either with the name (in Latin!) or the 3-letter code assigned by the International Astronomical Union, IAU.

Finally, in the third panel, the satellite track may be annotated with an indication of the phase (which is the angle between the satellite and the Sun). We have never found this to be very useful, so it is disabled by default, but it is there if you want it. Labels showing phase are drawn once every 10 points along-track. Often the values will be the same.

On the right-hand side is the panel devoted to the **Pass View** window.

Firstly, we have the choice of time zone for the time axis. The same one is used for all four plots. The default is UTC, as we use throughout *SatTracker*. But it also possible to choose the 'local' time zone, taken to be the time zone of the host computer.

The next is the selection of the elevation scale between log and linear scales. Linear may seem more natural, but log gives more prominence to low elevations and is useful for examining low-elevation passes. The same choice applies to all four graphs.

The third panel addresses the colours to be used for the sections of the trace in sunlight and eclipse. Clicking one of the coloured squares brings up a standard colour picker. The default orange and blue can be restored by clicking the **Default** button.

The final panel controls whether the background to the graphs shows the sky colour or a plain background.

7.6.   The Timers Tab

The **Timers** tab in the Settings windows is relatively sparse in comparison to earlier tabs. It only contains three drop-down menus which control the frequency at which things happen in *SatTracker* – and in one case whether it happens at all.
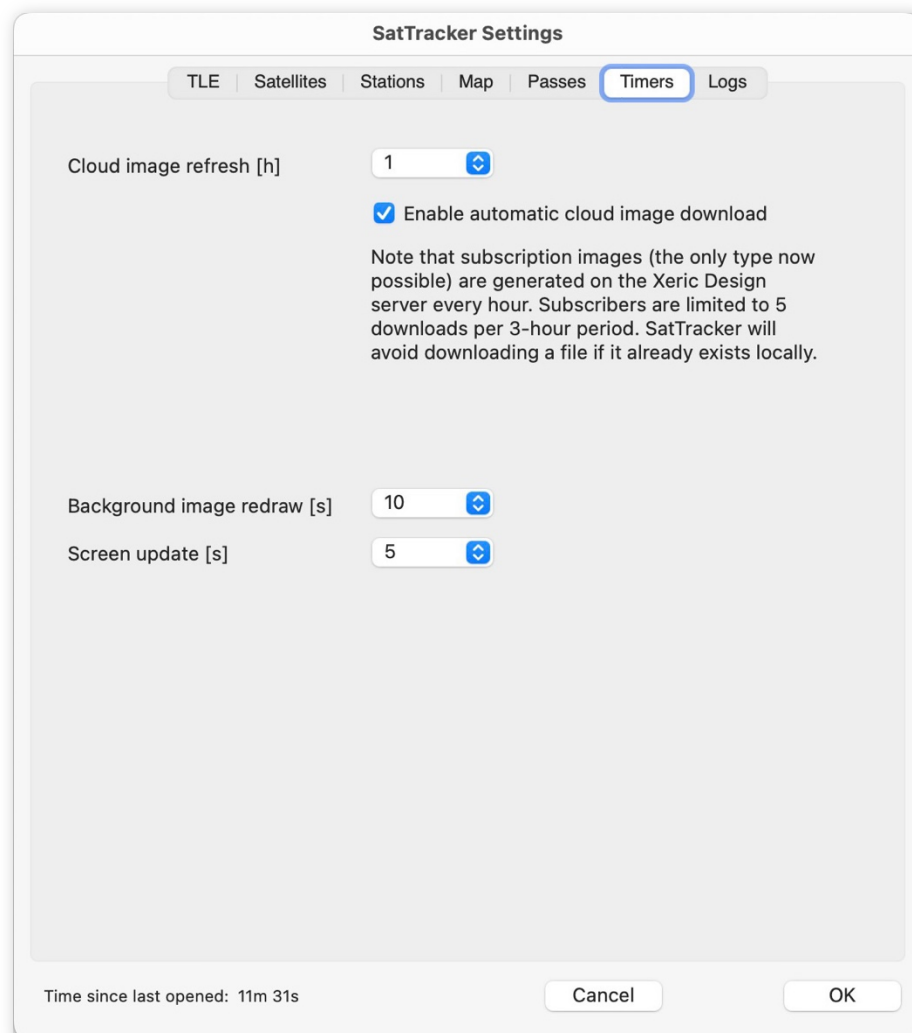
Figure 53. The Timers tab of the Settings window.

The first item is the automatic download of cloud images. The checkbox marked **Enable automatic cloud image download** does exactly what it says. If it is ticked, then periodically the cloud image is automatically downloaded from the *Xeric Design* repository.

The interval at which this happens is controlled by the drop-down menu marked **Cloud image refresh [h]**, and this gives the interval in hours. For most users it is sufficient to request a new image every 1 hour, as images are only available on subscription, and are refreshed every hour.

The next item, **Background image redraw [s]**, is the rate at which the background image, with its features like ground station positions and day/night boundaries, is regenerated. The default value (which is also the shortest) is 10 s. Nothing really changes in such a time, so this is adequate.

The final item is the **Screen update [s]**. This is different from the background image because this is where the satellites and their tracks are drawn. As we mentioned earlier, if the load of drawing too many satellites becomes excessive this value will be progressively changed up to its maximum value of 240 s (4 minutes!). If you bring it back to 1 s without reducing this load, it will automatically go back up again.

7.7.   The Logs Tab

```
SatTracker, GerSpatial 2023 Version 2.0 (Build 104)
Logfile created at 2023-04-19 09:47:14
--
2023-04-19 09:47:13:  Reading SAA contour files ...
2023-04-19 09:47:13:  SAA contour files read
2023-04-19 09:47:13:  Reading TransformArray files ...
2023-04-19 09:47:14:  TransformArray files read
2023-04-19 09:47:14:  Reading Preferences ...
2023-04-19 09:47:14:  Preferences read
2023-04-19 09:47:14:  Reading printer Page Setup ...
2023-04-19 09:47:14:  printer Page Setup read
2023-04-19 09:47:14:  Opening database files ...
2023-04-19 09:47:14:  Checking existence of satellite database file ...
2023-04-19 09:47:14:  Checking existence of station database file ...
2023-04-19 09:47:14:  All Database files opened
2023-04-19 09:47:14:  Opening database files ...
2023-04-19 09:47:14:  Stars database file opened
2023-04-19 09:47:14:  Opening AntennaDB database file ...
2023-04-19 09:47:14:  Checking existence of AntennaDB database file ...
2023-04-19 09:47:14:  AntennaDB database file opened
2023-04-19 09:47:14:  Previously selected satellites shown
2023-04-19 09:48:30:  Downloading TLE files:
2023-04-19 09:48:31:  Downloading last-30-days
2023-04-19 09:48:32:  Downloading stations
2023-04-19 09:48:32:  Downloading visual
2023-04-19 09:48:33:  Downloading weather
2023-04-19 09:48:33:  Downloading resource
2023-04-19 09:48:34:  Downloading geo
2023-04-19 09:48:34:  Downloading science
2023-04-19 09:48:35:  Downloading geodetic
2023-04-19 09:48:37:  Downloading starlink
2023-04-19 09:48:37:  Unpacking last-30-days
2023-04-19 09:48:37:  190 objects: 0 new, 190 updated, 0 duplicated, 0 skipped.
2023-04-19 09:48:37:  Unpacking stations
2023-04-19 09:48:37:  29 objects: 0 new, 29 updated, 0 duplicated, 0 skipped.
2023-04-19 09:48:37:  Unpacking visual
2023-04-19 09:48:37:  163 objects: 0 new, 163 updated, 0 duplicated, 0 skipped.
2023-04-19 09:48:37:  Unpacking weather
2023-04-19 09:48:37:  47 objects: 0 new, 47 updated, 0 duplicated, 0 skipped.
2023-04-19 09:48:37:  Unpacking resource
2023-04-19 09:48:37:  180 objects: 0 new, 180 updated, 0 duplicated, 0 skipped.
2023-04-19 09:48:37:  Unpacking geo
2023-04-19 09:48:37:  564 objects: 0 new, 564 updated, 0 duplicated, 0 skipped.
2023-04-19 09:48:37:  Unpacking science
2023-04-19 09:48:37:  60 objects: 0 new, 59 updated, 0 duplicated, 1 skipped.
2023-04-19 09:48:37:  Unpacking geodetic
2023-04-19 09:48:37:  8 objects: 0 new, 8 updated, 0 duplicated, 0 skipped.
2023-04-19 09:48:37:  Unpacking starlink
2023-04-19 09:48:39:  3923 objects: 0 new, 3923 updated, 0 duplicated, 0 skipped.
2023-04-19 09:49:22:  Too many satellites (3925) selected for effective screen update. Drawing aborted at satellite 1094
2023-04-19 09:49:22:  Automatically switching screen update interval from 10 s to 60 s
2023-04-19 11:05:15:  Finished processing of new cloud image, in 348.6 ms
2023-04-19 11:05:28:  Quitting application and closing down
```

Figure 54. *Example of a log file.*

In Fig. 54 above we can see an example of one of the log files which *SatTracker* generates. Generation of these files is optional and controlled in the final tab, the **Logs** tab, Fig. 55.
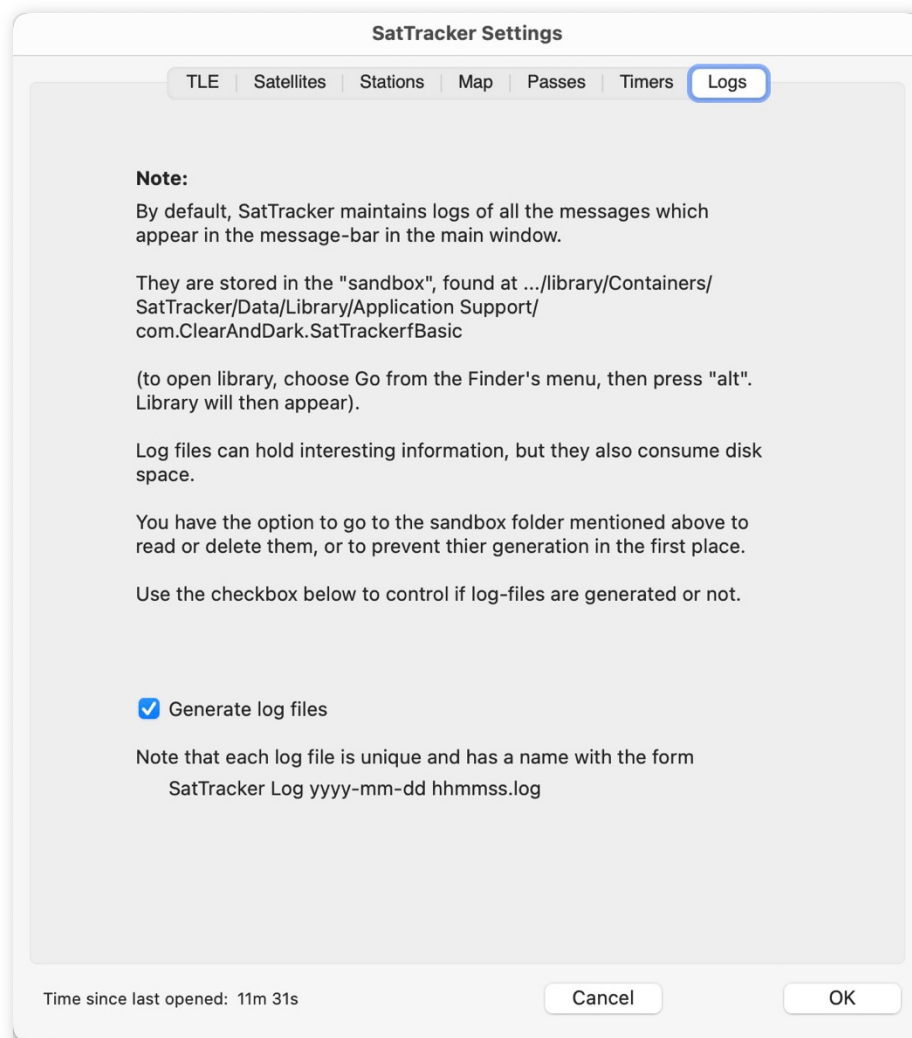
Figure 55. *The Logs tab of the Settings window.*

It has only one item, a checkbox to control whether log files are generated or not. Log files are written to the Application Support folder, which is in the 'sandbox'. They are text files and so don't take a lot of space but may be considered as clutter – unless you are interested in details of what is going on as *SatTracker* runs. They may be suppressed with the checkbox.

The setting of this checkbox is memorised in *SatTracker's* internal settings file (which we mentioned in Section 7.4.2). The logging function includes some activity which happens before this stored setting is recovered from disk, which is potentially a chicken-and-egg situation. So *SatTracker* stores log messages in an internal buffer until it knows if a log file is to be generated or not.

The example shown in Fig. 54 above may help you decide if you want to keep logs or not. This extract is continuous and was recorded in a short session. For long sessions

the log file can be quite long and naturally there will be lots of repetitive entries. In this example you can note references to too many satellites being selected.

As log files give insight into what the software is doing it's natural that we, as developers, are in favour of them. But you might be more in favour of saving disk space.

