SALSA user manual: Telescope control and data analysis

Written by Eskil Varenius
Onsala Space Observatory
Chalmers University of Technology
SE-439 92 Onsala
Sweden

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Contents

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. From these measurements we can learn about the kinematics and distribution of gas in our galaxy, 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 document *Mapping the Milky Way* on the SALSA website.

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.

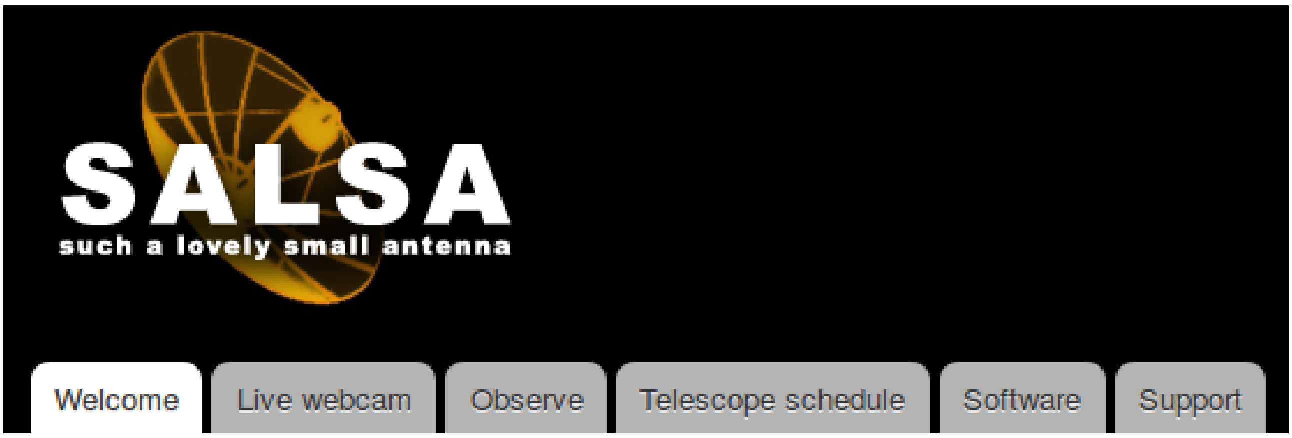

Figure 1.1: A part of the SALSA website. Here you find a lot of useful information as well as the booking system used to reserve observing time with SALSA.

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.

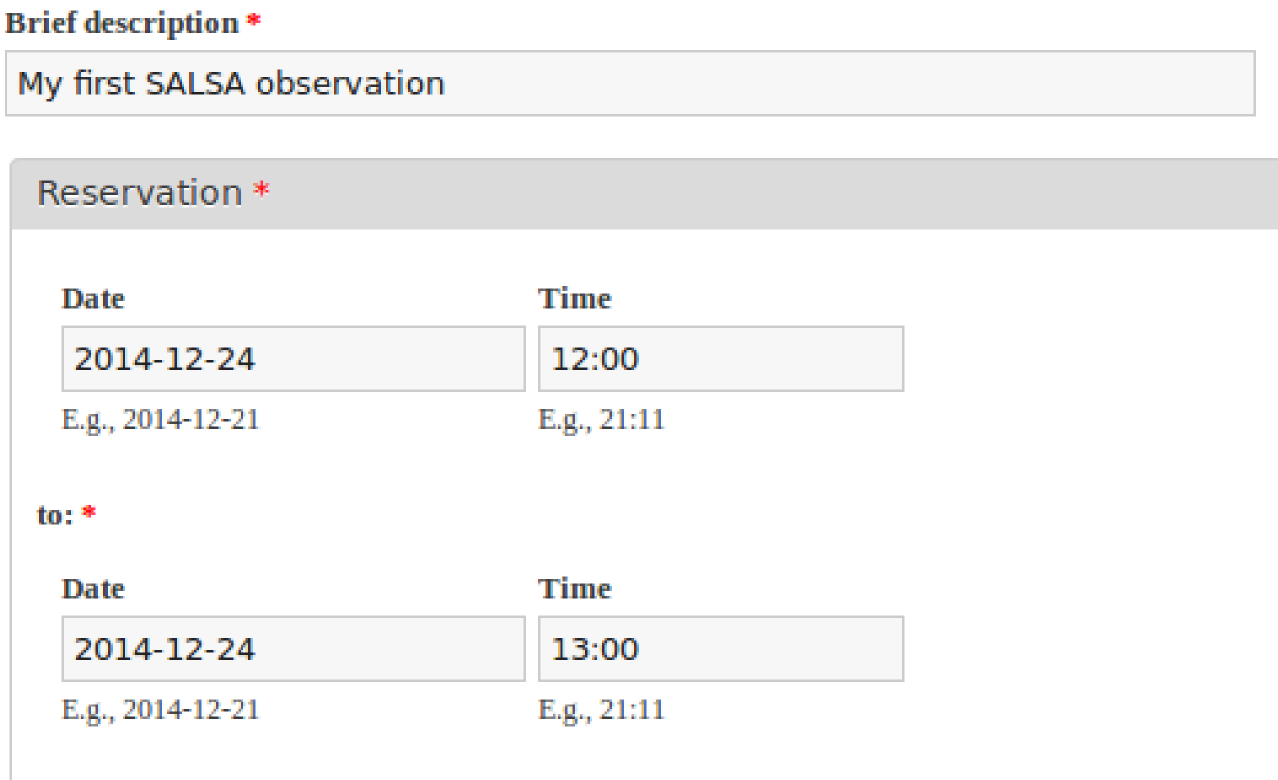

Figure 1.2: The page used to create a new reservation, i.e. book observing time with SALSA.

