SALSA user manual: Telescope control and data analysis

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Abstract

SALSA-Onsala ("Such A Lovely Small Antenna") is a 2.3 m diameter radio telescope built at Onsala Space Observatory, Sweden, to introduce pupils, students and teachers to the marvels of radio astronomy. The sensitive receiver makes it possible to detect radio emission from atomic hydrogen far away in our galaxy, the Milky Way. From these measurements we can learn about the structure and kinematics of the Milky Way.

In this document we describe in detail how to operate the telescope and how to extract information from the data files you obtain with SALSA. We also include a summary of the technical capabilites and limitations of a SALSA telescope.

Please note that this document does not include any scientific interpretation. A guide to interpreting your measurements can be found in the documents describing the possible projects on the SALSA website, for example the project *Mapping the Milky Way*.

Coverimage: Image of the SALSA telescopes in Onsala.

Chapter 1

The SALSA website

The SALSA telescopes have their own website at **http://vale.oso.chalmers.se/salsa**, a part of the page can be sen in Fig. 1.1. Here you can find a lot of useful information and software to assist you when using the telescope and analysing data.

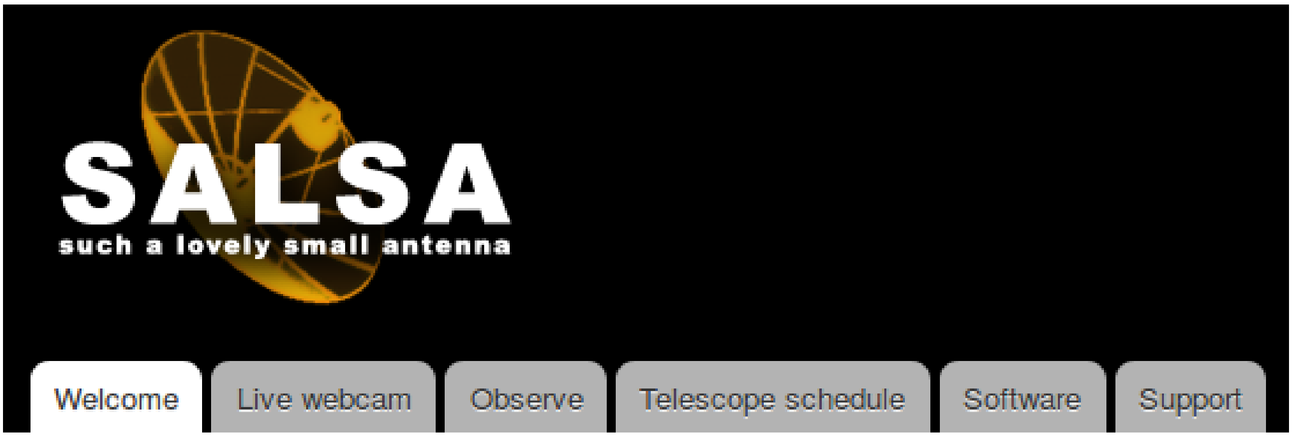

Figure 1.1: A part of the SALSA website. Here you find a lot of useful information as well as the booking system used to reserve observing time with SALSA.

1.1 Create an account

To be able to control the telescopes you need to register on the SALSA website. If you have not already, please find the link *Create new account* and fill in your details. You should now get an email confirmation with login information, if not - please check your spam filter.

1.2 Book observing time

To be able to observe you first have to book observing time. This is required to ensure that only one user may control a SALSA telescope at any given time. Bookings are made via the SALSA website. Once you are logged in with your account, go to the page *Observe*. On this page you find a link to *Book a time*. Click here to make a new reservation. A new page appears where you need to enter a *brief description* of your observation, see Fig. 1.2.

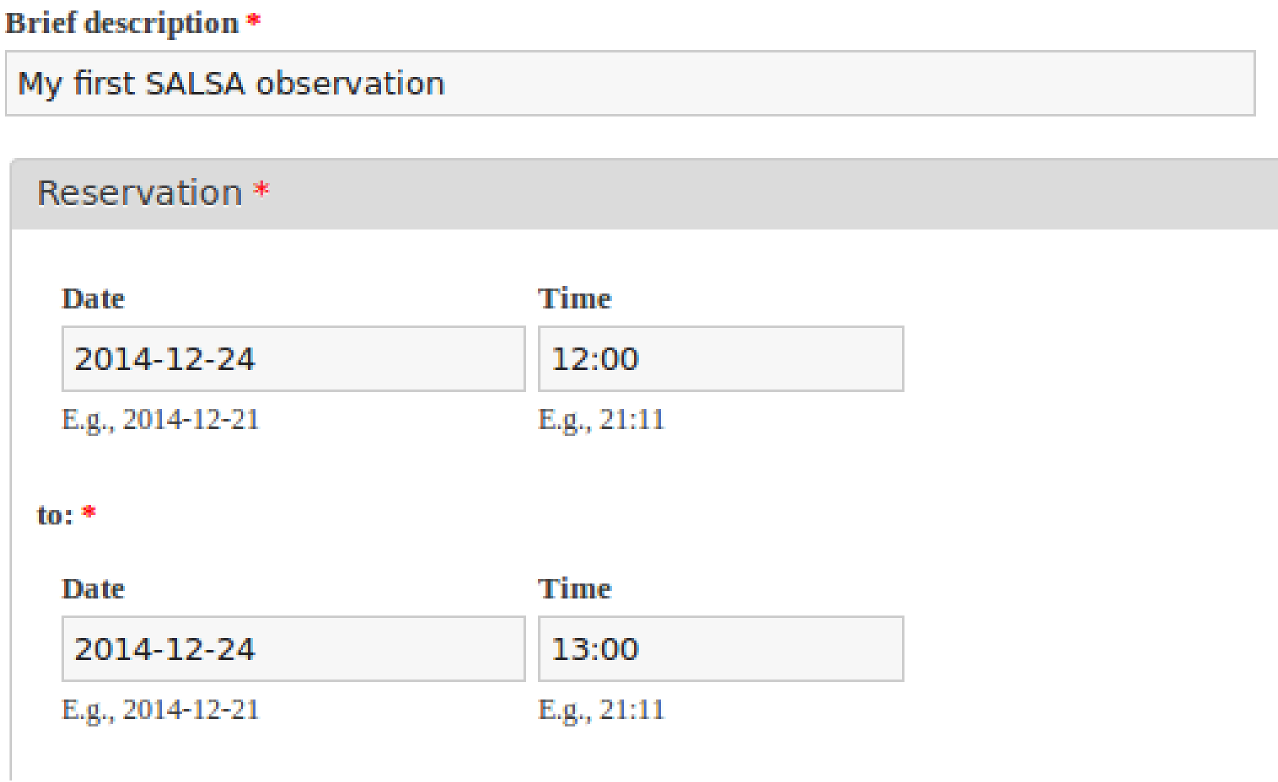

Figure 1.2: The page used to create a new reservation, i.e. book observing time with SALSA.