8. Reference: Sky View

The **Sky View** window is accessed from the main menu, under the menu item **Window**. It opens as a resizable window, as shown in Fig. 56.
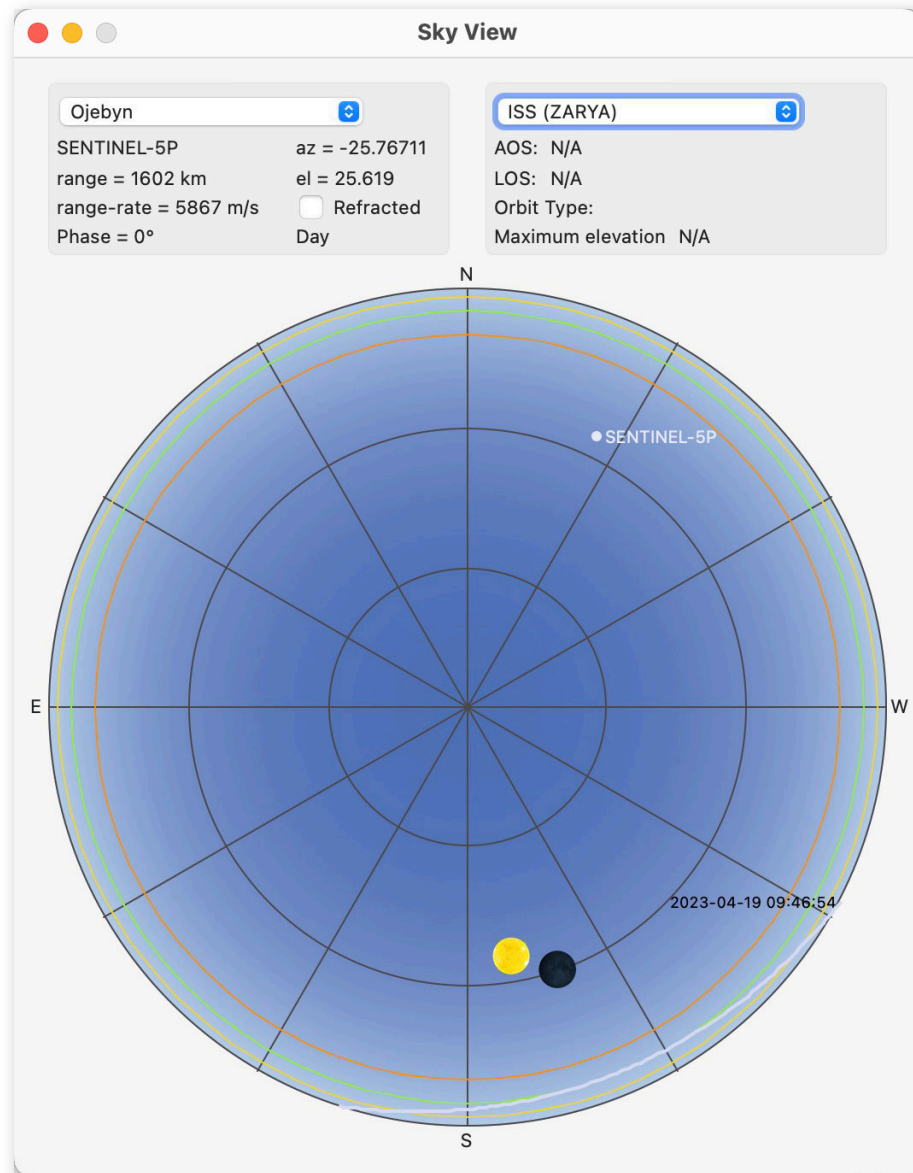
Figure 56. *Sky View from the Öjebyn ground station. Sentinel-5P is visible in the sky and we see some details in the upper left panel. But no track is shown because the satellite selected in the upper right panel is the ISS (by default as it is earlier in the list of selected satellites). An ISS path across the sky is visible in the South-West, with the AOS time marked. The physical, RX and TX horizons are all shown.*

To illustrate this Chapter we have selected six ground stations in the Viasat Real Time Earth network. For satellites we chose the ISS and all of the currently active satellites of the EU's Copernicus Programme:

‣ Sentinel-1A (a Synthetic Aperture Radar imaging satellite);

- Sentinel-2A and -2B (identical satellites carrying, a multispectral visible and infra-red imager);
- Sentinel-3A and -3B (identical satellites with a set of instruments for ocean monitoring, including visible/infra-red imagers for ocean colour and temperature, and an ocean topography payload centred on a radar altimeter);
- Sentinel-5P (carrying an instrument to measure trace gases and pollutants in the atmosphere), and
- Sentinel-6 which carries a set of instruments to measure ocean topography, again centred on an altimeter.

Please note the warning about updating the pass list given in Section 8.3.

8.1.   The Sky

The main part of the window shows a disk, which represents the sky above the selected ground station. The desired station can be chosen from amongst those selected in Settings by means of the drop-down menu at the top left. Resizing the window is constrained such that this disk always remains circular, and it maintains the labels for the cardinal compass points, N, S, E and W, in the correct positions.

The disk represents the sky: the horizon is around the circumference and the zenith at the centre. The southern horizon is at the bottom of the window and marked 'S'. To its right, in the anti-clockwise direction, is the west, marked 'W', as it is if you were looking at the real southern horizon.

There are grid lines, by default every 30°, in both azimuth and elevation. These grid lines respect the selection for map grid lines selected in the Settings window in the Map tab.

The station's horizon is also drawn, also in accordance with the choices in the Map tab. So up to three horizon lines will be shown, in the colours selected.

The Sun and Moon are also shown, again according to the Map tab.

The sky colour represents the illumination conditions: daytime, civil, nautical or astronomical twilight, and night-time. The darker skies feature stars (like the real sky!). *SatTracker*'s star database includes stars down to magnitude 5.0, each with a diameter related to its magnitude. Optionally constellation stick figures (following *Sky and Telescope* magazine) and constellation names or abbreviations can be shown too. Names (if chosen) are the standard Latin names, while 3-letter abbreviations are those defined by the *International Astronomical Union*, IAU.

If one or more satellites (from the satellites selected in Settings) are visible from the station they will also be shown, in the proper position in terms of azimuth and elevation. However, their paths across the sky will only be shown if the satellite is selected in the upper right panel. This behaviour is shown in Fig. 56 above and Fig. 57 below.
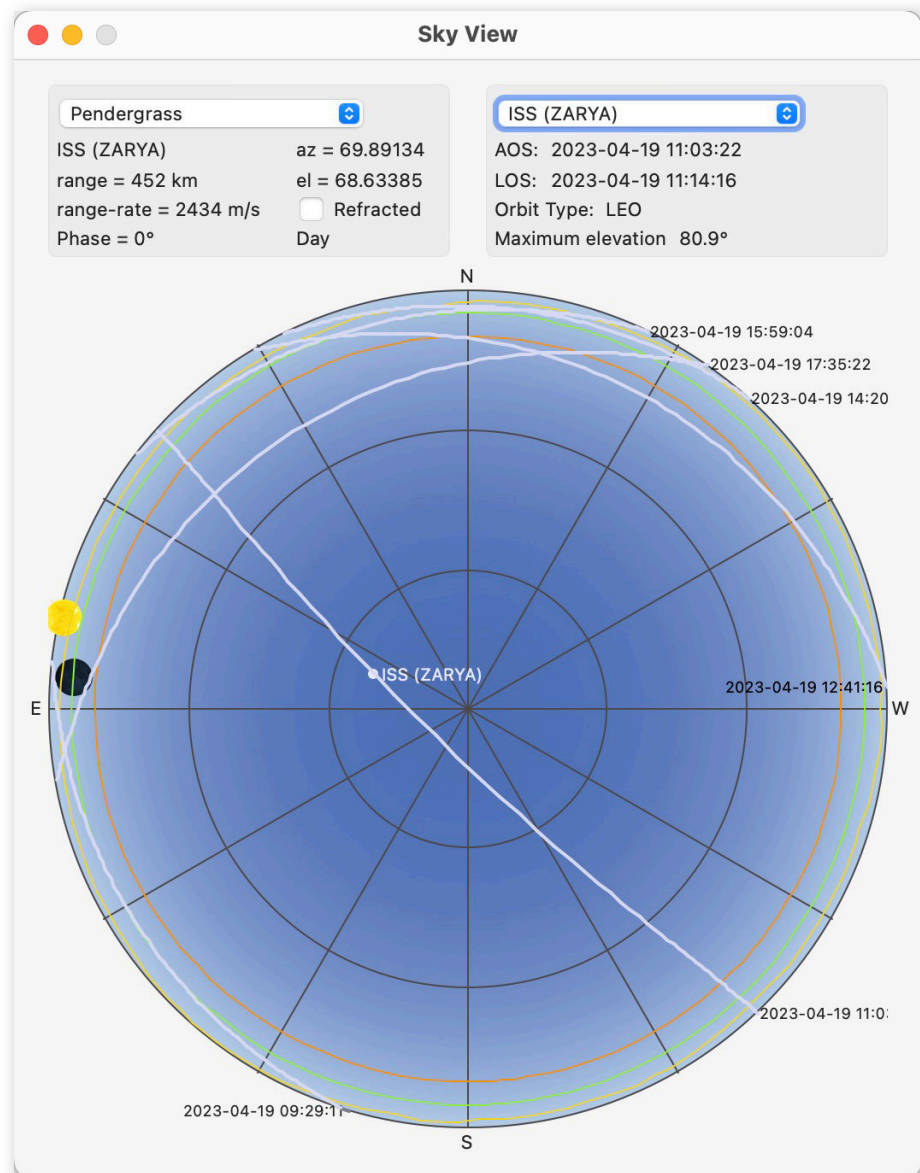
Figure 57. *Sky View from the Pendergrass ground station. The ISS is making a pass and now the path is shown because the satellite selected is the ISS by default. Other ISS paths (earlier and later) are also shown, with the AOS times marked. It is just after dawn at Pendergrass.*

Note: in some cases, satellite visibility may seem to differ from the visibility according to the horizon mask drawn on the map in the main window. **Sky View** is always right! This is because the horizon masks on the main map correspond to a given satellite altitude which may be different from the altitude of the satellite(s) visible.

For example, if the altitude used as reference to draw the horizons (see Section 7.4.5) is the ISS, which is very low, then significantly higher satellites such as many Earth observation satellites, will be visible in the sky though not necessarily inside the ISS horizon mask. At the extreme, satellites in geostationary orbits can be seen from about 70% of a hemisphere.

8.2. Data Panels

Visible satellites will have some relevant information in the top-left panel. If more than one satellite is visible, the earliest one in the selection list (as recorded in the drop-down menu in the top-right panel) will be shown.
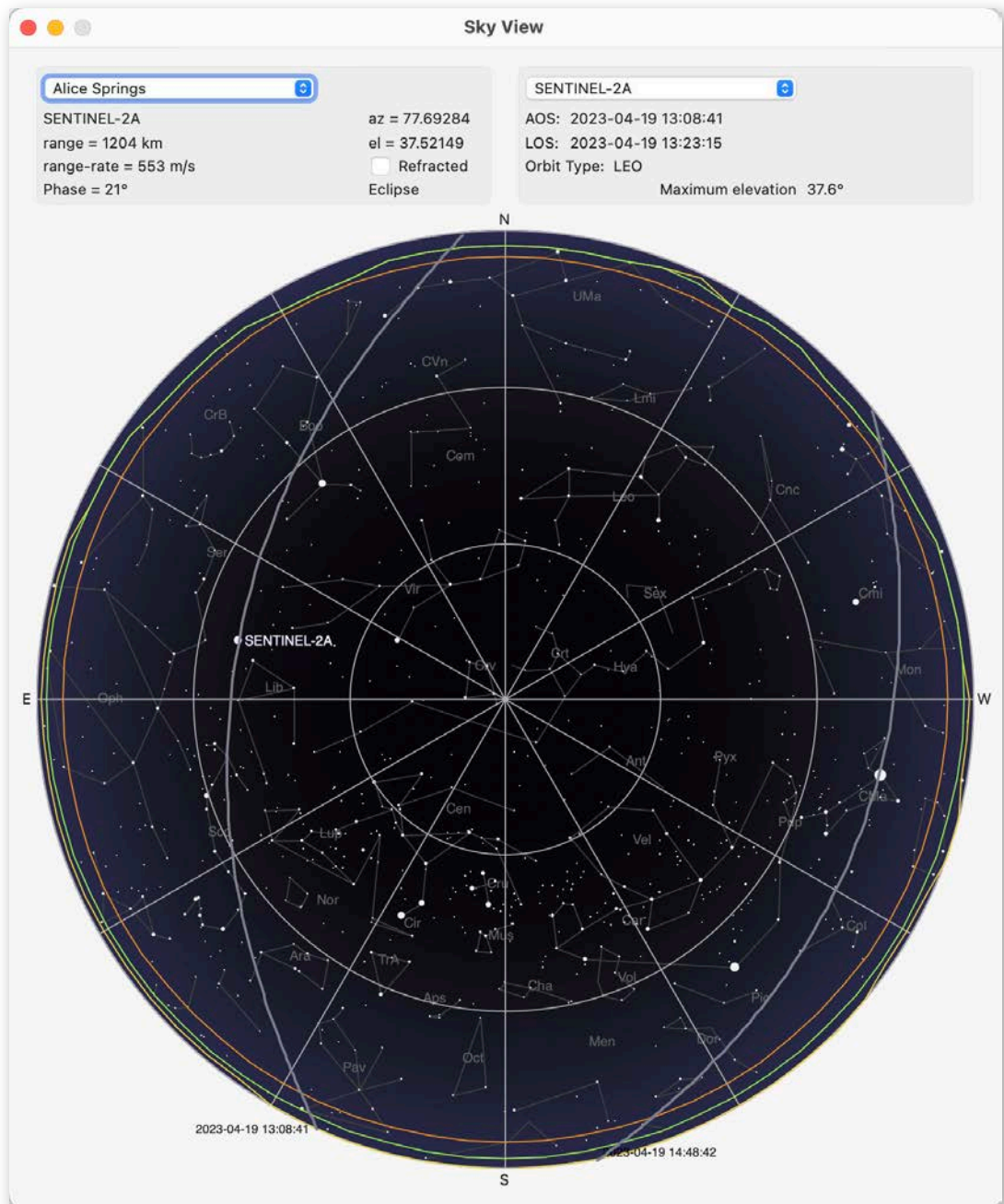
Figure 58. *Sky View from the Alice Springs ground station. Sentinel-2A is making a pass, and we have selected it in the upper right panel. The physical, RX and TX horizon are shown in the colours chosen in Settings (or the defaults, as here). Display of stars and constellations may be switched off in Settings, if desired (note for Northern hemisphere dwellers: Alice Springs is in the Southern hemisphere so the sky may look unfamiliar.*

The data fields on the left are: Satellite name; range from the station; the range-rate (which is the speed along the line-of sight to the satellite); phase (which is the angle between the satellite and the Sun).

On the right side are 3 data fields and a checkbox. The data fields are azimuth and elevation, and a verbal description of the optical visibility of the satellite. The checkbox is used to apply a refraction correction to the elevation value. This only applies to visual observations and has no effect for radio-frequency links. Many astronomy planetarium-style applications apply a refraction correction, so this allows a more representative comparison of positions.

The top-right panel, with the drop-down menu of satellite names, controls the tracks which will be plotted on the Sky View. Assuming there are passes for the selected ground station and satellite combination, it will plot all the tracks computed for the combination. The tracks have the same colour coding for daylight and eclipse as those defined in the **Map** tab of Settings for the main window. At the AOS end of the track is the date and time of AOS (in UTC), which differentiates the start and end of the track.

If a pass for the selected satellite is underway then the data fields AOS, LOS and Maximum elevation will have values, otherwise they read 'N/A'. The field for the orbit type (LEO, SSO etc.) is always shown.

8.3. Update of pass list

All the functions depending on lists of passes and stations: **Sky View**, **Pass View**, **Station Pass List** and **Satellite Pass List** use a pre-computed set of events. This set is re-computed every time a change is made to the selection of satellites or stations. It is also periodically refreshed.

If you change a selection and then immediately open one of the windows mentioned above, it may not reflect your current selection because the list is still being computed.

If it seems the list has not been updated as it should, then close the affected window and force an update using the button **Update Passes**, below the map in the main window.