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 save 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. 2.4.

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 we observe 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*.

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*.

2.2 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 almost any computer. There are two common ways to connect to the computer in Onsala:

- *The free software NoMachine.* This is the most common way to control a SALSA telescope. Before your first observations, you will need to download the free software NoMachine from www.nomachine.com and install it on your computer. The first time you connect using the NoMachine software you may follow the step-by-step guide in Appendix A. Once you are connected you may start the control program by clicking on the SALSA-shortcut on the virtual desktop.
- *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". You may then start the control program from the terminal with the command `SALSA`.

2.2.1 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 NoMachine, you close your connection by closing the NoMachine window (e.g. by clicking the x in the upper corner) and then chose `Terminate` when asked how to quit the session. If you are connected via SSH in a terminal, you close your connection by typing `exit`.

2.2.2 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.
- Some users who connect to SALSA using the NoMachine program will by default get a window which is so small that one cannot see the bottom part of the control program window. This means that one may be unable to see the Upload-button, and hence unable to save measurements. This can be solved by manually adjusting your window size or screen resolution, either in NoMachine or remotely at the control computer.

2.3 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

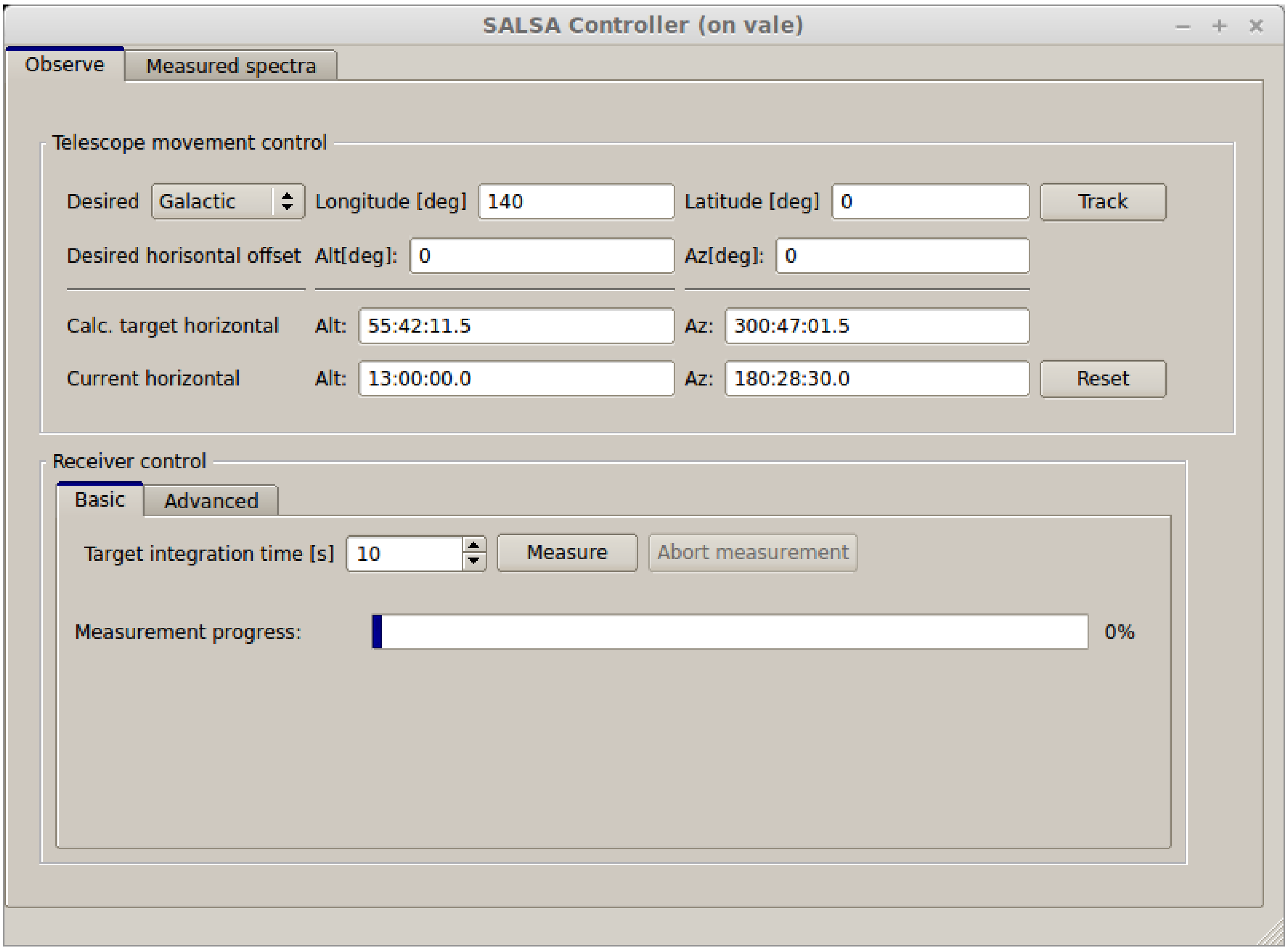

Figure 2.1: Startup display of the SALSA control program.