Then, select start and end times of your observation. (You may want to check the page *Telescope schedule* to find a suitable time.) Note that you may click in the date-fields to get a pop-up calendar where you can select a day. The time fields specify hours and minutes on the selected day. Note that you can switch from editing hours to minutes by clicking with the mouse or using the right and left arrow-keys on your keyboard. Note that times are displayed in the timezone you selected when registering. (If you want to check or change your timezone, click on *My account*.)

Finally you need to chose a telescope. We try to always have at least one telescope available, but sometimes there are two or three telescopes available. They are booked independently, so if one telescope is booked at a certain time you can select another. Select at least one telescope and then press *Save* to save your reservation. You should now see your reservation on the page *My reservations*, as well as on the page *Telescope schedule*.

You will now be able to control the telescope you booked during your reserved time. Note that you cannot access the telescopes if you have not booked. Note also that should your reservation end while you are observing, your observations will be terminated. Please make sure to save your data while observing, see below, and do not leave it to the end. If you realise while observing that you will require more time, you can try to extend your reservation. This can be done on the page *My reservations*: just use the link *edit* to change a specific reservation.

1.3 Live webcam

It is much more fun to move telescopes if you can see them move! Therefore we have put a camera in a nearby building which you can access through the page *Live webcam* on the SALSA website.

1.4 Online data archive

When you have made a measurement with SALSA you can upload it to an online archive. To access your archived data, log in to the SALSA website and click the link *Data archive*. This page displays your personal archive, showing all your saved observations. Each measurement can be downloaded as three different formats: as PNG (an image, convenient for a quick look at your measurement), as TXT (a plain text file with the raw numbers), and as FITS (a common data format in astronomy to inspect the data in great detail). Instructions on how to read the data in these formats are given in Sect. 2.5.

Date and time of observation	Observer	Galactic longitude [d : ' : "]	Galactic latitude [d : ' : "]	Bandwidth [MHz]	Center frequency [MHz]	Target integration time [s]	Telescope	Download FITS	Download PNG	Download TXT
2014-12-21 18:19	eskil	190:04:00.1	-0:15:10.9	2	1420.400	30	vale	FITS	PNG	TXT
2014-12-21 18:18	eskil	185:07:30.2	-0:14:49.2	2	1420.400	30	vale	FITS	PNG	TXT
2014-12-21 18:17	eskil	179:54:58.6	-0:03:37.6	2	1420.400	30	vale	FITS	PNG	TXT

Chapter 2

Observing with SALSA

It is important to be well prepared before you start observing with SALSA. Time is not only limited, because of the Earth's rotation some objects on the sky can only be seen during a specific part of the day. Please try to get a clear understanding of what you want to do before using the telescope. In this chapter we describe what can be observed, how to control the telescope, and how to extract your measurements. We strongly recommend you to read this document before starting your first observations.

2.1 What can be observed with SALSA?

Although the SALSA system was primarily designed for observing galactic hydrogen there are a few other ways to use the telescope. In the following subsections we describe the ideas we have tested so far. More projects will be added as we find the time.

2.1.1 The Milky Way

Most users of SALSA aim to detect emission from hydrogen gas in our galaxy the Milky Way. The aim here is to detect emission from hydrogen gas emitting at frequencies close to 1420.4 MHz. This is what the SALSA website and control program was designed for and most of the available documentation is related to this particular project. For an extended description of this project, see the document *Mapping the Milky Way* available via the SALSA website.

2.1.2 The Sun

The Sun is a bright radio source and can be detected easily with SALSA. Observations of the Sun can be used to determine the reception pattern of the SALSA antenna. More information about this project can be found in the document *Measure the beam of SALSA*, available via the SALSA website.

2.2 When can SALSA see my desired target?

Not all celestial objects are visible from Onsala, and some are only above the horizon for a short time each day. Before your observations it is good to prepare to make sure that your target is indeed visible. More information about how to do this can be found in Appendix A. Note that this appendix also includes a list of galactic coordinates which are always visible from Onsala, these may be a good start if mapping the Milky Way.

Another way to find out what you can see with SALSA at a specific time is to install the free software *Stellarium*, available at http://stellarium.org/. Tell the program that you are in Onsala (or in Kungsbacka, which the program knows about and is close enough to Onsala), and select a date and time. The program will then predict how the sky will look. Note that you can display coordinate grids within Stellarium, and both Galactic and Equatorial coordinates are supported.

2.3 Connecting to SALSA

The SALSA telescopes are controlled from a computer in Onsala. If you are at the observatory, then you can login to the computer directly. However, most observations are done remotely via internet. To control SALSA you thus need to login remotely to a computer in Onsala. This remote control has been tested on Windows, Mac OS X and Linux so you should be able to connect using any computer. There are two common ways to connect to the computer in Onsala:

- *In your browser.* This is the most common way to control a SALSA telescope. No software is needed except for a recent webbrowser. You find the links to the browser login pages for the telescopes at the page *Observe* at the SALSA webpage.

  Note: Your browser will complain that the connection is *untrusted*, because we have no certificate for the SALSA computers. Please ignore this warning to login to the telescope. To do so in Firefox, select *I Understand The Risk, Add Exception, Confirm Exception.* In Safari: click *continue.* In Explorer: click *continue.* Once connected you may start the control program by clicking on the SALSA-shortcut on the virtual desktop, or starting a terminal and typing SALSA.

- *In the terminal.* If you are used to working in the terminal you may login through SSH with graphics support using the command *ssh -X username@computer*, where computer is either vale.oso.chalmers.se or brage.oso.chalmers.se depending on what you booked. You may then start the control program from the terminal with the command `SALSA`.

2.3.1 Ending your session

When you are done observing, please close the control program using the x in the upper right corner. Then close your connection to the SALSA computer. If you are connected using the browser, you close your connection by closing the virtual desktop, e.g. by clicking the button in the upper corner. If you are connected via SSH in a terminal, you close your connection by typing `exit`.

2.3.2 Troubleshooting

Do you have trouble connecting to the telescope? Before contacting support, please check the three most common issues:

- The password for the control computer may be different from the password you chose for the webpage (to make bookings). To log in to a control computer you need to use your *telescope password* which you can find under *my account* on the SALSA website.
- Make sure you connect to the right computer. The host adress is different for different telecopes, but it has always the same format. For example, if you have booked the telescope *vale* then the computer is *vale.oso.chalmers.se*. If you have booked the telescope *brage* then the computer is *brage.oso.chalmers.se*.
- Make sure you have made a reservation at the correct time. The booking system shows all times in your selected timezone. You may check the time right now in your selected timezone by looking at the clock on the SALSA website.