9.   Reference: Pass View

The **Pass View** window is accessed from the main menu, under the menu item **Window**. It opens as a window resizable in the horizontal direction. See Fig. 59.
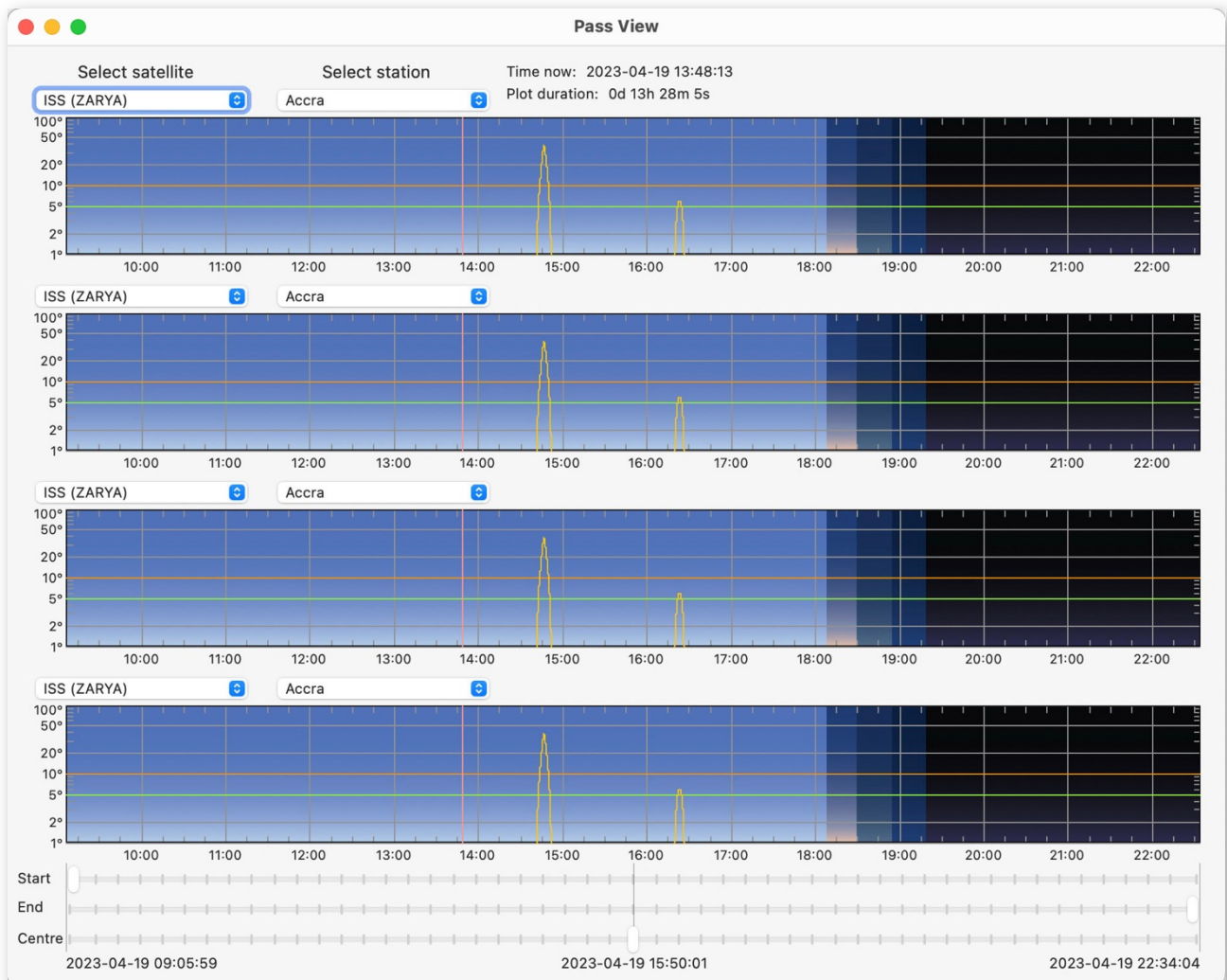
Figure 59. *Pass View when first opening the window. The four panels all show the same ground station and satellite combination, and these are the first entry in the respective lists.*

The purpose of the window is to visualise the availability of satellite passes, characterised by their elevation. Again, please note the warning about the pass list given in Section 8.3.

The window has four panels showing a sequence of passes as satellite elevation in the sky as a function of time. These can optionally be plotted as linear or log values (see Section 7.5). Each panel is dedicated to one satellite/ground station combination, which can be chosen (amongst the satellites and ground stations selected in Settings) using the drop-down menus above each panel.

The combinations are memorised during a session (assuming you don't deselect the entries) to avoid having to set it up each time the window is re-opened.

9.1. Case Study: Satellite Operations

For a satellite operator, for example, it allows a view of the passes of a single satellite over a set of four different ground stations. An example of this is shown here where the 4 stations used at the launch of Cryosat-2 are shown, together with its passes. We will not try to return to the launch time as the orbit represented by the TLE is different now[20].
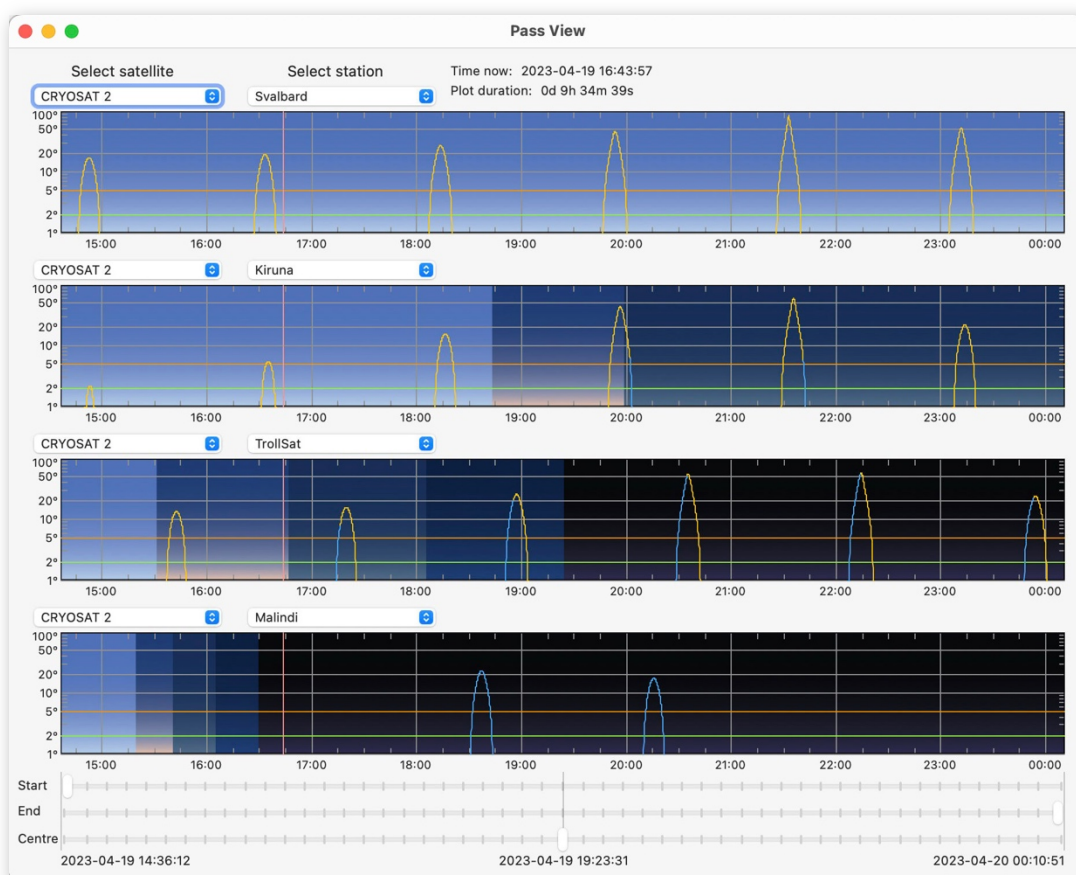
Figure 60. *View Passes showing the station configuration for the 'Launch and Early Orbit Phase' (LEOP) of CryoSat-2, which we mentioned in Chapter 2 and subsequently.*

Clearly the combination of Svalbard and Kiruna are mostly overlapping, but this combination provides extended coverage, longer than possible with a single ground station, which is very useful just after launch. The TrollSat station, at a similar longitude but in Antarctica, provides complementary coverage so that there is contact with CryoSat-2 from one station of this network twice per orbit. The role of Malindi is less obvious as it provides only two passes. But the station was carefully chosen because at the time the satellite separated from the launch vehicle, a crucial moment, it was in visibility of Malindi, heading south. There was little use for it after that.

---

[20] Several years ago, the CryoSat-2 orbit was slightly changed in order to maximise the collocated tracks with NASA's ICESat-2 mission.

9.2. Case Study: Ground Station operations

For the operator of a single ground station, this window allows the visualisation of the satellites which will have usable passes (that is, above the relevant RX and TX horizons). We will use Fig. 61 as an example.
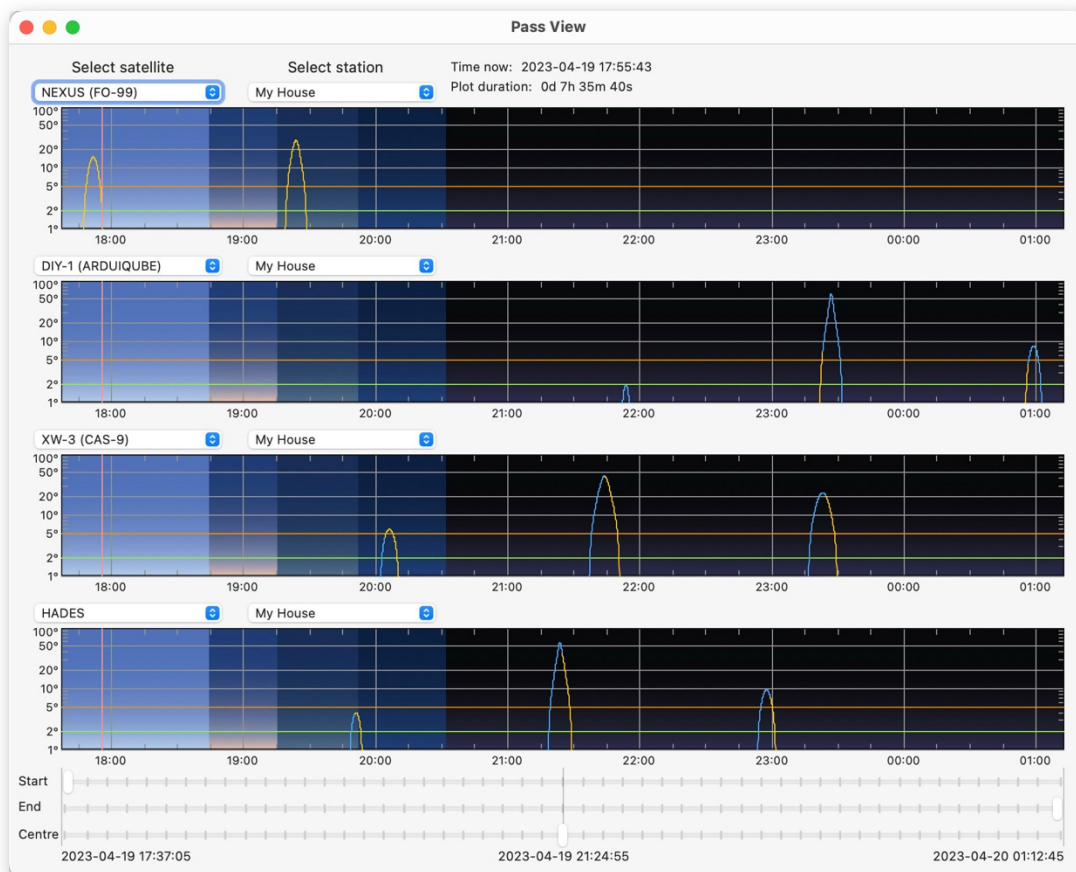
Figure 61. *View Passes showing the passes of a set of arbitrary Amateur Radio satellites over our hypothetical ground station 'My House'.*

Imagine we have a satellite amateur radio station at our home ('My House' as we established it in Section 7.3.8), and we wish to use passes of some amateur radio satellites, for example NEXUS (FO-99), DIY-1 (ArdiQube), XW-3 (CAS-9) and HADES[21][22].

By selecting our station as the common ground station and each of the four panels, we can see the combined load in terms of operations. Using the (default) log scale we can also more readily see the passes whose elevation exceeds our declared operational horizons for downlink and uplink.

---

[21] HADES is in the 'Active' family on the TLE tab. All the others are in the 'Amateur Radio' group.

[22] Please note that we are not involved in satellite amateur radio and selected these satellites using 3 criteria: (a) relatively recent launch, (b) apparently active and (c) different launch vehicles, so with rather different orbits. We have no idea of their capabilities otherwise.

9.3.   Details

The overall timescale of this view of passes is determined by the selection of satellites (and, to a minor extent, ground stations).

SatTracker computes sets of ground station passes in the background. For each satellite it computes passes over six orbits. For many combinations of orbits and ground stations there will be less than six passes, and in some cases, there may be no passes at all in this interval.

In other cases, as we saw back in Section 5.2 with XMM-Newton's 2-day orbit, the 6 orbits may take a long time, and the other, shorter-period, satellites, have finished their 6 orbits much quicker.

So, if there is a mix of long-period and shorter-period satellites, the time duration covered by the set of passes will be unevenly filled.

9.4.   Zooming
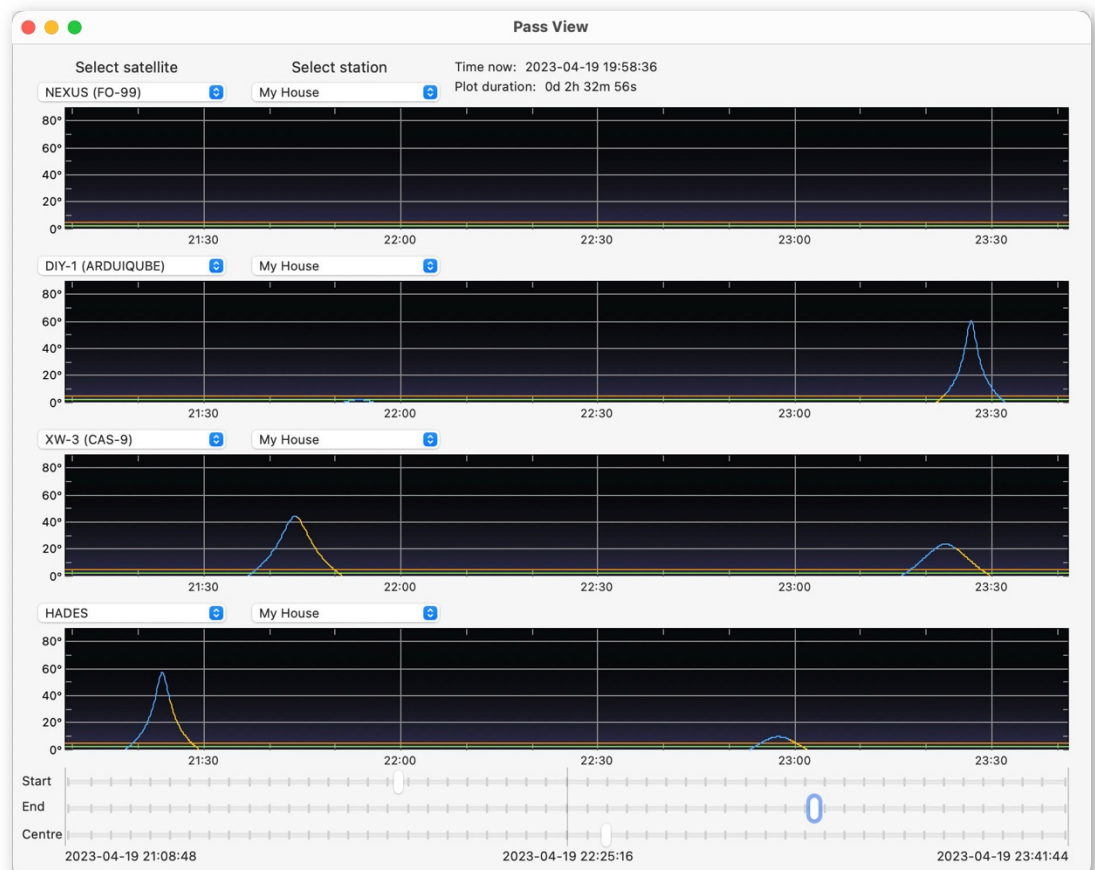
Figure 62. *Zoomed state of the View Passes window over our hypothetical ground station 'My House'. The zoomed period is during night-time and does not include the time 'now'. Here we have switched to a Linear representation.*

It will often be useful to zoom in to the presented plots, and this can be done using the sliders at the bottom of the window. An example of a zoomed in display is shown in Fig. 62. There are three sliders: the top one controls the location on the time axis of the start point of the plot, and the middle one controls the end point. Together they define the span, and this span is recorded in the label at the top of the window: Plot duration.