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.

2.3.1 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.

[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.

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 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.

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.

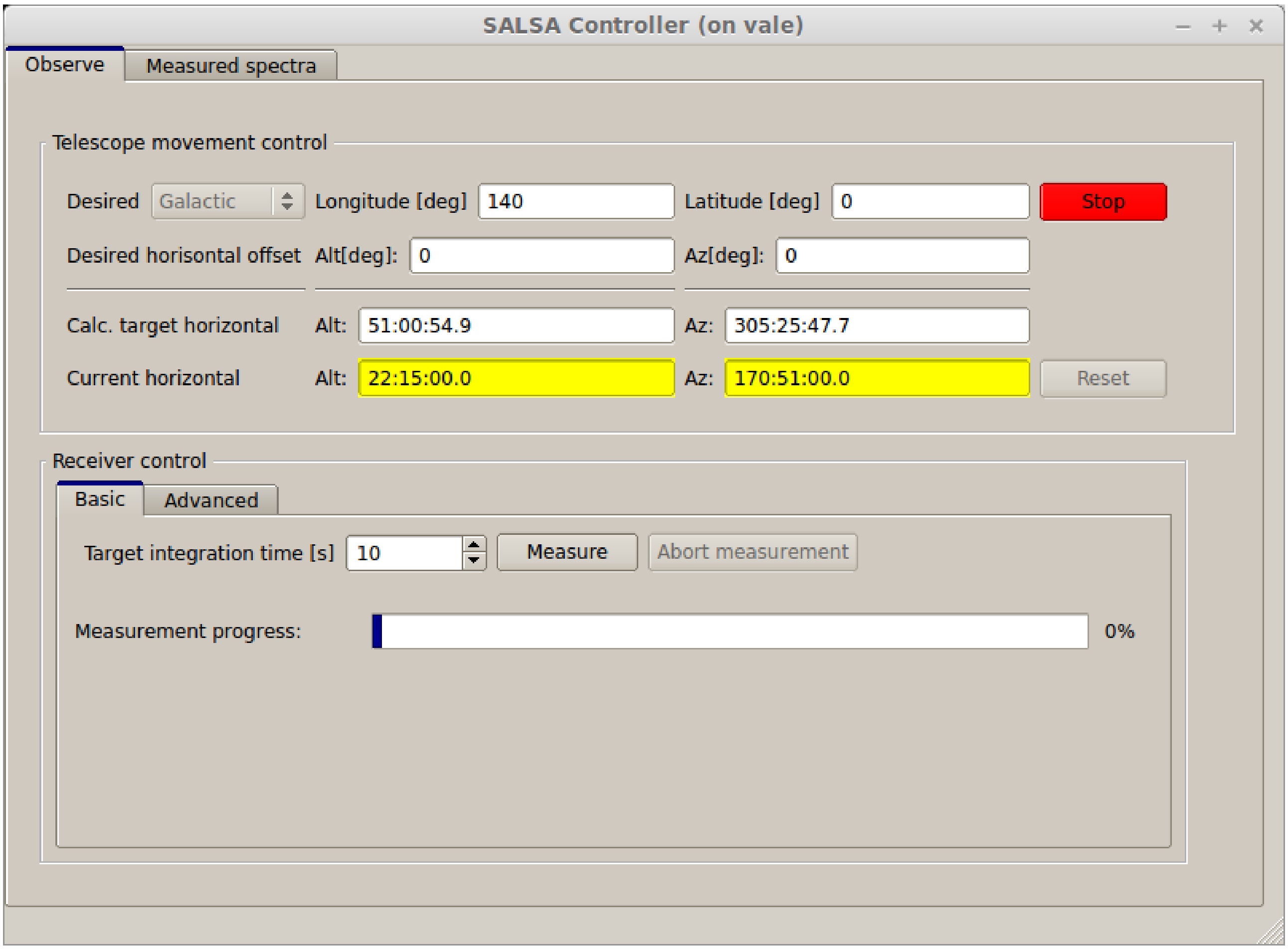

Figure 2.2: The telescope control program display when the telescope is moving.

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°.

2.3.2 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.