2.4 The telescope control program

When you are logged in on a telescope computer you can start the control program, by either clicking the icon *SALSA* on your desktop, or by running *SALSA* in a terminal. You should [1] now see the main control program looking very similar to Fig. 2.1. The control program is used to move the telescope and to record measurements. We will start by describing how to move the telescope, and then we describe how to record data.

2.4.1 Movement control: To point the telescope

The startup display of the SALSA control program contains a box labelled *Telescope movement control*. This box contains four rows of white fields. We now describe the purpose of these fields in detail.

The first two rows are for user input, i.e. you may enter values here. The first row is labelled *Desired*. This row must be specified by you, this is where you specify where you want the telescope to point. Different coordinate systems are valid, but Galactic coordinates are most common since they are used when observing galactic hydrogen. A few special objects can also be selected directly, for example the Sun.

The second row is labelled *Desired horizontal offset*. This row is only used in special cases, for example when doing beam measurments, and should be left at 0 for most observations, e.g. for galactic hydrogen.

The rows three and four are for display only, i.e. you do not enter any values here. The third row is labelled *Calc. target horizontal*. This row displays the target local (altitude-azimuth) coordinates as calculated by the control program given the desired coordinates you have entered (including a possible offset from the second row). Note that the coordinates are changing as

[1] Sometimes the window takes more than 10 seconds to appear, be patient. If you do not see any window, try again and wait up to 30 seconds. If you still see nothing, please contact support as described on the SALSA website.

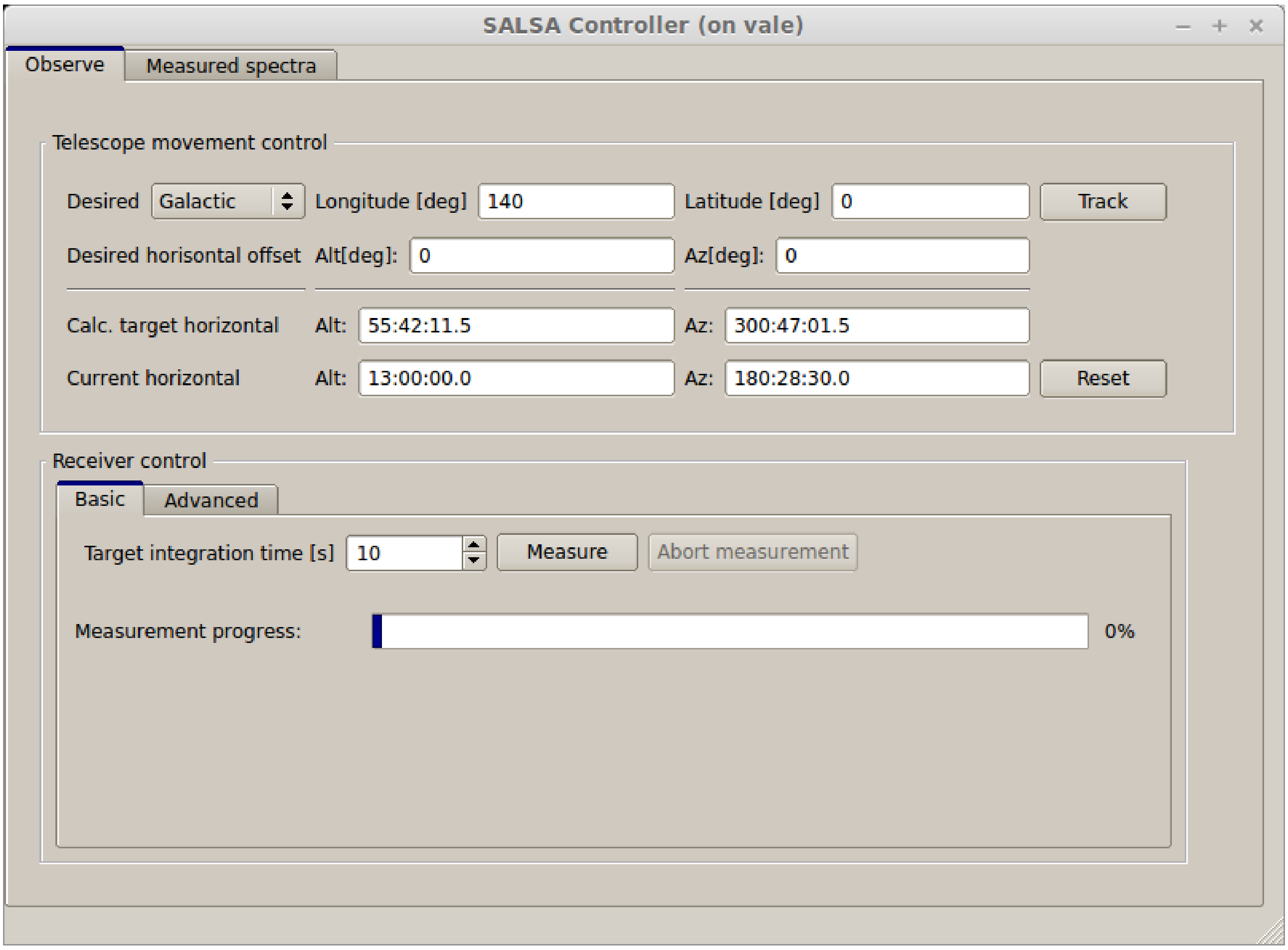

Figure 2.1: Startup display of the SALSA control program.

the current pointing is re-calculated every second. These calculations are done automatically by the program.

The fourth and last coordinate row shows the current local coordinates, i.e. where the antenna is pointing at this very moment. Once you tell the antenna to move, see below, it will start moving until the current coordinates (row four) is the same as (or very close to) the position calculated in row three.

Tracking

Tracking means to track or *follow* a specific object or coordinate on the sky. This means that the telescope needs to move to correct for the movement of the Earth (the rotation is about 0.25° per minute). Once you have specified the target coordinates correctly, click on the button `Track`. The telescope will now start moving, see Fig. 2.2, and will keep calculating and moving to follow your target on the sky until you tell it to stop by pressing the button `Stop`. Don't forget to look at the webcam at the SALSA website to check that the telescope is indeed moving. Once you reach the target you will probably not notice the minor tracking movement by eye, but if you look carefully you will see the *Current* coordinates will changing slightly over time to follow the change in the calculated position. Note that it may take up to a few minutes to reach your desired position if you started pointing far away on the sky. Measuring while moving will produce nonsense data.