This plot duration extends from the time (and date) recorded at the bottom-left of the window (below all the sliders) to that shown at the bottom right. The centre of the duration is shown at bottom centre of the window.

Having defined the duration, it can be panned around the plot using the bottom slider. All the above-mentioned labels change accordingly.

Please notice that at all times the time divisions on the plot maintain sensible time subdivisions; what we could call a 'nice time scale'

10. Reference: Station Pass List

The **Station Pass List** window is also accessed from the main menu, under the menu item **Window**. It opens as a resizable window, as shown in Fig. 63.

Please note the warning about the computation of the pass list given in Section 8.3.

The purpose of this window is to provide a chronological list of upcoming (and optionally recent past) passes of a given ground station for all the selected satellites. It also provides a description of all available information about the selected station.
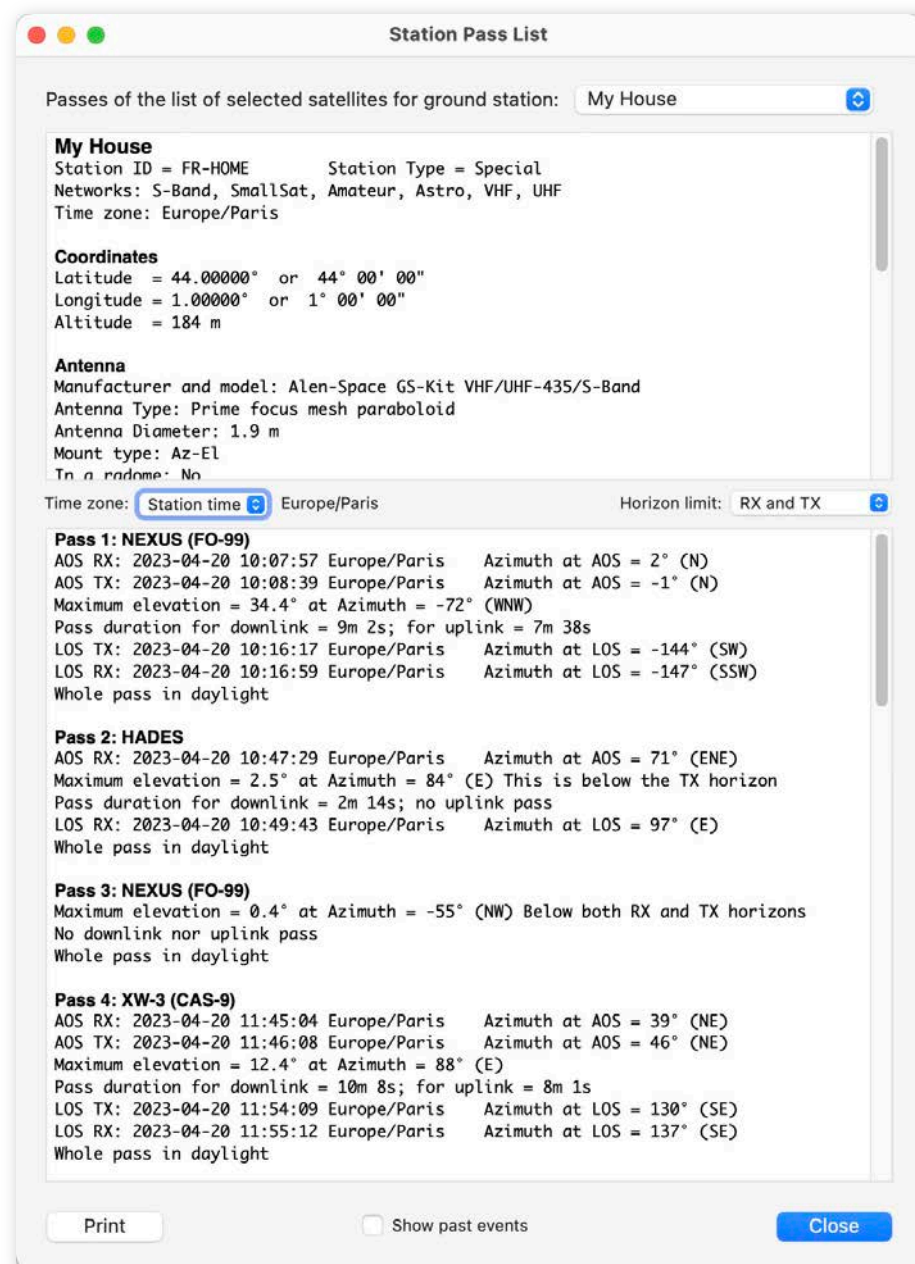
Figure 63. Pass list for the selected Amateur Radio satellites over 'My House'. The RX and TX horizons have been selected and each results in a set of RX and TX timings.

In the example shown in Fig. 63 we have selected the same combination of satellites and the single ground station used to illustrate Section 9.2, because it is intended for the same use case: a ground station operator interacting with a set of satellites.

The Station of interest is selected using the drop-down menu at the top of the window.

The first panel provides the full set of information known about the station from the Station database. The first group is the basic identifying information and the list of networks to which the station belongs. That is followed by location information.

The third group lists the details of the antenna and its mount, as well as the various horizons. Note that for this list the profile of the physical horizon is not plotted: instead an average value for the profile is computed and listed.

Next comes the RF (radio-frequency) characteristics (if any are available) and finally any Comments.

This section can be quite lengthy – the panel can be scrolled as necessary.

Between the two panels of text there are two drop-down menus.

The first, **Time zone**, has 3 entries: UTC, "Here" and Station Time. The first is obvious; the second means the local time on the host computer's clock, 'here'; the third entry sets the times for the passes listed to the local time zone of the station itself. The relevant time zone name is provided alongside the time of the events in the lower panel.

Before discussing the other menu, **Horizon limit**, we need to look at the panel below it. This lists the passes for all the selected satellites at this ground station. It lists, in order:

▸ the AOS time and time zone, and its azimuth;

▸ the value of the maximum elevation of the pass, and its azimuth;

▸ the duration of the pass, from AOS to LOS;

▸ the LOS time and time zone, and its azimuth;

▸ a description of the visibility of the pass in terms of solar illumination.

All the azimuth values are accompanied by an interpretation of the azimuth as a compass direction, and for low elevation passes it will be mentioned if the pass is below the RX or TX horizon, or both.

Returning to the **Horizon limit** menu; it has 5 entries, and defaults to the first one, the Theoretical horizon. This provides AOS and LOS values which would correspond to a flat, ocean-like horizon: a 'theoretical' horizon. There is only one entry for AOS and one for LOS, per pass, in the lower panel. The selection Downlink, RX and Uplink, TX are similar except that they use the appropriate RX or TX horizon values.

With the selection RX and TX, things get more interesting: now there are two AOS entries, for each of these horizons respectively, and two LOS entries. Furthermore the 'Pass duration' field provides more information, corresponding to the downlink and uplink duration respectively.

Finally, the selection All provides all the horizons (3 each for AOS and LOS) plus 3 pass durations.

In some case, for low elevation passes, one or more of these entries won't be meaningful, and if so, it is mentioned in the list.

At the bottom of the window are three items.

On the right, **Close** should be obvious.

On the left, the **Print** button gives the opportunity to print the information in the window, formatted to keep all the information for each pass on the same page. The station details are printed in full.

Finally, the central checkbox, **Show past events**, allows the window (and print) to show all of the events which have been computed. Normally only passes in progress, and future passes, are shown. If you are simulating past events using Time Control (see Chapter 14) then this must be ticked or no events will be seen.

11. Reference: Satellite Pass List

The **Satellite Pass List** window is accessed from the main menu, under the menu item **Window**. It opens as a resizable window.

Please note the warning about the computation of the pass list given in Section 8.3.
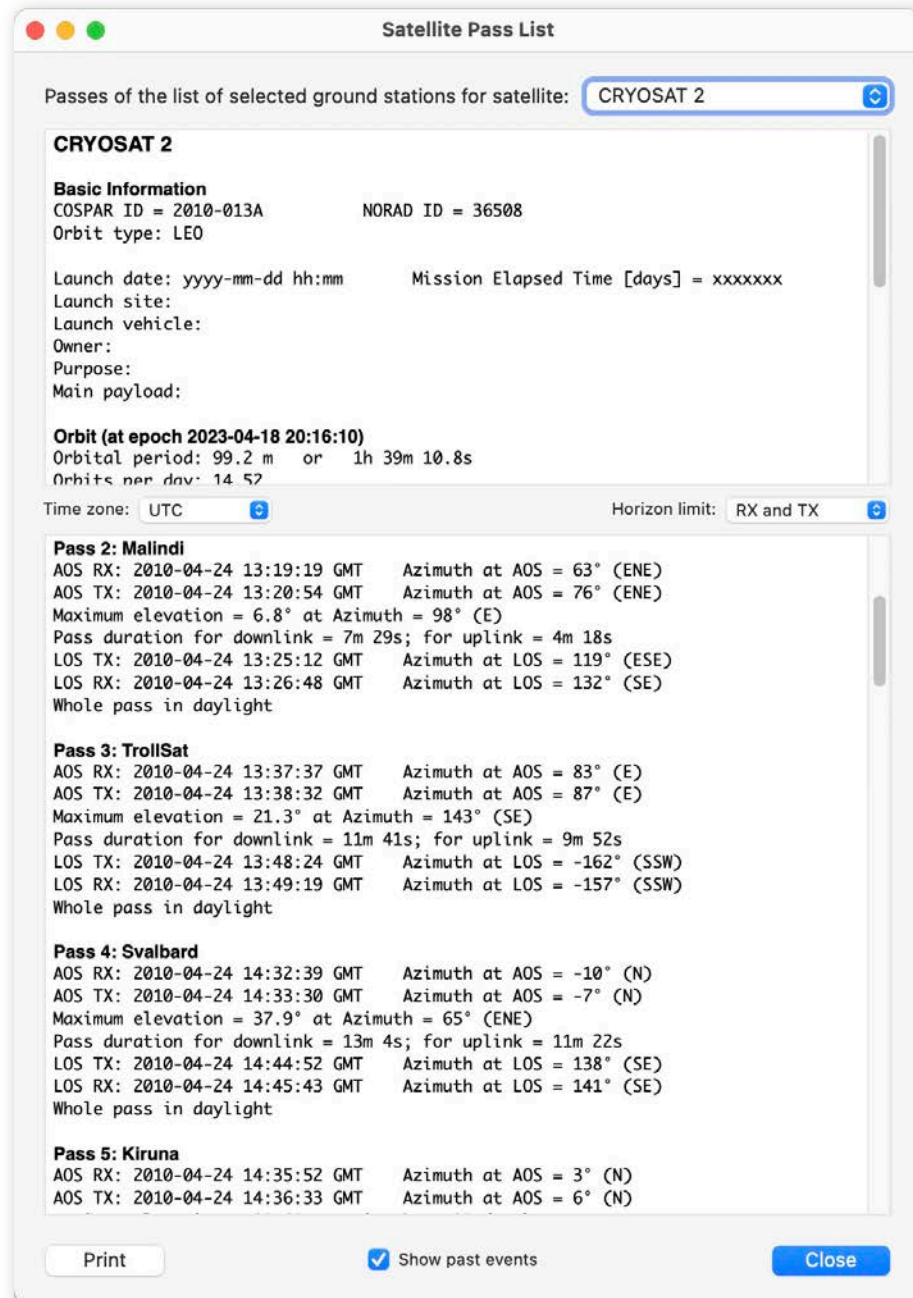
Figure 64. *Satellite Pass List for CryoSat-2 over the set of stations used for its Launch and Early Orbit Phase (LEOP) with RX and TX horizons selected. The date and time have been adjusted to correspond to its launch but due to orbit changes since then, the current TLE does not give exactly equivalent results (though they are surprisingly close). The 'Show past events' box **must** be ticked or no passes will be shown! Malindi was the first pass but is numbered 2 because the full orbit passes other stations first.*

The purpose of this window is to provide a chronological list of upcoming (and optionally recent past) passes of a given satellite for all the selected ground stations. It also provides a description of some information about the chosen satellite. Because the information in this window has more than transient value, there is specific support to print it, with a dedicated button.

The Satellite of interest is selected using the drop-down menu at the top-right of the window.

The first panel provides a lot of information about the satellite. The first group is the basic identifying information and the type of orbit, according to a broad classification.

After that is a section with a lot of blank fields. These are useful topics, and it would be good to have them filled in. However, the data are not available in the TLE and would require a separate database describing all potential satellites. So why are they here?

We plan to include such a database in a future version of *SatTracker* and we are laying the foundations for it. As we mentioned in the Quick Start, in Section 5.3.2, the problem is how to handle updates, especially since the advent of mega-constellations of thousands of satellites, and dozens in a single launch.

The next section lists the orbit parameters derived from the TLE. Orbits evolve all the time, so for that reason the epoch date of the TLE is listed in the heading to this section of the report. The first group are the properties of the orbit itself. The next set of three properties are the orbit height.