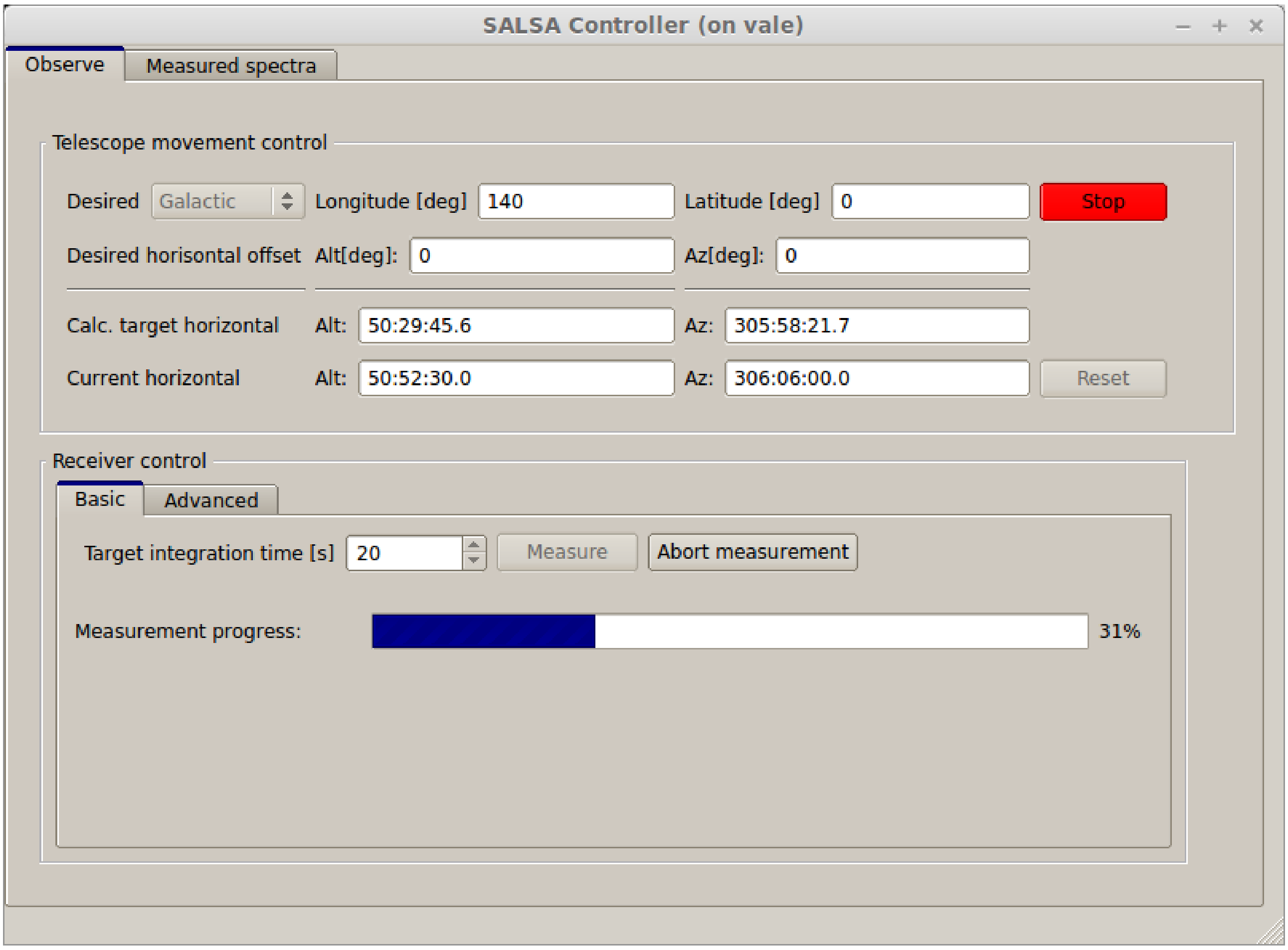

Figure 2.3: The telescope control program display when the telescope is measuring.

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.

2.3.3 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 (seince 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