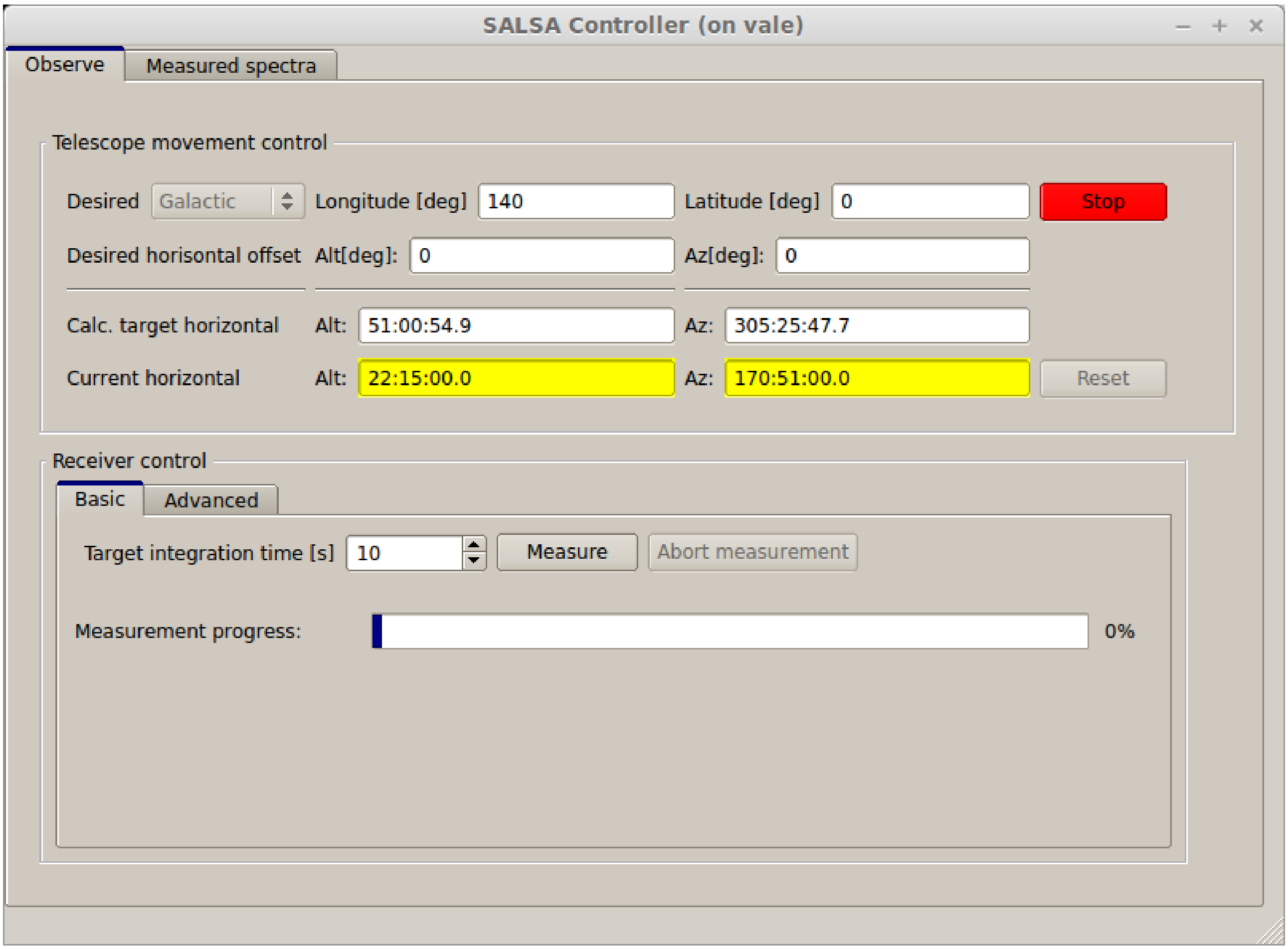

Figure 2.2: The telescope control program display when the telescope is moving.

What is the tracking accuracy?

The telescope is limited to a tracking accuracy of 0.5° because of its mechanical design. This is however much smaller than the angular size of the antenna *beam*, which has been measured to about 5.4° at 1420 MHz. Please wait until the telescope is within 1° of your desired position before you measure anything. The control program will assist you by changing the background color of the *Current* coordinates from yellow (meaning still not close enough to measure, see e.g. Fig. 2.2) to white (meaning close enough to measure). Further information on positional accuracy can be found in chapter 3.

Keep above 15° altitude

The telescope will refuse to move if you give it unreachable position, and you will be informed what the allowed limits are (i.e. you cannot break it). However, although the telescope can move down to the horizon it is wise to only measure at high enough altidudes to avoid disturbing radio emission from the Earth itself. As a rule of thumb, make sure that the target altitude is larger than 15°.

2.4.2 Receiver control: To measure a spectrum

When the telescope has reached a desired target coordinate you are ready to measure a spectrum. It is important to keep tracking during the measurement, so do not stop the tracking until your measurement is finished. Before starting a measurment you need to decide for how long you want to measure. A longer time means a clearer signal. The measurement time is called *integration time* and you find it in the box marked *Receiver control* in the middle of the control program window. One usually obtains a good spectrum of galactic hydrogen after 20 seconds. After entering the integration time, click on `Measure`. You will now se ee a progress bar increasing from left to right at the bottom part of the program, see Fig. 2.3.

Note: The telescope will measure for twice the specified integration time. This is because in addition to measure on the target (the signal you want), the telescope also needs to measure itself (how the receiver disturbs the signal from space). This means that if you select a *Target integration time* of 20 seconds, it will take approximately 40 seconds for the measurement to complete.

2.4.3 Measurement results

When a measurement is completed the resulting spectra is stored temporarily within the control program. To look at your measured spectra, click on the tab *Measured spectra* at the top of the program window. You will see a window looking like Fig. 2.4. On the left side is a list of all spectra taken in this session (since you started the program). On the right side is a graph over the currently marked spectrum. This plot is useful for a quick inspection of the data. You can zoom using the buttons below the figure, and if you hover with the mouse pointer in the figure the values for that particular point in the graph will appear below the plot. While this is the easiest way to extract information from your measurement, it may not be the most convenient. Instead, you may want to spend your time with SALSA doing observations, and then do a careful analysis of your measurements at another time. If so, you need to save your data. In the bottom left corner there is a button to save the selected spectrum to the online data archive. After saving a measurement it will be available to you at any time via the SALSA website, see Sect. 1.4. The data should appear in the archive within seconds of pressing the upload-button, so please check that you data has indeed been uploaded before leaving the control program. Please note that if you do not upload your measurement it will be deleted once you exit the control program.