To find the orbit height from the orbital properties we need to know the radius of the Earth, but of course the Earth is not a perfect sphere so there are various ways to specify its radius. We provide 3 of them, and the associated heights. The *equatorial radius* is the semi-major axis of the Earth's ellipsoid and the largest value that could conceivably be called its radius. Obviously, it results in the smallest orbital height values. The *mean radius* is the radius of a sphere that has the same volume as the Earth. Finally, the *ellipsoidal radius at the perigee latitude*, which must be calculated separately for each orbit definition, is an attempt to find the representative Earth surface at the position of the perigee and apogee (since these occur at opposite points of the orbit and so should have the same ellipsoidal height in the opposite hemisphere).

Between the two panels of text there are the same two drop-down menus as in the Station Pass List, described in Chapter 10 above. The only difference is that the Station Time option is missing from the Time zone drop-down menu as it is not very useful in this case.

The second panel of text is almost identical to that in the Station Pass List, with the exception that the Station is identified in the pass headings instead of the satellite.

Finally, the three items at the bottom of the window are also the same as in the Station Pass List.

The central checkbox, Show past events, is important for the case shown in Fig. 64, and any other cases where past events are simulated.

12. Reference: Antenna DB
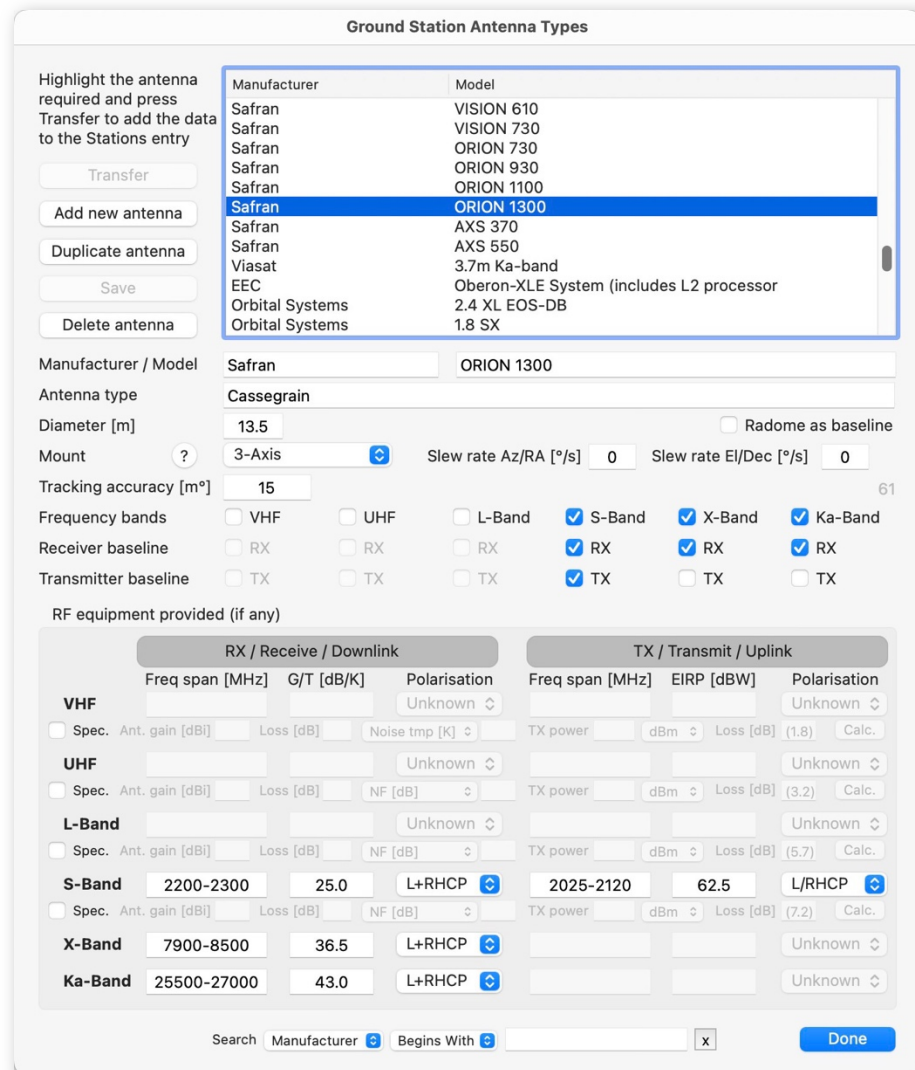
Figure 65. *The Antenna Database, with a large antenna selected.*

We already saw the principal use of the Antenna DataBase window in Section 7.3.8, where we used it to import the details of a ground station antenna and RF equipment into a new ground station.

It is populated with a large range of commercial ground station antennas, though naturally the list is not complete. It can be searched, using the familiar search tools at the bottom of the window. Like the search tools in the Settings window, you can search several of the fields in the database, and with the same string-matching options.

The database can be extended by adding new antennas: Press **Add new antenna**.

All the fields will be cleared ready for input.

Note: you must provide some text for at least the **Manufacturer** and **Model** fields or it will not be possible to save the new record, and *SatTracker* will complain that you have not done so if you try to move on. All other fields are optional.

The **Antenna type** field is used to give some information about the antenna construction, most notably if it is a Yagi antenna, a helix or an antenna with a dish-like reflector and feed. The field is free-text.

Then we have the **Diameter** of the antenna in metres (where relevant – it is not for a Yagi or helix) and whether it is supplied, as baseline, with a radome.

The next two lines concern the mounting. The first is a drop-down menu to identify the type of **Mount** (to ensure some consistency in naming) and a window with some help is available by pressing the **?** button. Then there is the maximum **Slew rate** about the two main orthogonal axes (there may be a third axis with an associate slew rate, but it is not provided for here). On the next line is the **Tracking accuracy** in millidegrees (so 0.05°, for example, is recorded as 50).

Next there is a set of checkboxes which are used to indicate the frequency bands in which the antenna can operate (the top row), and whether it can receive and/or transmit; these two rows are only enabled if the capability checkbox (i.e. the top row) is ticked.

The lower portion of the window is dominated by the box labelled **RF equipment provided (if any)**, which refers to any equipment provided as standard with the antenna. It covers the six frequency bands which *SatTracker* is concerned with and splits them into receive and transmit characteristics. All the fields are disabled until an appropriate checkbox is ticked in the group we described above. So, for example, to enable the entry of information about S-Band reception and transmission capabilities, both the **RX** and **TX** checkboxes under S-Band need to be ticked, and that can only be done one the **S-Band** checkbox is itself ticked.

The fields here are the same as those found in the Settings window, as we described in Section 7.3.5. Usually, they can all be found in the manufacturer's data sheets, but sometimes G/T and/or EIRP figures are not given. In some cases, of course, the power amplifier for the uplink is not provided by the manufacturer (even if he provides the rest of the equipment) and so the EIRP cannot be known – it will depend on which amplifier is eventually procured. In other cases, though, especially at the lower frequencies, the manufacturer will instead specify some related parameters, such as the antenna gain, the receiver noise and the transmitter power. It's possible to calculate the G/T and EIRP from these but it needs some assumptions to be made about other system parameters. In Fig. 66 we can see how it works.

Let's imagine we have a UHF antenna, and the manufacturer says that the antenna is a crossed Yagi with a gain of 16 dBi, the LNA (Low Noise Amplifier) noise figure is 0.7 dB and the transmitter power is 60 W. He also gives the receiver and transmitter frequency range so we can immediately enter those into the relevant boxes. To start the calculation of G/T and EIRP we need to tick the checkbox marked **Spec.**, just under the caption **UHF**, on the far left.
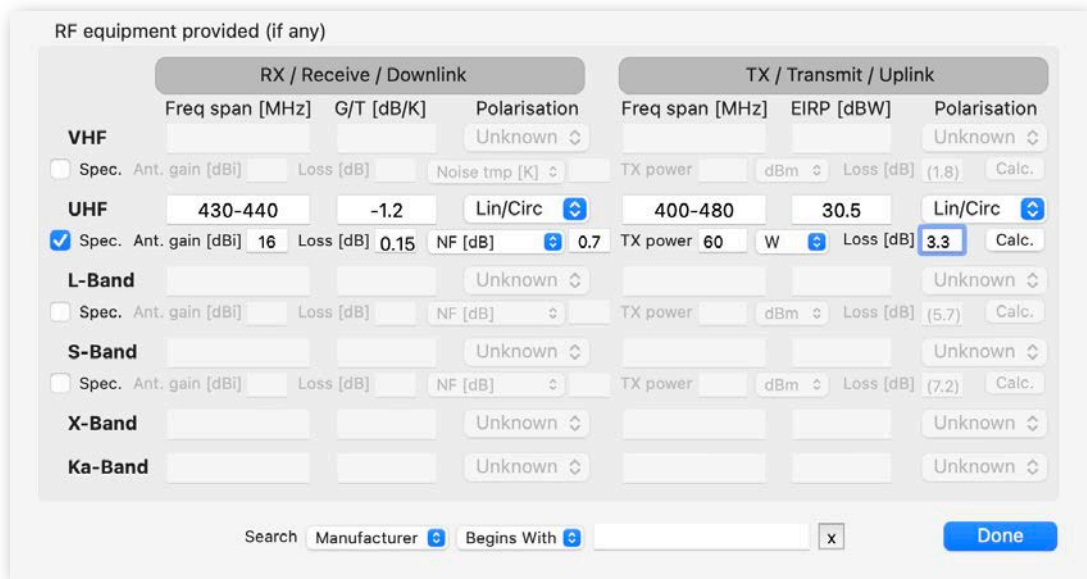
Figure 66. *The Antenna Database, calculating link parameters for a UHF antenna.*

This will enable the row of controls to its right. We can start entering the data: **Ant. gain [dBi]** is 16 and in the field after the drop-down menu saying **NF [dB]** we can enter 0.7. The drop-down menu has another entry, **Noise tmp [K]**, because some manufacturers specify input noise in that way. Then we can enter the TX power as 60, but we must choose the proper units from the drop-down menu just afterwards: it can be **W** (watts), **dBm** (dB relative to 1 mW) or **dBW** (dB relative to 1 W), depending on the manufacturer's preferences. We can press the **Calc.** button now to do the calculation and automatically enter the values in the proper fields, but it will not be as accurate as it should be, because we have not taken losses into account.

The first place we need to do this is on the receive side. Here we are mostly interested in the insertion loss into the LNA, plus any other losses in the reception chain. The LNA insertion loss is often provided by the manufacturer. Typically, it will be something like 0.15 dB at UHF, for a good quality system, and perhaps double that at VHF.

On the transmit side we are more concerned with losses in the cables and connectors between the transmitter output and the antenna feed. This is quite strongly dependent on cable length and cable type. Cable loss is often specified in dB/m or dB/100 feet. Clearly, the closer the transmitter is to the antenna the better! For greatest accuracy you need to know the cable length, type and number and type of connectors. Here we will assume that we have 30m of RG8 cable and good-quality connectors. We will then find there is 3.1 dB of cable loss, and let's assume 0.1 dB per connector for 2 connectors, so 3.3 dB in total.

Pressing the **Calc.** button we find that the G/T is -1.2 dB/K and the EIRP is 30.5 dBW.

Notice that tooltips for these input parameters are available by hovering the mouse above the various items.

The final things to complete are the polarisations[23] for receive and transmit (they are often, but not always, the same). Here there are two drop-down menus in the interest of maintaining consistency, and of course a tooltip to explain which is which. A simple Yagi antenna always has linear polarisation, while crossed Yagis can provide linear or circular. Single helix antennas are always circular. The feeds of reflecting antennas can be designed for any kind of polarisation but are usually circular.

Once everything necessary has been entered, press the **Save** button. Details can be updated at any time and saved again. If there are changes, or you have not saved the initial input, *SatTracker* will warn you if you try to move on without saving.

Entry of data for a new antenna can be streamlined by selecting a similar one and pressing the **Duplicate antenna** button. The changes can then be made and saved.

Unwanted antennas or duplicated can be removed using the **Delete antenna** button.

The window is closed with the **Done** button.

[23] See Annex Annex D for a fuller description of polarisation.

13. Reference: View TLE

13.1. Explanation of the TLE

The North American Aerospace Defence Command, NORAD, *via* its Space Track branch, uses radar and optical means to track every object in near-Earth space. Naturally there are some feasibility limits so here, by "every object", we mean objects larger than a few centimetres. This generates an enormous catalogue which is stored internally at NORAD in an unknown[24] but presumably complete way. Space Track disseminates the bulk of this catalogue to registered users, which includes, vitally for us, CelesTrak, from where we obtain our data.

The format used, the Two-Line Element (TLE) was developed by NORAD and is a means of encoding the mean Keplerian orbital elements, and other information. TLEs are generated using the Simplified General Perturbation Theory and are particularly adapted for use with the SGP4 Orbit Propagation Library, as we use in *SatTracker*.

According to Space Track Report No. 3, from 1980, concerning TLEs: *"The most important point to be noted is that not just any prediction model will suffice. The NORAD element sets are "mean" values obtained by removing periodic variations in a particular way. In order to obtain good predictions, these periodic variations must be reconstructed (by the prediction model) in exactly the same way they were removed by NORAD. Hence, inputting NORAD element sets into a different model (even though the model may be more accurate or even a numerical integrator) will result in degraded predictions. The NORAD element sets must be used with one of the models described in this report in order to retain maximum prediction accuracy."*

In this Chapter we are going to decode the TLE into the relevant parameters, which include the mean Keplerian elements. However, these decoded values need to be treated with caution: we can examine them to understand characteristics of the orbit, but, given the caveats mentioned above, we should definitely not extract them for use in any other type of orbit propagator[25].

But what do we mean by orbital elements at all? They are a set of numbers which uniquely define the position and movement of an object in a specific orbit at a given moment. In general, we need six parameters, and an associated time, to define an 'orbit'.

But bear in mind that orbits, and the parameters which define them, change over time. This is because, firstly, the earth is not a concentration of mass all at one point, like a black hole: it has a non-uniform gravity field and this changes the orbits of

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[24] Unknown to anybody outside NORAD, of course!

[25] Similarly, generating good-quality TLEs from generalised orbital elements is not trivial. In time we plan to add such a capability to *SatTracker*, but the recipe to enable this is not available at present.

satellites. Secondly, there are non-gravitational forces, like air-drag, which also change the orbit.

So what are these six parameters? Well, there are several options, including:

Cartesian **state vector**: this is a set of two 3D vectors defining the satellites position and velocity, in an inertial reference frame, centred at the Earth's centre of mass, plus the time (also called 'epoch').