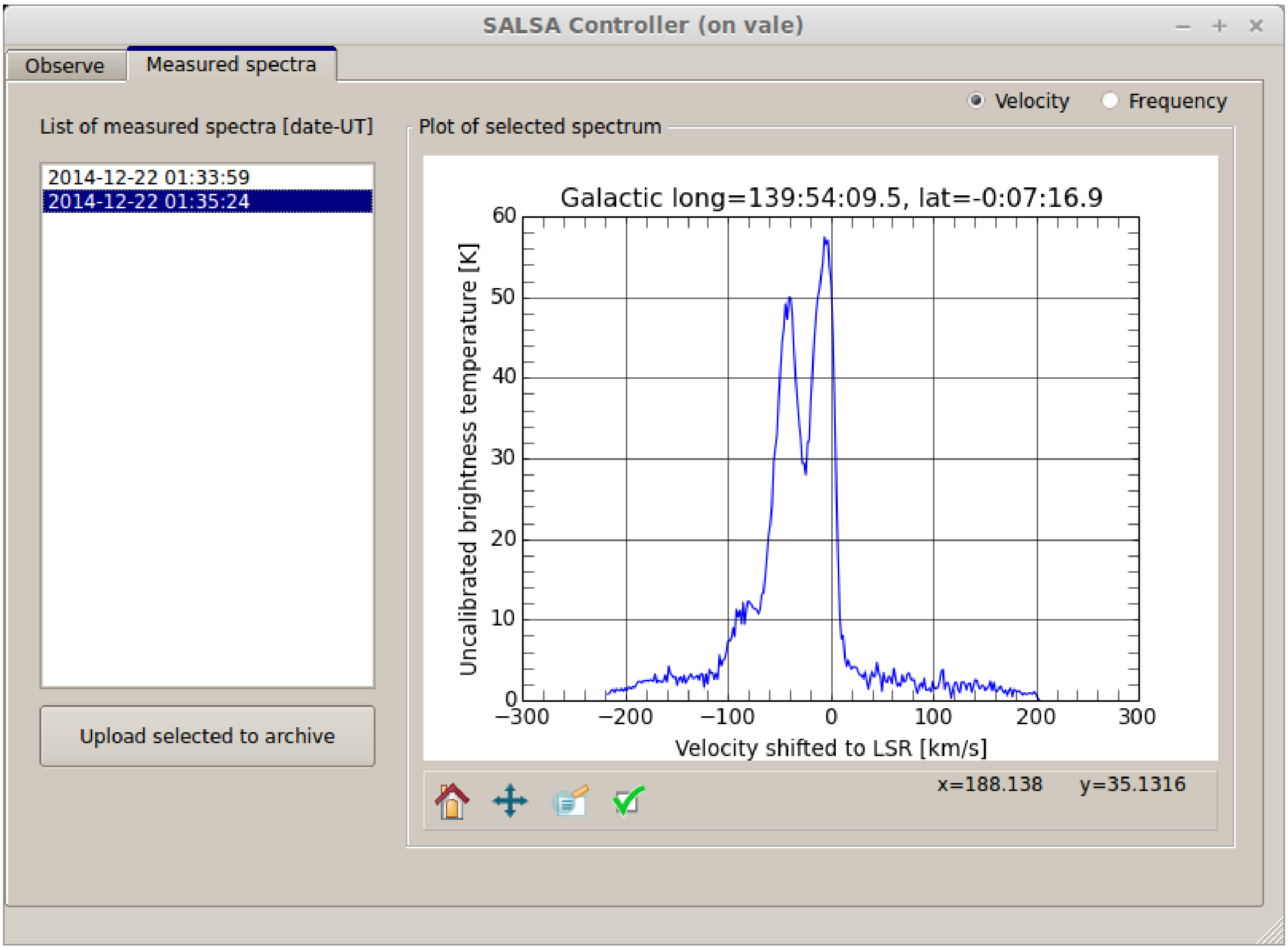

Figure 2.4: The tab *Measured spectra* in the control program. To the left is a list of all measurements done in this session. The right plot shows the currently selected spectrum. You may select a different spectrum by clickin in the list. In the bottom left corner there is a button to save the selected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

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 on. 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.

2.4 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 simples option, but in some cases you may want to do a more careful analysis offline. In this section we describe briefly how to download data from the archive and what software you may use to inspect the data offline. Aside from direct inspection in the control program, the most common way to process the data is by using Matlab to read the FITS files, see below.

2.4.1 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. However, it may still be accurate enough for quick estimates of, for example, the center velocities of peaks in the spectrum. An accurate analysis of your data will however probably require access to the actual numbers, which is provided as TXT and FITS, see below.

2.4.2 TXT: Textfiles

The TXT format contains the spectrum in plain text, i.e. as list of velocity/intensity pairs. This format can be read by many programs, for example the free office suite LibreOffice available at http://www.libreoffice.org. If you know computer programming you may also write your own code to display the data in the TXT files using your favourite programming language.

2.4.3 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. Because this format is popular, there are multiple ways to process the data. Below we list the most common ways to read FITS file from SALSA.

SalsaJ - Free graphical software

The software SalsaJ is available at http://www.euhou.net/ (click on Software and then on SalsaJ). This is a program which you download to your computer. SalsaJ can read the FITS files easily. However, there is a minor discrepancy between the current version of SalsaJ and the FITS files produced by the recently upgraded SALSA control program. You can still try to read your files, but at the time of writing this we know that some additional testing is necessary before you can read SALSA FITS files properly with SalsaJ.

[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 with MATLAB - see the SALSA website.

Matlab: The SalsaSpectrum class

SalsaSpectrum is a data reduction software, written in the popular MATLAB language, which can be used to view and analyse data from SALSA. For users that are familiar with MATLAB, it may be the best option as there are both plotting and programming capabilities available. It is possible to reduce large numbers of spectra simultaneously, and to easily plot the results. The SalsaSpectrum software is available at the SALSA website, along with extensive documentation. Pleas note that Matlab is not free software and you need to have a license to use it - the observatory cannot provide Matlab licenses.

Python

If you are familiar with the programming language Python you can read the FITS files using the library *astropy*.

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 5.4° (*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 tracking is limited by the mechanical design to an accuracy of about 0.5°. We are working to make the telescope even more accurate by improving the hardware design. Note that the accuracy is always the same for any position, any error present for one observation does not carry or accumulate to the next one. This means that while the position may have a small error, the error will never get worse even if you observe for a very long time.