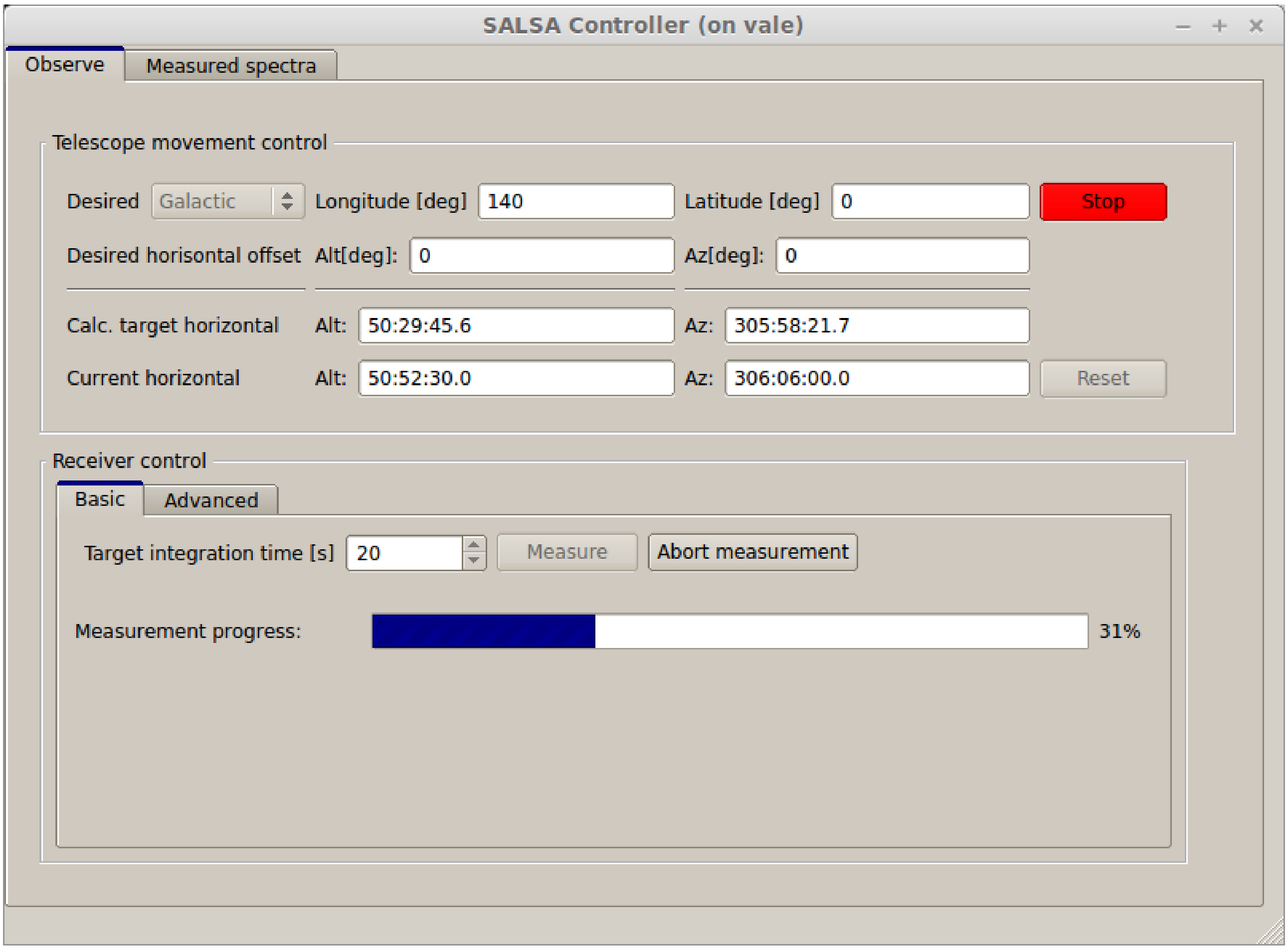

Figure 2.3: The telescope control program display when the telescope is measuring.

2.5 How to process archived data

As mentioned in the previous section you may inspect your data directly within the control program itself. This is the simplest option, but in some cases you may want to do a more careful analysis offline, or you want to focus your observing time on getting data and do the processing later. In this section we briefly describe the most common ways to analyse the SALSA data you can download from the archive at the SALSA webpage.

2.5.1 PNG: Images

The PNG format is an image of the spectrum just as it looked in the control program when you pressed the upload button. This is useful for a quick look, but is less accurate than inspecting the data in the control program since you cannot get the exact values from the graph in a simple way. An accurate analysis of your data will however probably require access to the actual numbers, which is provided as TXT and FITS, see below.