Mean or osculating **Keplerian elements**, where there are also six parameters plus the epoch. Two of the parameters define the shape and size of the orbit's ellipse:

▸ eccentricity, e

▸ semi-major axis, a

Two define the plane of the orbit:

▸ inclination, i

▸ Right Ascension of the Ascending Node (RAAN), Ω

One defines the orientation of the ellipse in its plane:

▸ argument of perigee, ω

And the last one defines the position of the satellite on the ellipse, at the epoch time:

▸ mean (or true) anomaly, ν

These are illustrated in Fig. 67.
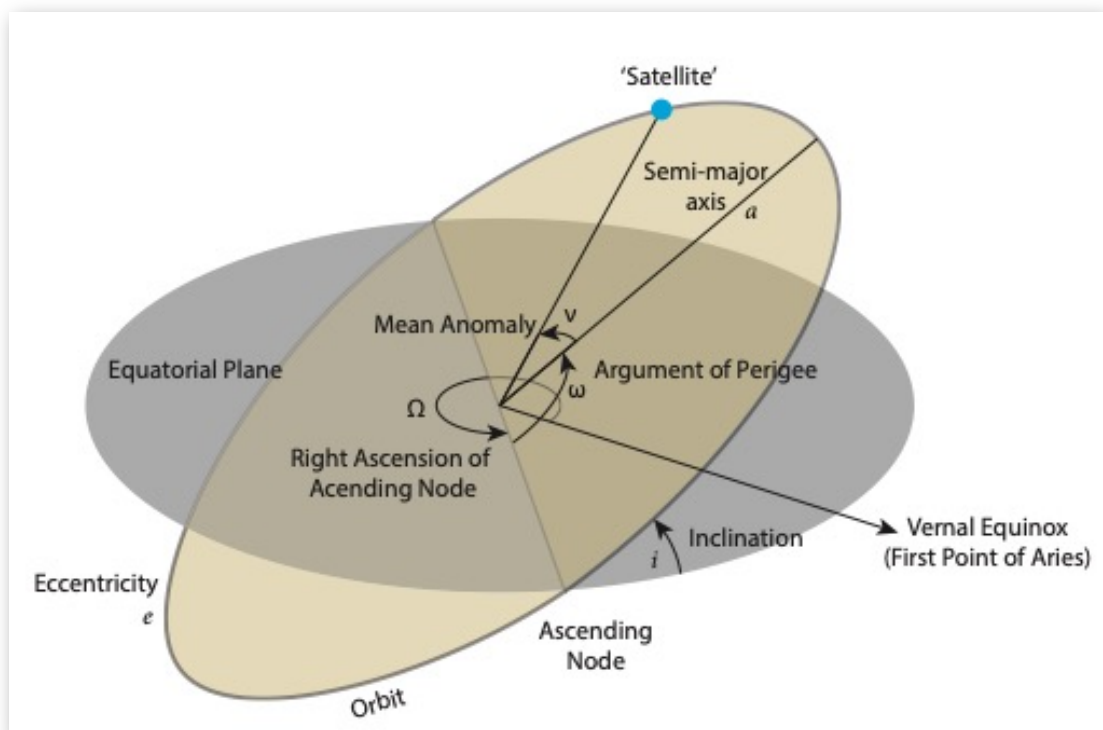
Figure 67. *Illustration of the meaning of the 6 Keplerian elements.*

The True Anomaly represents the actual angular position of the satellite with respect to the perigee, while the Mean Anomaly is the fraction of the orbital period which

has elapsed since the perigee passage, expressed as an angle. For a circular orbit it is the same as the True Anomaly, but otherwise it is the location of a fictitious satellite which would have that position in a circular orbit.

Now we need to look at the difference between mean Keplerian elements and osculating elements. As we mentioned above, the Earth's gravity field is not uniform, as it would be if there was a simple point mass at the centre. The gravity field reflects the distribution of mass throughout the body of the Earth, and recent satellite missions have shown this up in exquisite detail: the NASA-DLR GRACE missions showed up long-term changes and the ESA GOCE mission, at extremely low altitude, was able to pick up the most subtle features of the field. A visualisation of its results (Credit ESA), looking towards the large 'bump' in the gravity field over the Western Pacific, is shown in Fig. 68, below.
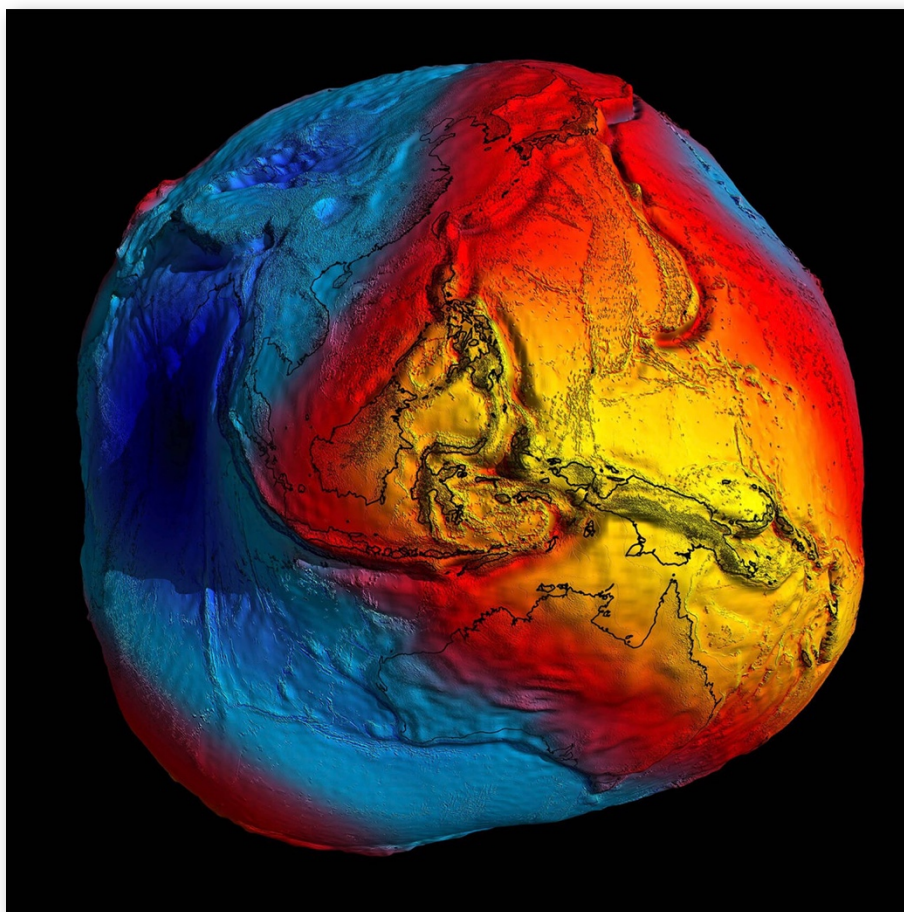
Figure 68. *An exaggerated view of the terrestrial geoid, derived from ESA's GOCE mission. The large 'bump' in the Western Pacific is evident, and so is the large depression in the Indian Ocean. [credit ESA]*

The osculating[26] elements represent the true state of the satellite at a given moment: they are the Keplerian elements "now"! Of course, due to the non-uniform gravity field, the osculating Keplerian elements will be different.

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[26] 'Osculating' is derived from the Latin *osculum*, to kiss, because the orbital paths of the instantaneous and mean are more intimate than a mere tangent might be.

The mean elements, on the other hand, do **not** represent the instantaneous state. But they are useful for long term analyses, such as the generation of ground tracks. And, as we mentioned at the start of this Chapter, the TLEs contain these mean elements, and so are ideally suited to our purpose of generating ground tracks.

It is worth mentioning here that the conversion from osculating elements (such as might be determined form a set of instantaneous measurements) to mean elements is non-trivial.

13.2.   View the TLE

The **View TLE** window is called up from the main menu (see Fig. 33 in Chapter 6) and allows the display of the TLE for any of the satellites which have been selected in Settings. They appear in the drop-down menu at the top of the window (see Fig. 69, for example).

The format of the TLE file is rigidly defined and some information has implicit formatting, omitted details or may be in inconvenient units. In the **View TLE** window all of this is handled so that you can see how the TLE is made up and what is in it.

The TLE entry for a satellite consists of one line with the satellite name – it's the one in the drop-down menu – and two lines of numbers and letters. In the **View TLE** window they are laid out, as they are, in the two lines of monospaced text in the coloured boxes: they are the lines with larger characters starting with 1 and 2 in the field labelled *Card*[27].

The way to decode the fields is written directly into the coloured boxes which contain each field. In one case (*Satellite Number*) they are repeated in each line. The single character at the far right is a checksum character.

The decoded versions of these numbers are given in the (non-editable!) text boxes below, together with an indication, using the pair of coloured boxes to the right, of where the parameters are to be found in the TLE. These all have tooltips to help in their interpretation. So, for example, the 6th item down is Semi-major axis [km], an element which defines the size of the orbit's elliptical shape (as we indicated in the previous Section). To its right is an indicator with no colour at the top and purple below. this means that the information came from the purple box on the bottom row. This is labelled *Mean motion (rev/day)*, not Semi-major axis, but these two are linked by a simple formula. And, in fact, this same information in the purple box is used to extract three more pieces of information about the orbit. See if you can find them.

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[27] The TLE format is pretty old, and dates from the time of punched card data storage. A typical punched card had 80 positions.

Punched cards remained in use for a surprisingly long time, and perhaps especially in the orbital mechanics domain. We can recall that the master copy of a major orbit propagation system was kept as thousands of punched cards in special drawers in the office adjacent to ours in the late 1980's.

We should make a few observations here: the third field in the first card (*Class*) is always set to 'U', for unclassified. Another value, 'S' for secret, does exist, but these TLEs are not available outside NORAD. The two fields in the first card, *Mean motion derivative* and *Mean motion second derivative*, are not used in the SGP4 algorithm. The field *Type* (near the end of Card 1) is intended to represent the orbital model used for generation of the TLE. It is *always* set to 0, for SGP4. Finally, the last field of Card 1, the *Element Set Number*, goes up to a value of 999 and is then not incremented further.

The three example TLEs illustrating this Chapter are the same three satellites we chose as examples at the beginning of this manual. That was because they have three very different types of orbit. Now we can look in more detail.
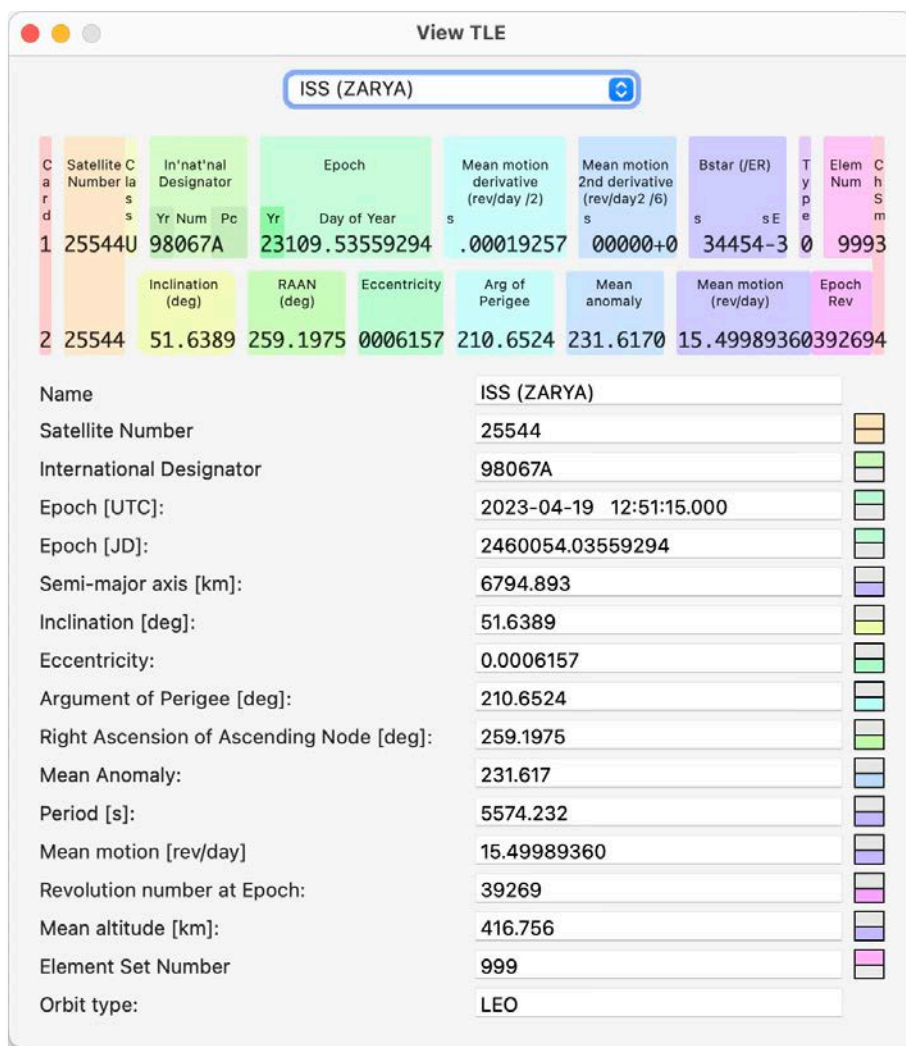
Figure 69. *The TLE for the ISS.*

The ISS, Fig. 69, has a low-altitude orbit, at 417 km and it's nearly circular, with an eccentricity of 0.0006. Because it's low, it orbits the Earth many times per day: just over 15.5 times.

If you use this window to view the ISS TLE yourself you will probably find some variation in these orbital parameters: it flies rather low, and has a large drag cross-section, so that its orbit changes rather quickly. It decays by about 100 m each day, so

the crew have to undertake orbit maintenance manoeuvres (called 'reboost') about once per month. It uses about 7000 kg of fuel per year for this.