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.

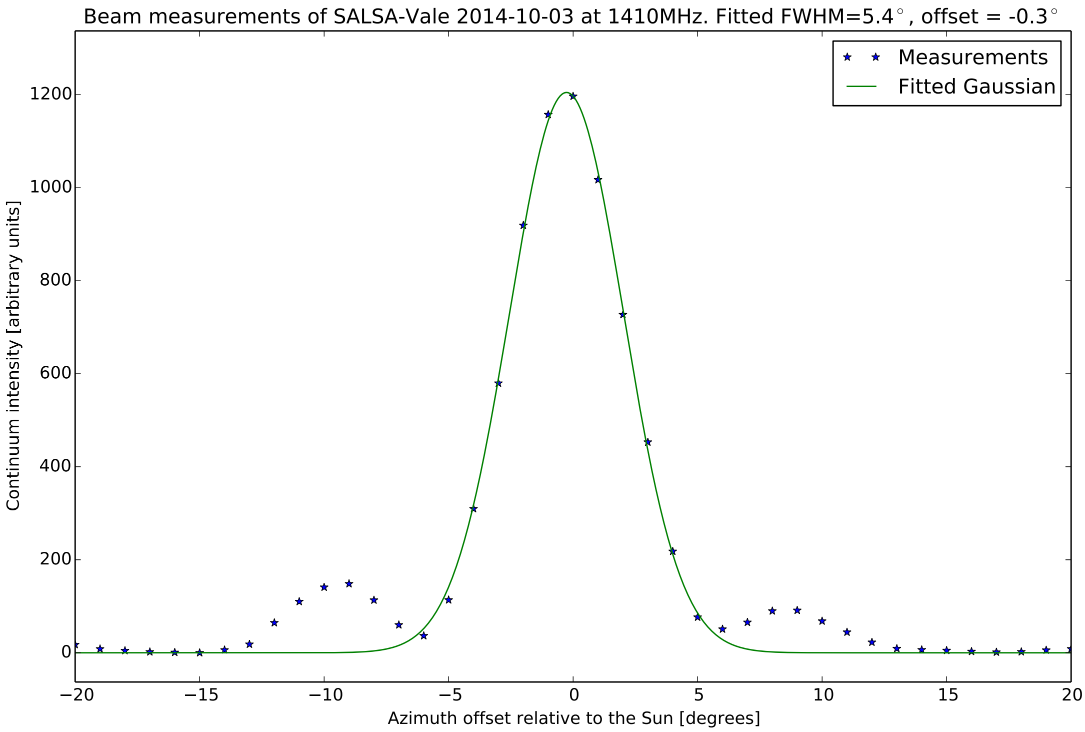

Figure 3.1: The beam of Vale measured using the Sun at 1410 MHz. A Gaussian fit gives the FWHM=5.4°. The sidelobes of the Sinc-function are clearly visible, as expected for a circular aperture.

Appendices

Appendix A

How to connect to SALSA using Nomachine 4

The program NoMachine 4 can be used to connect to the control computers brage or vale. This tutorial was compiled using the program Nomachine 4.0.366 for Windows XP/7/8 available from http://www.nomachine.com 2013-11-25. It might also be useful for connecting with NoMachine 4.0 on Mac (OS X) or Unix/Linux although the tutorial has not been tested on these systems.

A.1 Quick summary

When creating your connection you need to use Protocol: SSH, and also press the button "Advanced" on the same screen and choose number two: "Use the NoMachine login" to authenticate on host. See figures A.2 and A.3.

A.2 Connecting: Step-by-step instructions

In this example we will be connecting to a SALSA control computer called *vale* using the program Nomachine 4.0.366 for Windows XP/7/8 available at www.nomachine.com. First, download and Install the Nomachine program. Then, start the NoMachine program (e.g. using the shortcut on your desktop) and click continue through the welcome screens until you arrive at the screen *Recent connections* shown in fig. A.1. From here, follow the instructions in the figure captions.