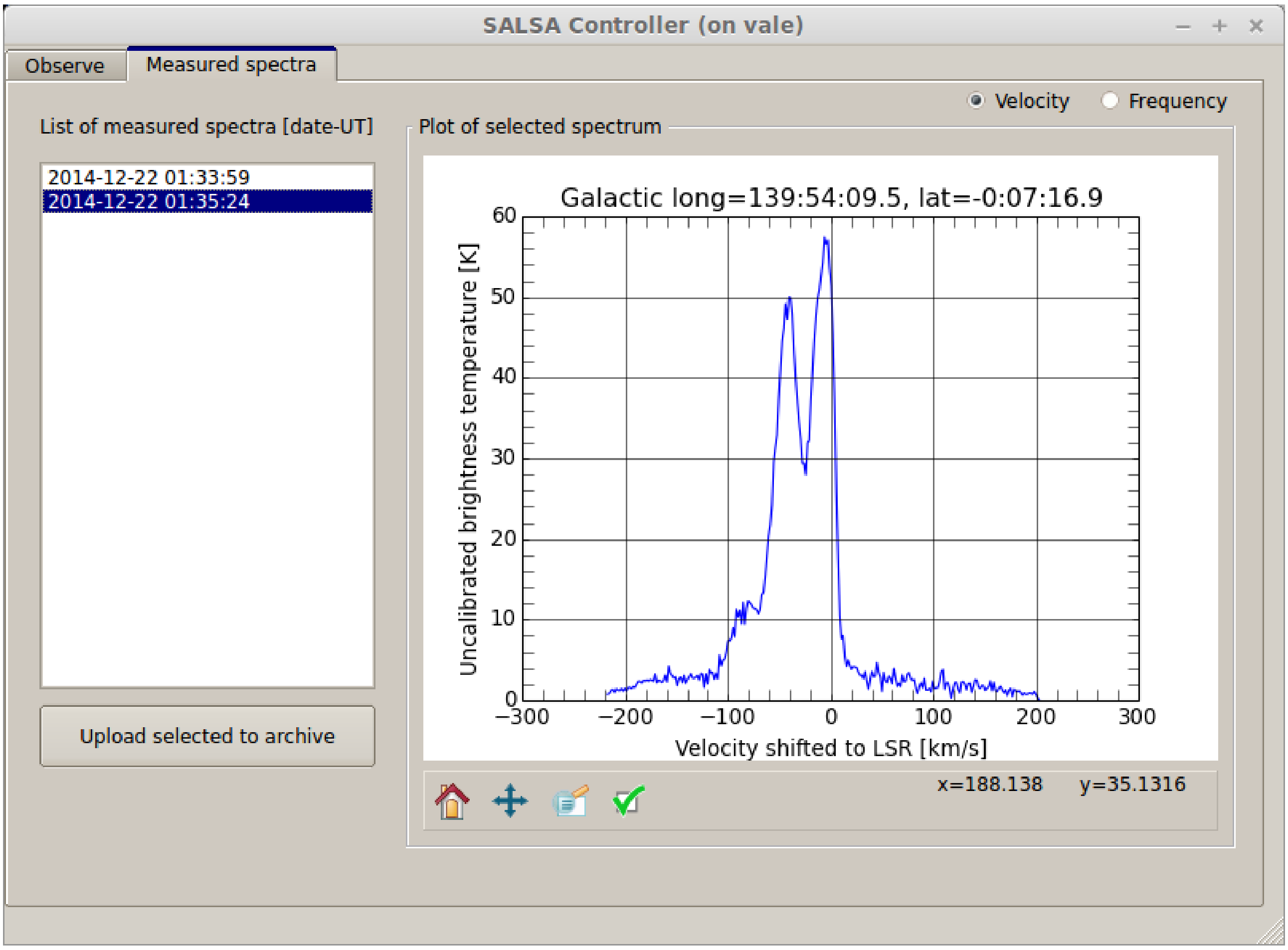

Figure 2.4: The tab *Measured spectra* in the control program. To the left is a list of all measurements done in this session. The right plot shows the currently selected spectrum. You may select a different spectrum by clickin in the list. In the bottom left corner there is a button to save the selected spectrum to the website data archive.

2.5.2 FITS: A common format for astronomical data

A FITS file[2] is a common format in astronomy. This format provides the most functionality and meta-information. There are currently two main ways to analyse FITS files from SALSA:

- **SalsaJ** was developed within the EU-HOU project. SalsaJ can be used to analyse spectral data from the SALSA telscopes, but can also be used as a simple image editor and processor. The main advantage of SalsaJ is its easy-to-use point-and-click interface. The main disadvantage is that reducing many spectra can be tedious. SalsaJ is available from the SALSA webpage `http://vale.oso.chalmers.se/salsa/software`, together with step-by-step instructions for opening FITS files from the webarchive.

[2]Flexible Image Transport System (FITS) format. A FITS file contains two parts: a header followed by a binary record of the data. The binary table can be interpreted and displayed with FITS-reading software, for example SalsaJ - see the SALSA website.

- **SalsaSpectrum** is a data reduction environment written in the popular mathematical software MATLAB - aimed for reduction of data from SALSA Onsala, developed by Daniel Dahlin. The main advantage is that many spectra can be processed quickly. The main disadvantage is that it requires the user to have a working installation of Matlab, which is non-free software. Please note that the observatory cannot provide Matlab licenses, but many university students have free access to Matlab. SalsaSpectrum is available from the SALSA webpage `http://vale.oso.chalmers.se/salsa/software`, together with step-by-step instructions for opening FITS files from the webarchive.

2.5.3 TXT: Textfiles

The TXT format contains the spectrum in plain text, i.e. as list of velocity/intensity pairs. This is a simple format, and it is possible to use the file together with the PNG images to get accurate measurements of the peak velocities. First get a rough estimate from the PNG-file, and then read the exact values in the TXT file. If you know programming you may also write your own code to show the TXT-files in your favourite language.

2.5.4 Python

If you are familiar with the programming language Python you can read the FITS files using the library *astropy.io.fits*. Please make sure to read the VLSR-correction and reference pixels correctly. You can compare with the results in the TXT and PNG-files. You may also skip the FITS files and read the TXT-files directly with python. If you want to process many FITS files with Python, you may find the scripts made by Michael Olberg, available at https://github.com/molberg/salsa, to be a good starting point.

2.5.5 R

If you are familiar with the programming language R you can read the FITS files using R. You may find the scripts made by Michael Olberg, available at https://github.com/molberg/salsa, to be a good starting point.

Chapter 3

Technical specifications

SALSA onsala is a modified television antenna with a diameter of 2.3 m and designed to operate at 1420 MHz.

3.1 Angular resolution and accuracy

SALSA has an angular resolution of about 6° (*full width half maximum*) at 1420 MHz. This value has been measured using the Sun, see Fig. 3.1. For comparision, remember that the full moon has an angular diameter of about half a degree, or 30 minutes of arc. The motors track in steps of 0.125° around each axis, hence this is the telescope accuracy in perfect conditions. However, if it is windy[1] the telescope may wobble in the wind (around the wanted position) and hence disturb the pointing of the telescope during small time intervals with 1-2°. This should however not be a big concern for users since the wobbles are smaller than the angular resolution.

3.2 Spectral resolution and accuracy

The telescope uses the *Universal Software Radio Peripheral* (USRP) to record data. The USRP acts as a sampler which records a time stream to the hard drive of the control computer. The channelisation, i.e. construction of the spectrum, is done in software (FFT). This means that the number of channels (spectral resolution) is not fixed, nor is the bandwidth. The spectral resolution is limited by the free space and processing speed of the control computer. Up to 10 MHz bandwidth with 8192 channels have been tested, but for most observations the standard settings of 2 MHz bandwidth and 256 channels are sufficient, i.e. a frequency resolution of 7.8 kHz per channel. If a finer resolution is needed, it may be selected from the *Advanced* tab in the *Receiver control* part of the SALSA control program, but we cannot offer support for these advanced modes yet.