Let's contrast that with XMM, Fig. 70, which as we saw, has a most peculiar shaped orbit track. XMM's orbit is highly elliptic, and it has evolved considerably in the years since its launch in December 1999. It started with an inclination of 40°, and eccentricity of 0.79 and an apogee altitude of 114 000 km; nearly a third of the distance to the Moon. The apogee is in the Southern hemisphere. This orbit was selected both to avoid spending much time in the Earth's radiation belts, and to avoid loss of observation time due to periods of eclipse in the Earth's shadow. Over its long lifetime the apogee has varied between 114 000 km and about 100 000 km, while the perigee has changed between 7 000 km and 28 000 km. Naturally the eccentricity has changed considerably too and is approaching 0.52, the expected value in May 2024. The inclination has also increased from the initial 40° to about 70° now.
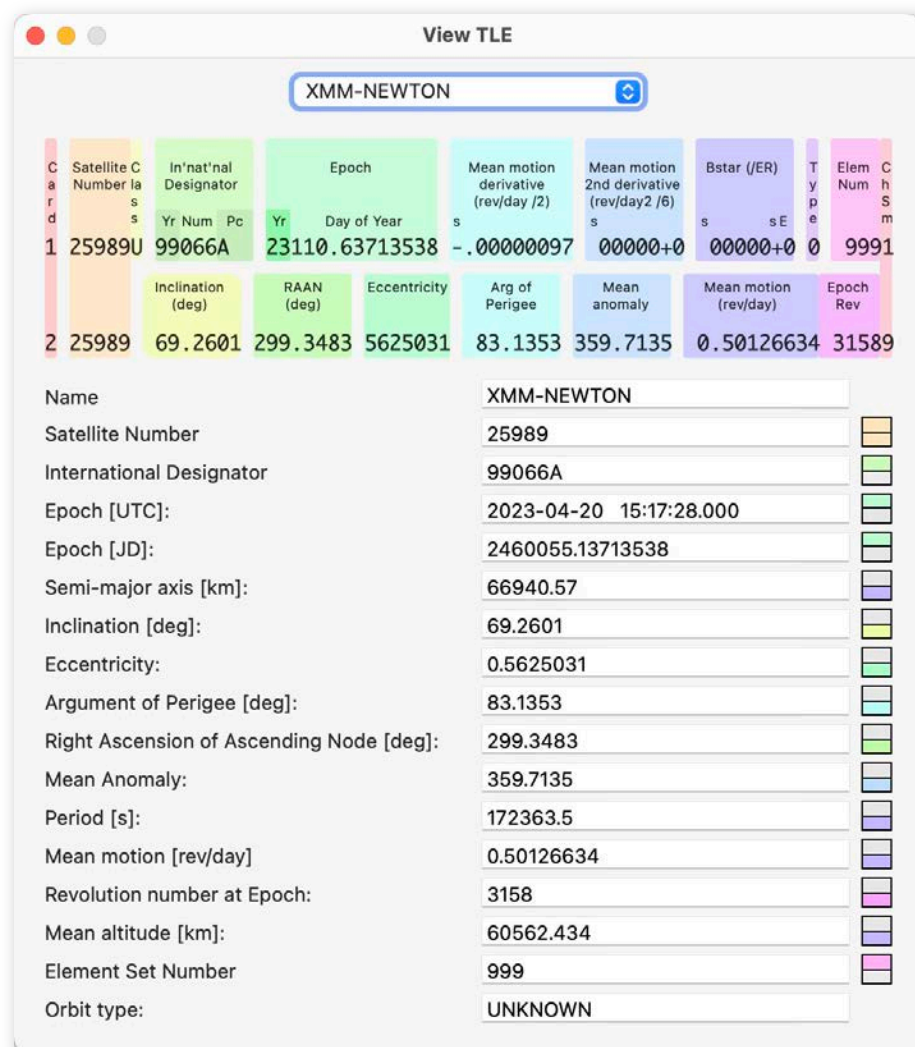
Figure 70. *The TLE for XMM-Newton.*

The orbital period is very close to 0.5 revs per day, so it takes almost exactly 2 days to go around, which is why its ground track always seems to be in roughly the same place on the Earth's surface.

Finally, we have Meteosat-9, Fig. 71, which is a geostationary weather satellite. Geostationary satellites have an orbital period of exactly one day, so they go around the Earth at the same rate that the Earth itself rotates, allowing them to keep pace with the Earth. And if the orbit is in the equatorial plane (that is to say, with an inclination of 0°) then it will stay above one (equatorial) spot on the Earth's surface.

Meteosat-9, (which was called MSG-2 during its development) has been in orbit since 2005 and, though still active, is nearing its end-of-life. The inclination of its orbit has been allowed to increase to over 6°, which we assume is the result of budgeting the remains fuel to prioritise the East-West station-keeping over maintaining its position on the equator.

Admittedly, TLEs are never going to be enormously exciting, but the display in **View TLE** allows them to become rather more interesting that just a couple of rows of numbers!
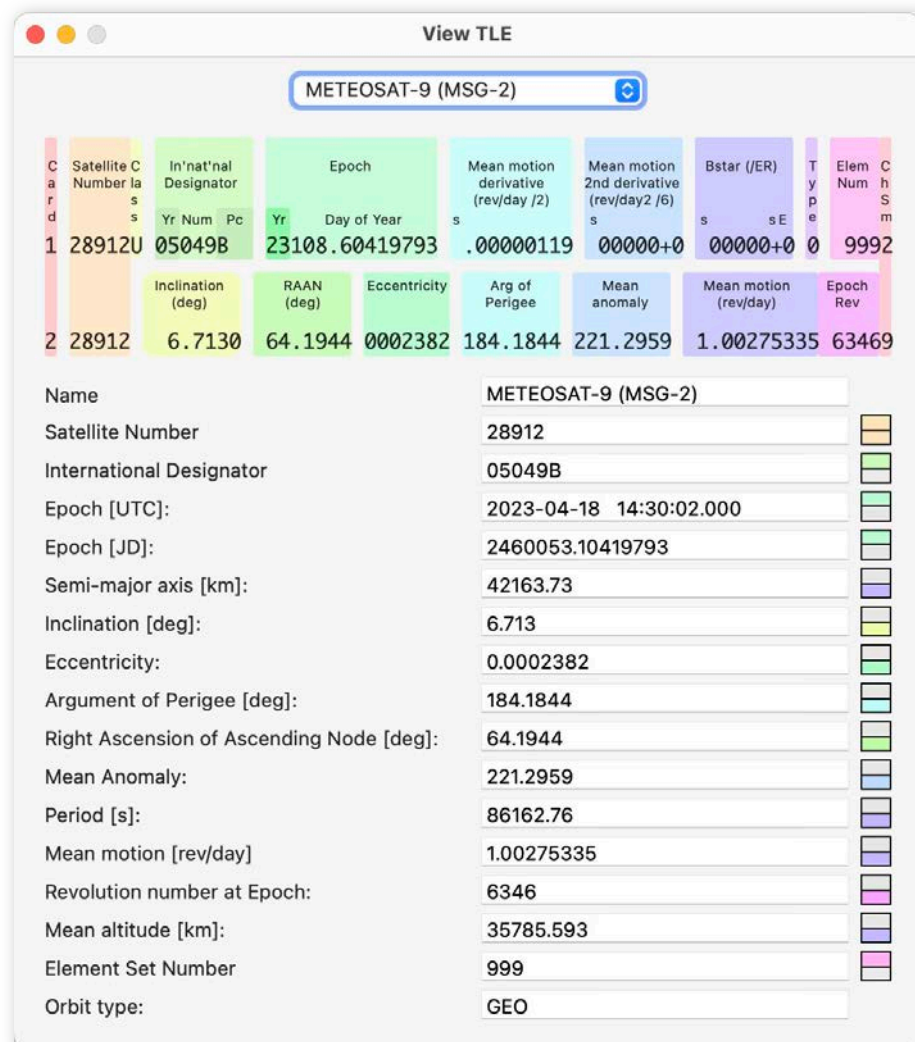
Figure 71. *The TLE for Meteosat-9.*

14.   Reference: Time Control

Time Control, called up from the application's main menu (see Fig. 33 in Chapter 6), is a very useful feature which can shift the time of the events displayed in *SatTracker*.

On opening the window, the display shows the current time. It is in **Real Time** mode, and updates in real time.

The date and time can be manipulated – when doing so the Time Mode automatically changes to **Stopped**, so it is not incremented automatically. The date can be changed directly in the calendar display, or it can be changed in the text boxes, either by entering text or by using the arrow controls to their right.

The time can also be changed with the lower row of boxes, which display hours, minutes and seconds. These also have arrows to the right which increment (or decrement) the value, and arrows to the left, which provide increments of 10.

After adjusting the time and date, pressing the **Simulated** radio button will then cause the main window to resume the flow of time at the normal rate, but at this simulated time instead of real-time.
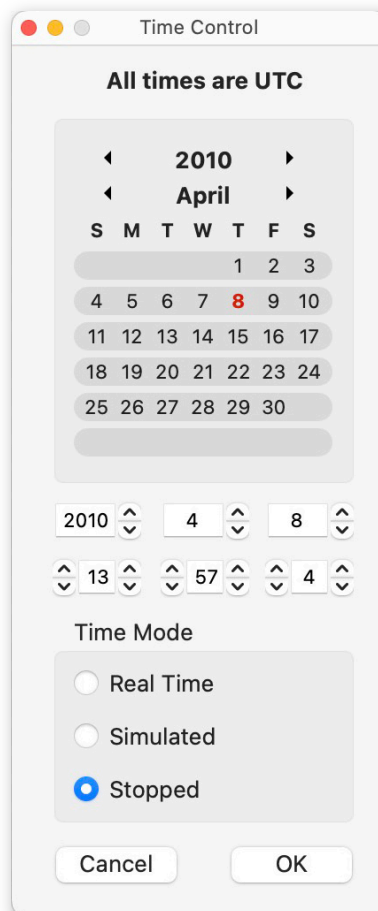
Figure 72. *The Time Control window. It is stopped and showing the exact date and time of CryoSat-2's launch (it was 4 seconds late!).*

Annex A.   List of ISO Country Codes

Country	Code
Afghanistan	AF
Albania	AL
Algeria	DZ
American Samoa	AS
Andorra	AD
Angola	AO
Anguilla	AI
Antarctica	AQ
Antigua and Barbuda	AG
Argentina	AR
Armenia	AM
Aruba	AW
Australia	AU
Austria	AT
Azerbaijan	AZ
Bahamas (the)	BS
Bahrain	BH
Bangladesh	BD
Barbados	BB
Belarus	BY
Belgium	BE
Belize	BZ
Benin	BJ
Bermuda	BM
Bhutan	BT
Bolivia (Plurinational State of)	BO
Bonaire, Sint Eustatius and Saba	BQ
Bosnia and Herzegovina	BA
Botswana	BW
Bouvet Island	BV
Brazil	BR
British Indian Ocean Territory (the)	IO
Brunei Darussalam	BN
Bulgaria	BG
Burkina Faso	BF
Burundi	BI

Cabo Verde	CV
Cambodia	KH
Cameroon	CM
Canada	CA
Cayman Islands (the)	KY
Central African Republic (the)	CF
Chad	TD
Chile	CL
China	CN
Christmas Island	CX
Cocos (Keeling) Islands (the)	CC
Colombia	CO
Comoros (the)	KM
Congo (the Democratic Republic of the)	CD
Congo (the)	CG
Cook Islands (the)	CK
Costa Rica	CR
Croatia	HR
Cuba	CU
Curaçao	CW
Cyprus	CY
Czechia	CZ
Côte d'Ivoire	CI
Denmark	DK
Djibouti	DJ
Dominica	DM
Dominican Republic (the)	DO
Ecuador	EC
Egypt	EG
El Salvador	SV
Equatorial Guinea	GQ
Eritrea	ER
Estonia	EE
Eswatini	SZ
Ethiopia	ET
Falkland Islands (the) [Malvinas]	FK
Faroe Islands (the)	FO
Fiji	FJ
Finland	FI
France	FR

French Guiana	GF
French Polynesia	PF
French Southern Territories (the)	TF
Gabon	GA
Gambia (the)	GM
Georgia	GE
Germany	DE
Ghana	GH
Gibraltar	GI
Greece	GR
Greenland	GL
Grenada	GD
Guadeloupe	GP
Guam	GU
Guatemala	GT
Guernsey	GG
Guinea	GN
Guinea-Bissau	GW
Guyana	GY
Haiti	HT
Heard Island and McDonald Islands	HM
Holy See (the)	VA
Honduras	HN
Hong Kong	HK
Hungary	HU
Iceland	IS
India	IN
Indonesia	ID
Iran (Islamic Republic of)	IR
Iraq	IQ
Ireland	IE
Isle of Man	IM
Israel	IL
Italy	IT
Jamaica	JM
Japan	JP
Jersey	JE
Jordan	JO
Kazakhstan	KZ
Kenya	KE

Kiribati	KI
Korea (the Democratic People's Republic of)	KP
Korea (the Republic of)	KR
Kuwait	KW
Kyrgyzstan	KG
Lao People's Democratic Republic (the)	LA
Latvia	LV
Lebanon	LB
Lesotho	LS
Liberia	LR
Libya	LY
Liechtenstein	LI
Lithuania	LT
Luxembourg	LU
Macao	MO
Madagascar	MG
Malawi	MW
Malaysia	MY
Maldives	MV
Mali	ML
Malta	MT
Marshall Islands (the)	MH
Martinique	MQ
Mauritania	MR
Mauritius	MU
Mayotte	YT
Mexico	MX
Micronesia (Federated States of)	FM
Moldova (the Republic of)	MD
Monaco	MC
Mongolia	MN
Montenegro	ME
Montserrat	MS
Morocco	MA
Mozambique	MZ
Myanmar	MM
Namibia	NA
Nauru	NR
Nepal	NP
Netherlands (the)	NL

New Caledonia	NC
New Zealand	NZ
Nicaragua	NI
Niger (the)	NE
Nigeria	NG
Niue	NU
Norfolk Island	NF
Northern Mariana Islands (the)	MP
Norway	NO
Oman	OM
Pakistan	PK
Palau	PW
Palestine, State of	PS
Panama	PA
Papua New Guinea	PG
Paraguay	PY
Peru	PE
Philippines (the)	PH
Pitcairn	PN
Poland	PL
Portugal	PT
Puerto Rico	PR
Qatar	QA
Republic of North Macedonia	MK
Romania	RO
Russian Federation (the)	RU
Rwanda	RW
Réunion	RE
Saint Barthélemy	BL
Saint Helena, Ascension and Tristan da Cunha	SH
Saint Kitts and Nevis	KN
Saint Lucia	LC
Saint Martin (French part)	MF
Saint Pierre and Miquelon	PM
Saint Vincent and the Grenadines	VC
Samoa	WS
San Marino	SM
Sao Tome and Principe	ST
Saudi Arabia	SA
Senegal	SN

Serbia	RS
Seychelles	SC
Sierra Leone	SL
Singapore	SG
Sint Maarten (Dutch part)	SX
Slovakia	SK
Slovenia	SI
Solomon Islands	SB
Somalia	SO
South Africa	ZA
South Georgia and the South Sandwich Islands	GS
South Sudan	SS
Spain	ES
Sri Lanka	LK
Sudan (the)	SD
Suriname	SR
Svalbard and Jan Mayen	SJ
Sweden	SE
Switzerland	CH
Syrian Arab Republic	SY
Taiwan (Province of China)	TW
Tajikistan	TJ
Tanzania, United Republic of	TZ
Thailand	TH
Timor-Leste	TL
Togo	TG
Tokelau	TK
Tonga	TO
Trinidad and Tobago	TT
Tunisia	TN
Turkey	TR
Turkmenistan	TM
Turks and Caicos Islands (the)	TC
Tuvalu	TV
Uganda	UG
Ukraine	UA
United Arab Emirates (the)	AE
United Kingdom of Great Britain and Northern Ireland (the)	GB
United States Minor Outlying Islands (the)	UM
United States of America (the)	US

Uruguay	UY
Uzbekistan	UZ
Vanuatu	VU
Venezuela (Bolivarian Republic of)	VE
Viet Nam	VN
Virgin Islands (British)	VG
Virgin Islands (U.S.)	VI
Wallis and Futuna	WF
Western Sahara	EH
Yemen	YE
Zambia	ZM
Zimbabwe	ZW
Åland Islands	AX

Annex B. Import file format

Horizon data

The format for importing ground station horizon data is simple.

Each line shall be a pair of numbers, being azimuth and elevation respectively, separated by a comma (any white space will be stripped out). The file format is 'comma-separated values', CSV.