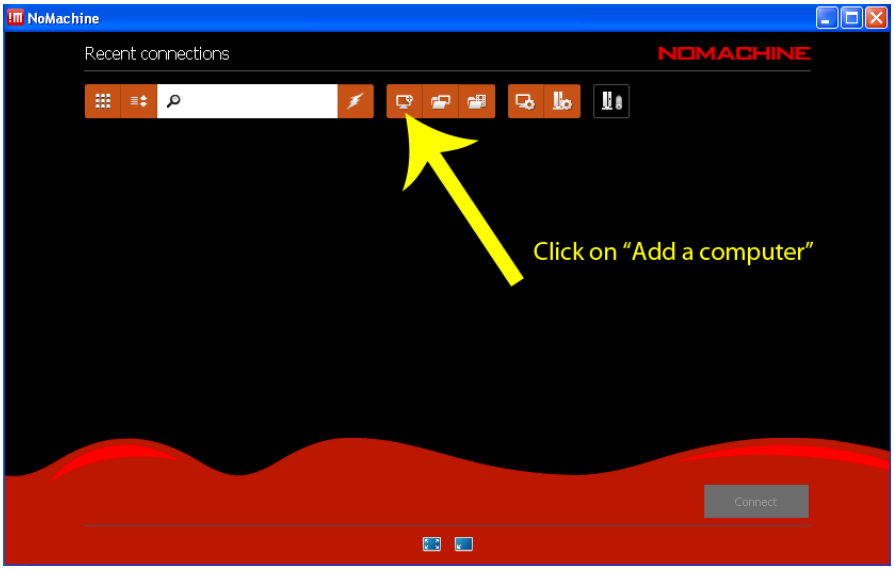

Figure A.1: The startup screen of Nomachine 4 after clicking through the welcome instructions. Click on *Add computer* marked with an arrow here.

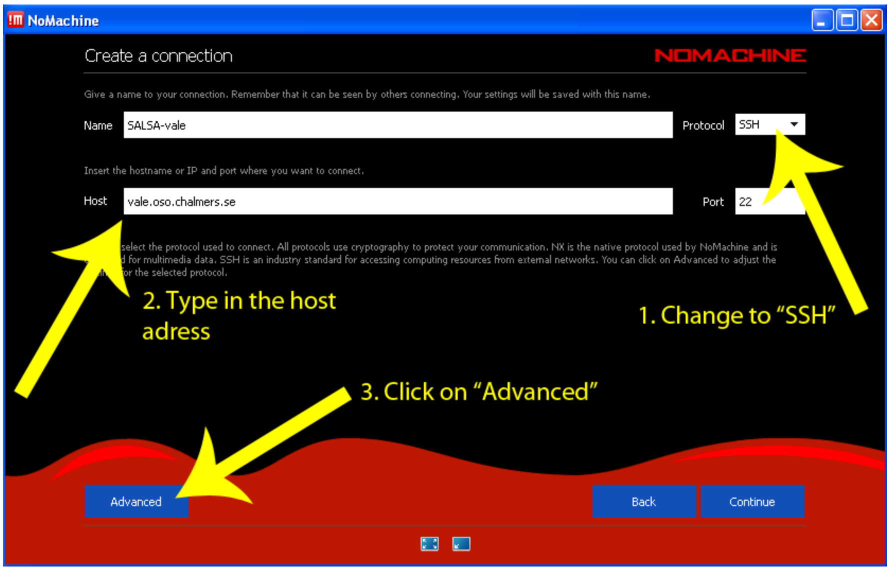

Figure A.2: The screen for creating a new connection. Here you need to change the host adress, the protocol to SSH and finally click on the button *Advanced*.

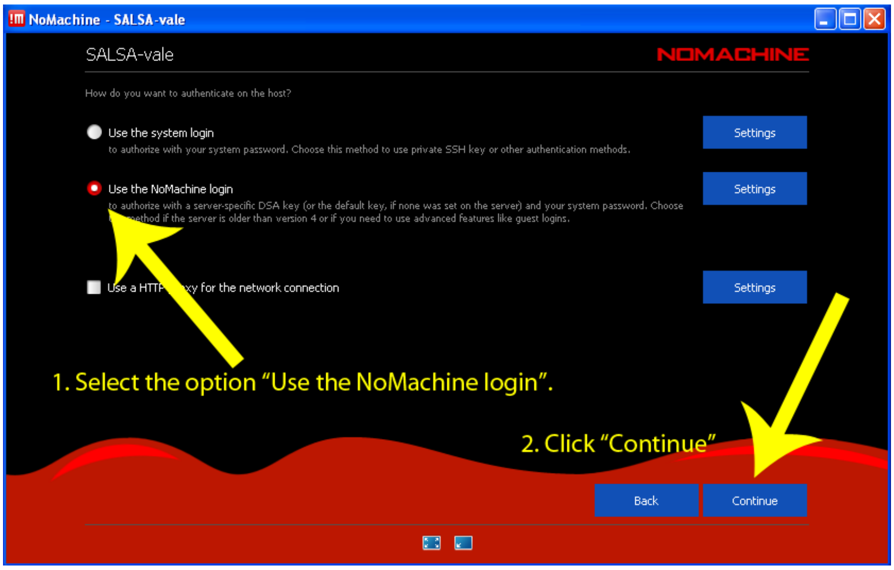

Figure A.3: After you click *Advanced* you need to select option 2: "Use the NoMachine login", see fig. A.3. Then press *Continue*.