[1] You can check the current wind speed at http://wx.oso.chalmers.se/weather/

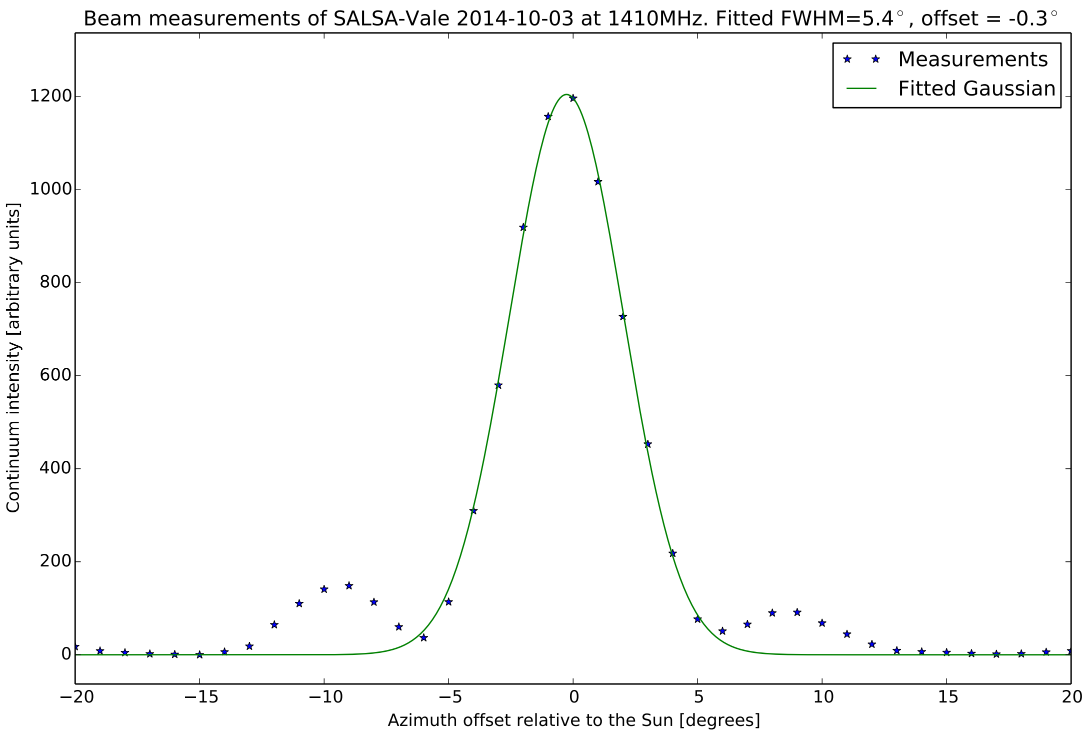

Figure 3.1: The beam of Vale measured using the Sun at 1410 MHz. A Gaussian fit gives the FWHM=5.4°. The sidelobes of the Sinc-function are clearly visible, as expected for a circular aperture.

Appendices

Appendix A

The celestial sphere and astronomical coordinates

A.1 A place on Earth

The terrestrial equator is defined as the great circle halfway between the North and the South Poles. The "Prime Meridian" was defined in 1884 as the half circle passing through the poles and the old Royal Observatory in Greenwich, England (see Fig. A.1).

A location on the surface of the Earth is defined by three numbers: the longitude λ, the latitude ϕ, and the height above sea level, h.

The longitude of a given point on Earth is measured westward from Prime Meridian to the intersection with the equator of the circle of longitude that passes through the point.

The latitude is the angle measured northward (positive) or southward (negative) along the circle of longitude from the equator to the point.

Onsala Space Observatory is located just a few meters above sea level, at the following longitude and latitude:

$$\boxed{\lambda = 12°01'00''\mathrm{E} \qquad \phi = 57°25'00''\mathrm{N}.}$$

A.2 The celestial sphere

A.2.1 Equatorial coordinates

The celestial sphere is an imaginary sphere concentric with the Earth, on which astronomical objects appear (see Fig. A.2). The celestial equator is the natural extension of Earth's equator. Because of the inclination of Earth's axis of rotation, the apparent annual path of the Sun on the celestial sphere (the *ecliptic*) doesn't coincide with the celestial equator; the ecliptic makes an angle of 23.5° with the celestial equator. The point where the Sun crosses the celestial equator going northward in spring is called **the Vernal Equinox**. On the equinox, the Sun lies in the Earth's equatorial plane, and the day and night are equally long. The solstices mark the dates when the Sun is farthest from the celestial equator and occur around June 21 and December 21.

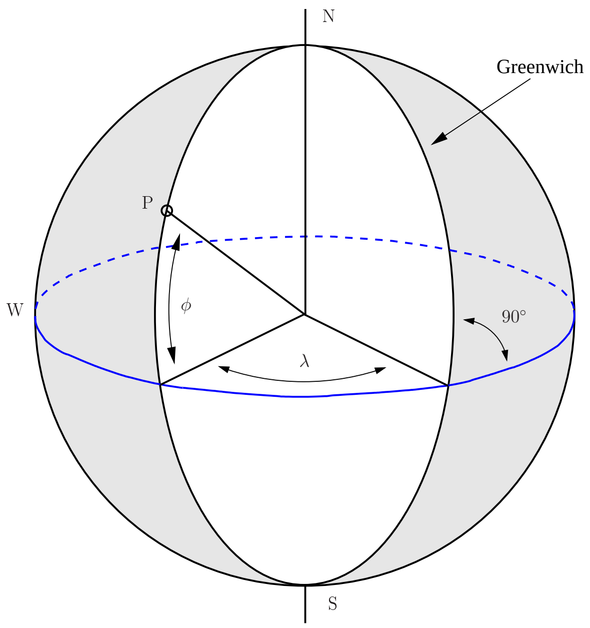

Figure A.1: Illustration of the terrestrial system, with longitude (λ) and latitude (ϕ). Great circles passing through the poles are circles of longitude. Circles parallel to the Earth equator are circles of latitude.

→ **Mark the north and south celestial poles, the celestial equator, the ecliptic, the solstices and the equinoxes on Fig. A.2.**

Positions on the celestial sphere are defined by angles along great circles. By analogy with terrestrial longitude, right ascension (RA), α, is the celestial longitude of an astronomical object, but it is measured *eastward* from the Vernal Equinox along the celestial equator. RA is expressed in hours and minutes of time, with 24 hours corresponding to 360°.

In analogy with terrestrial latitude, declination (DEC), δ, is the angular distance of an object from the celestial equator. Right ascension and declination (α, δ) specify completely a position on the celestial sphere.

Imagine now that we find ourselves at location P on Earth at a latitude ϕ, and we want to observe the sky. An astronomical object of declination δ reaches a maximum altitude above the horizon, $h_{\max}$, and a minimum altitude, $h_{\min}$, given by

$$\begin{aligned} h_{\max} &= 90° - |\phi - \delta| \\ h_{\min} &= -90° + |\phi + \delta|. \end{aligned} \tag{A.1}$$

→ **In Onsala, astronomical objects with $\delta > 33°$ always remain above the horizon (they are circumpolar); those with $\delta < -33°$ never rise above the horizon.**

A.2.2 The Local Sidereal Time

The convention of measuring RA eastward was chosen because it makes the celestial sphere into the face of a clock. The hand of the clock is **the local meridian**, the north-south line

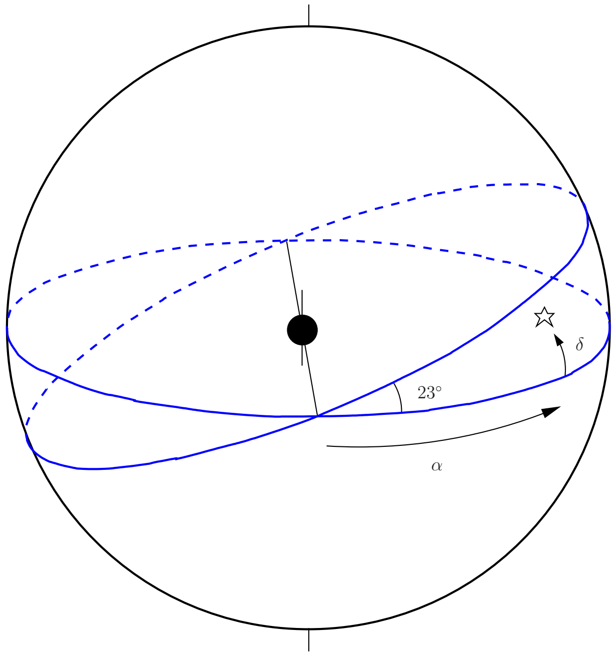

Figure A.2: Illustration of the celestial coordinate system, with right ascension α and declination δ. Earth is at the center. The plane of the ecliptic is inclined by 23.5° with respect to the celestial equator.

passing through the observer's zenith (the zenith is the upward prolongation of the observer's plumb line – right overhead!).