Parameter	Units	Comment
Azimuth	degrees from North	In the range 0–360
Elevation	degrees	In the range 0–90

The points will be sorted into ascending azimuth order after import.

Ground Stations

Ground station data in Comma-Separated Value (CSV) files have fields separated by a comma, with any leading or trailing white space being stripped out. The layout and order of fields is defined in the table below.

Parameter	Units	Comment
Station ID	text	Will be truncated to 8 characters
Name	text	Free text
Type	text	Next table defines understood types
Latitude	degrees	Signed decimal degrees in range -90 – +90 (North is positive)
Longitude	degrees	Decimal degrees in range -180 – +180 or 0 – 360 (East is positive)
Altitude	metres	Can be left blank
Azimuth slew rate	degrees / s	Can be left blank
Elevation slew rate	degrees / s	Can be left blank
Mount type	index number	0 = Az-EL; 1 = Polar; 2 = X-Y ; 3 = 3-Axis ; 4 = None ; 5 = HexaTrack ; 6 = Unknown
Physical horizon	degrees	Only fixed horizons are supported
Receive horizon	degrees	Can be left blank
Transmit horizon	degrees	Can be left blank
Antenna diameter	metres	Can be left blank
Antenna manufacturer	text	Can be left blank
Antenna model	text	Can be left blank
Antenna type	text	Can be left blank
Radome	Yes | No	If left blank, 'No' is assumed
Tracking accuracy	millidegrees	Can be left blank

Time zone	text	If blank, or if invalid, an arbitrary time zone at the given longitude is assumed. This will be in the form 'Etc/GMT±n'. The sign is inverted because these Etc/GMT zones comply with the POSIX standard.
Comment	text	Free text
The following entries are repeated, in order, for each of the 6 bands (VHF – Ka-Band). All can be left blank if not applicable		
RX capability	Yes | No	If left blank, 'No' is assumed
Frequency span for RX	Text (in MHz)	Free text, eg 7800-8500
G/T	dB/Kelvin	
RX polarisation	text	Allowed values: Linear, Circular, Lin/Circ, LHCP, RHCP, L+RHCP, L/RHCP, Unknown. Anything else will be recorded as Unknown.
TX capability	Yes | No	If left blank, 'No' is assumed
Frequency span for TX	Text (in MHz)	Free text, eg 2025-2120
EIRP	dBW	
TX polarisation	text	Allowed values: Linear, Circular, Lin/Circ, LHCP, RHCP, L+RHCP, L/RHCP, Unknown. Anything else will be recorded as Unknown.

Something to note: in writing text into the Comments field, in particular, it is easy to generate non-ASCII characters (by the default of the operating system), such as sloping quotation marks, and apostrophes. The storage of these in the SQLite database engine which we use is such that they end up with strange double character replacements on import.

Another note: for polarisation we are tolerant of reversed L and R!. So a field imported as 'R/LHCP' instead of 'L/RHCP', for example, will be accepted and recorded as 'L/RHCP'.

We did consider whether to suppress unused frequency band information, which would save disk space. But finally, we decided it is more convenient, for compilation and checking of large sets of stations, to have a uniform field structure.

The network and type of station are decoded from the text in the imported file according to the following table (text is given here in upper case, but lower or mixed case is also accepted):

Text	Network	Type
VHF	VHF	Ground Station
UHF	UHF	Ground Station
L-BAND, L, LBAND, L_BAND	L-Band	Ground Station
S-BAND, S, SBAND, S_BAND	S-Band	Ground Station
X-BAND, X, XBAND, X_BAND	X-Band	Ground Station
KA-BAND, KA, KABAND, KA_BAND	Ka-Band	Ground Station
OPTICAL, OGS	Optical	Ground Station

DSN, DEEP SPACE, DEEP SPACE NETWORK	DSN	Ground Station
ESTRACK, ESA	ESTRACK	Ground Station
NASA, NEN, NEAR EARTH NETWORK, NSN, NEAR SPACE NETWORK	NASA	Ground Station
PRIORANET, SSC, SSC-CONNECT, SSC CONNECT, USN	SSC	Ground Station
KSAT, KSATLITE, KSATMAX	KSAT	Ground Station
ATLAS	ATLAS	Ground Station
AWS, AMAZON, AMAZON WEB SERVICES	AWS	Ground Station
VIASAT RTE, VIASAT, RTE, REAL TIME EARTH	Viasat RTE	Ground Station
LEAF, LEAFLINE, LEAFKEY	Leaf	Ground Station
INFOSTELLAR	Infostellar	Ground Station
CONTEC	CONTEC	Ground Station
SMALLSAT, SMALLSATS, CUBESAT	SmallSat	Ground Station
AMATEUR, RADIO AMATEUR, RADIO, RADIO HAM	Amateur	Special
ASTRO, OBSERVATORY, ASTRONOMY, TELESCOPE	Astro	Special
USER	User	Other
LASER, SLR	–	Laser
DORIS	–	DORIS
Any other text	User	Other

Annex C. Export file format

The export file format is based on the input format, so exports may be re-imported. Note that the only CSV files are supported. The file layout is defined below:

Parameter	Units	Comment
Station ID	text	8 characters
Name	text	Station name in free text
Type	text	See below
Latitude	degrees	Signed decimal degrees
Longitude	degrees	Decimal degrees
Altitude	metres	Will be 0.0 if undefined in database
Azimuth slew rate	degrees / s	Will be 0.0 if undefined in database
Elevation slew rate	degrees / s	Will be 0.0 if undefined in database
Mount type	index number	0 = Az-EL; 1 = Polar; 2 = X-Y ; 3 = 3-Axis ; 4 = None ; 5 = HexaTrack ; 6 = Unknown
Physical horizon	degrees	Only fixed horizons are supported. Variable horizons will be assigned an average value. The separate Horizons export function can be used to populate the horizon record later.
Receive horizon	degrees	Will be 0.0 if undefined in database
Transmit horizon	degrees	Will be 0.0 if undefined in database
Antenna diameter	metres	Will be 0.0 if undefined in database
Antenna manufacturer	text	Will be blank if undefined in database
Antenna model	text	Will be blank if undefined in database
Antenna type	text	Will be blank if undefined in database
Radome	Yes | No	Will be 'No' if undefined in database
Tracking accuracy	millidegrees	Will be 0.0 if undefined in database
Time zone	text	A valid time zone definition according to the TZ database
Comment	text	Free-form text
The following entries are repeated, in order, for each of the 6 bands (VHF – Ka-Band). All may be blank if not applicable		
RX capability	Yes | No	Will be 'No' if undefined in database
Frequency span for RX	Text (in MHz)	Free text
G/T	dB/Kelvin	
RX polarisation	text	Allowed values: Linear, Circular, Lin/Circ, LHCP, RHCP, L+RHCP, L/RHCP, Unknown.
TX capability	Yes | No	Will be 'No' if undefined in database
Frequency span for TX	Text (in MHz)	Free text
EIRP	dBW	
TX polarisation	text	Allowed values: Linear, Circular, Lin/Circ, LHCP, RHCP, L+RHCP, L/RHCP, Unknown.

An important deviation from the import format concerns the type or network of the station. This is caused by *SatTracker*'s ability to assign a given station to multiple networks (e.g. S-band and X-band plus a commercial provider), while the import format (and therefore the export format) only allows one type or network.

Of the three possibilities for defining the set of stations for export (All, Selected stations or All of a Type or Network), only the last gives information about the user's intent with respect to networks.

Therefore, the first two choices (All, Selected stations) will result in the third field (Type) exporting the type as *Ground Station*, *Laser*, *DORIS*, *Special* or *Other,* as appropriate, ignoring any Network selections.

The third option (All of a Type or Network) will record either the Type as described above, or the Network, depending on the selection in the popup menu in the Export window.

Annex D. Polarisation

In the general description of an electromagnetic wave the electric field and magnetic field oscillate orthogonally to each other, and both are orthogonal to the propagation direction. Conventionally the polarisation state is always referenced to the electric field vector.

If we imagine a plane surface orthogonal to the direction of propagation the maximum, or "tip", of the electric field vector in this plane will describe a figure as a function of time. For a plane, **linearly polarised** wave it will oscillate along a straight line, but in the general case it will describe an ellipse. The linearly polarised wave is a special case, as is the **circular polarised** case in which case the ellipse becomes a circle. The parameters used to describe the ellipse are *axial ratio* or *ellipticity* (the ratio of the major to the minor axes) and the *orientation angle* or *tilt angle*, as shown below.
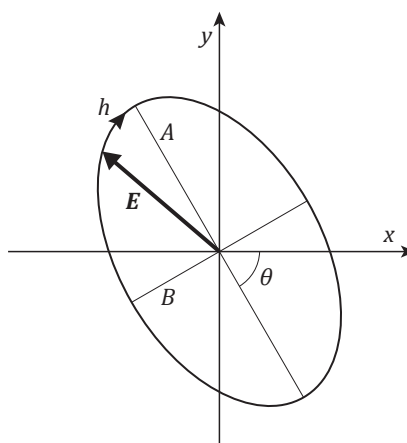
*The electric field vector **E** moves around a polarisation ellipse in the direction **h**. The axial ratio is the ratio between the major axis A and the minor axis, B. The orientation angle θ is the angle between the major axis and an arbitrary reference frame (here labelled as x-y).*

The orientation angle is defined relative to a reference frame and the definition of this frame is arbitrary; we can choose it to be defined by reference to the local vertical at the Earth's surface, so that we can use the terms *vertical* and *horizontal* polarisation when convenient. A final necessary parameter is the direction of the electric field in describing the ellipse (clockwise or anticlockwise). This is properly called *chirality*, but is also referred to as *handedness*, as in **right- or left-hand polarised**.

Many satellite antennas, especially for housekeeping and commanding, are designed to be circularly polarized so that the reception by a terrestrial antenna is not degraded if the satellite is not in the correct orientation.

Similarly, most satellites have a back-up antenna which ensures that even if the main antenna is not facing the Earth, there is nevertheless the possibility of contact. There is a philosophical choice if this should have the same polarisation as the main antenna (e.g. Right-Hand Circular) or the opposite (e.g. Left-Hand Circular). If the same, the communication continues without interruption; if opposite, then communication can continue if the ground station operates in both polarisations simultaneously, and furthermore the polarisation gives some information about the satellite orientation.

Annex E. Troubleshooting

Problem:	App does not start, and maybe just shows a small white rectangle.
Diagnosis:	Corrupted database files
Root cause:	1. Improper closure (quit) of app 2. Attempting to plot far too many satellites
Cure:	Delete the database files so that they will be reset to default values on next start-up
Procedure:	1. In Finder, option-click the 'Go' menu item and choose Library. 2. Select and open Containers>SatTracker (in older macOS versions it appears with its underlying real name, Containers>com.ClearAndDark.SatTrackerBasic.) 3. Select and open Data>Library>Application Support 4. Select and open com.ClearAndDark.SatTrackerBasic 5. Delete the file SatDatabase.sqlite (in rare cases it may be necessary to also delete StationDatabase.sqlite) 6. Launching SatTracker again will recreate these database files fresh, as in the original version of the app
Notes:	Deleting the satellites database file is painless because it is dynamically repopulated every time new satellite elements (TLSs) are downloaded. On the other hand, deleting the ground station database will result in the **loss of any user-entered ground stations** and will return the database to the default set the app ships with. In this same location you will find the log files, generated during every run of the application. These may be deleted if required.

Problem:	Some spacecraft, like NASA's Artemis mission to the Moon, have orbit tracks which look all wrong.
Diagnosis:	These satellites are not in Earth orbit but on a trajectory away from the Earth (or maybe coming back)
Root cause:	*SatTracker* is designed to process satellites in Earth orbit, not interplanetary trajectories
Cure:	None – avoid selecting interplanetary spacecraft for display

Annex F.   Upgrading from an earlier version

F.1   Upgrading from version 1.3

Version 1.3 was the previous version in the Mac App Store, released on 4 Feb 2023.

In this version 2.0 there are some minor updates to the structure of the Station Database, but these are applied silently in the background when *SatTracker* v. 2.0 first launches.

During the silent update process, some of the new content is copied into the new data fields from the internal default database. The key used to identify the corresponding stations is the unique identifying number mentioned at the start of Section 7.3.2. These are automatically allocated by *SatTracker* when creating a new station.

There are more stations in the database shipped with *SatTracker* v.2.0 than with other versions, so if you have added stations to your own database, these are likely to have been allocated the same number as one of the extra stations in the v.2.0 database. Therefore, the new content (for example the Time zone field) will be wrong and you will need to correct it.

The default database shipped with the app contains much more information compared to the version shipped with v.1.3.

Because of the extra stations and extended content, it is **highly recommended** to replace your version of the Station Database with the default version. See Section F.4 '*Replace Station Database*', below.

Before doing this, you should export any stations you have added and want to keep. See Section F.3 '*Export stations you have added*', below.

F.2   Upgrading from a version before version 1.3

If you are upgrading from a version of *SatTracker* before v. 1.3 there will be several incompatibilities between the Station Database you already have and the current version of the database.

These are sufficiently major that *SatTracker* cannot work with the older database.

SatTracker will detect this situation at launch and present a window, titled 'Update Station Database', to guide you through the upgrade process.

You *must* either update your existing database, using the Update button, or replace it with the built-in default database, with the Replace button.

As the '*Update Station Database*' window explains, there are two situations which may apply: either you have made no additions to the original database which shipped with the older version of *SatTracker*, or you have made additions which you want to keep.

If you have not made any changes that you want to keep, or if you can easily recreate any stations you have added, then the easiest approach, by far, is to use the Replace button. This will delete your old database and cause *SatTracker* to quit. When you launch it again, the default database will be installed.

If, though, you have added stations which you want to retain, the approach is different. First use the **Update** button. This will bring structure of the Stations Database into a compatible form, and some network allocations will change too. This is explained in the '*Update Station Database*' window (and there is another informational window to reinforce this message before anything happens).

Please take note of the box above, with information about the upgrade process. It also applies to this case!

Now the plan is to export your added stations, and any horizon profiles (unless you still have any files used to create them). See Section F.3 '*Export stations you have added*', below. Then replace the Station Database with the default (Section F.4 '*Replace Station Database*'), and then re-import your stations.

Although it should not be possible, make sure you don't **Update** more than once! If you do, nothing will be lost, but your stations will become shuffled among the networks, and it will probably take some work to restore the previous status.

F.3   Export stations you have added

Exporting stations is covered in Section 7.3.9. You should use a choice of export type to isolate your stations: if you export stations which are in the default database and then re-import them, you will lose any extra information in the new, version 2.0, database.

One way to ensure this is make sure all your stations are in a type like 'Special' and then only export that type.

The export of horizon profiles is covered in Section 7.3.3.

F.4   Replace Station Database

Replacing the Station Database with the default, shipped one can be done at any time.

The *SatTracker* main menu has an item in the Edit sub-menu: **Edit > Replace Station DB.**

This will launch a dialog explaining what will happen; in brief, the existing database will be deleted and *SatTracker* will then quit. On its next launch, the default database will be installed.