When the Vernal Equinox is on the local meridian, the Local Sidereal Time (LST), or star time, is said to be 0 hours. On the Spring equinox (around March 21), this happens at noon (solar clock).

→ **To remember: On the Spring equinox (around March 21), LST= 0 h at noon (solar time).**

As time passes, astronomical objects on the local meridian will have a larger RA. At any moment and any location on Earth, the LST equals the RA of astronomical objects on the local meridian.

The celestial clock moves ahead of the solar clock every day. This is because Earth rotates both around its own axis, and also around the Sun, as illustrated in Fig. A.3. After 24 hours of solar time, a given location on Earth finds itself at the same solar time (which is with respect to the Sun). For instance, every day the Sun reaches its highest elevation at the same solar time. But relative to the stars, it finds itself on the same position a little bit earlier (corresponding to only one rotation around its axis). 24 hours of LST time pass in only 23 hours 56 minutes 05 seconds of solar time. A certain LST time occurs about 4 minutes earlier than it had the day before.

We have said that on the Spring equinox, around March 21, the LST is 0 h at 12 h solar time (noon). The next day at noon, the LST will be 0 h 3 min and 56 sec; inversely, 0 h of LST time correspond to 11 h 46 m 05 s solar time. With each passing month, a given LST time occurs 2 hours earlier.

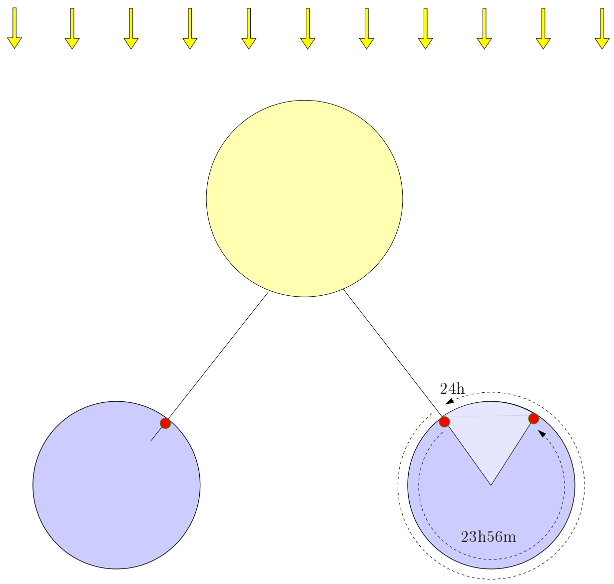

Figure A.3: The Local Sidereal Time is the time relative to the stars, whereas the solar time is relative to the Sun. 24 hours of LST time pass in only 23 hours 56 minutes 05 seconds of solar time, because Earth, having moved on its orbit around the Sun, finds itself the next day at the same position relative the stars *a bit earlier* than at the same position relative to the Sun. In one year (365 days), Earth has moved 360° around the Sun and lost one turn (24 hours) relative to the stars. So the difference in one month is 2 hours, and in one day it is 24 hours/365 = 3m56s.

A.2.3 How can I know whether my source is up?

Let's imagine that we want to observe in a certain direction in the Galactic plane (a certain Galactic longitude l, and a Galactic latitude $b = 0$) at a certain time.

First of all, we need to convert the Galactic coordinates into celestial equatorial coordinates: RA and DEC. For this, we may use the table to find α and δ.

As we have shown above, some sources will never rise above the horizon in Onsala (the ones with $\delta < -33°$).

It is best to study examples to learn how to find out when a source is visible.

Example 1. I have been allocated time to observe with the radio telescope on May 5, starting at 15 hours local time in Onsala. This corresponds to 13 hours solar time. What is the corresponding LST time? What part of the Galaxy can I observe?

On March 21, LST=0 h at noon.

$\Rightarrow$ LST= 1 h at 13 h.

May 5 occurs 1.5 months after March 21. The LST time shifts by 24 hours per year, or 2 hours per month. So, 1.5 months after March 21, LST=1 h will occur at $= 13-(1.5\times 2) = 10$ h. And at 13 h, LST= 4 h. This means that sources will $\alpha = 4$ h will cross their meridian (be highest above the horizon) at that time.

Looking at the table, we see that $l \simeq 150°$ corresponds to $\alpha \simeq 4$ h. Since that Galactic longitude doesn't reach a very high elevation in Onsala, it is a good idea to start by observing

l	$\alpha(J2000)$	$\delta(J2000)$
°	h m	° ′
0	17h45	–28:56
20	18h27	–11:29
40	19h04	06:17
60	19h43	23:53
80	20h35	40:39
100	22h00	55:02
120	00h25	62:43
140	03h07	58:17
160	04h46	45:14
180	05h45	28:56
200	06h27	11:29
220	07h04	–06:17
240	07h43	–23:53
260	08h35	–40:39
280	10h00	–55:02
300	12h25	–62:43
320	15h07	–58:17
340	16h46	–45:14

Table A.1: Conversion from Galactic coordinates to right ascension and declination for different values of l, with $b = 0$. The Galactic longitudes in bold face (and green) are circumpolar at the latitude of Onsala ($\delta > 33°$). The Galactic longitudes in red are always below the horizon at the latitude of Onsala.

it because it will be setting quickly.

Example 2. Today is Christmas Eve (December 24), and I have been offered a small optical telescope. I would like to use it to observe the beautiful Whirlpool galaxy M 51. Is it possible?

The coordinates of M 51 are $\alpha \simeq 13$ h 30m, $\delta \simeq +47°$. This means that M 51 will be at its highest elevation above the horizon at LST=13 h 30.

LST= 0 h at noon = 12 h around March 21.

LST= 0 h at $12 - (2 \times 9) = -6$ h (or $24 - 6 = 18$ h) around Dec. 21 (9 months after March 21, since the LST time shifts ahead by 2 hours every month).

LST=13 h 30 at 18+13 h 30= 7 h 30.

M 51 will be highest up on the sky in the morning at 7 h30, and it will be rising during the second part of the night.