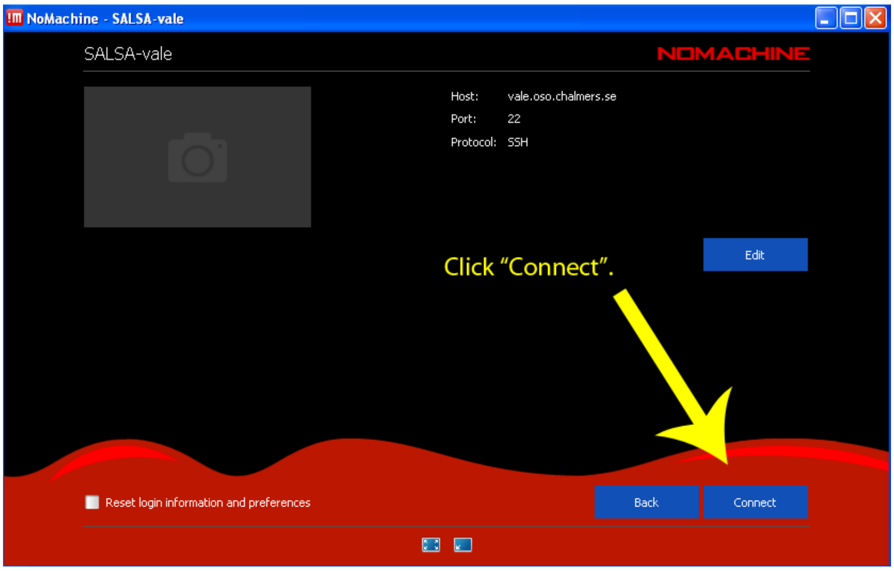

Figure A.4: Verify that the host adress is correct, e.g. vale.oso.chalmers.se to connect to the computer "vale" or brage.oso.chalmers.se to connect to "brage", and that "Port:22" and "Protocol:SSH", then click *Connect*.

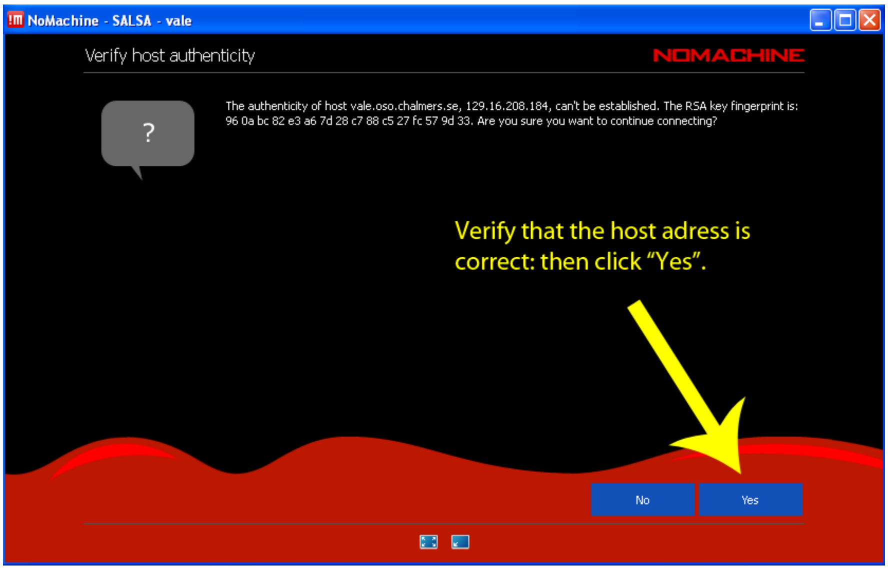

Figure A.5: The first time you connect you will get a warning to "Verify host authenticity". Check that the host adress is indeed correct, then click *Yes*.

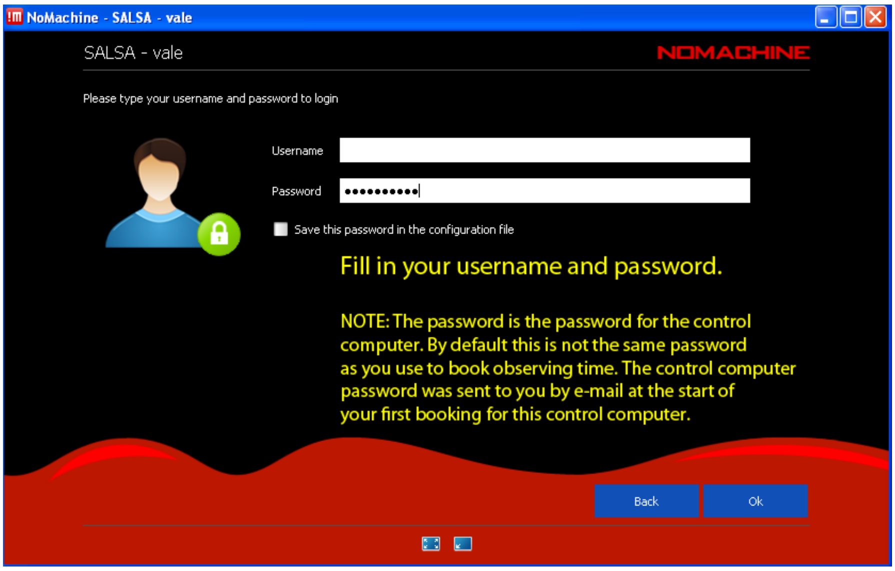

Figure A.6: Fill in your username and password. Then click *OK*. **Note:** Here you need to use your "telescope password", which may be different than the password you use to book observing time. Check the SALSA-webpage, under "My account" to find your telescope password.

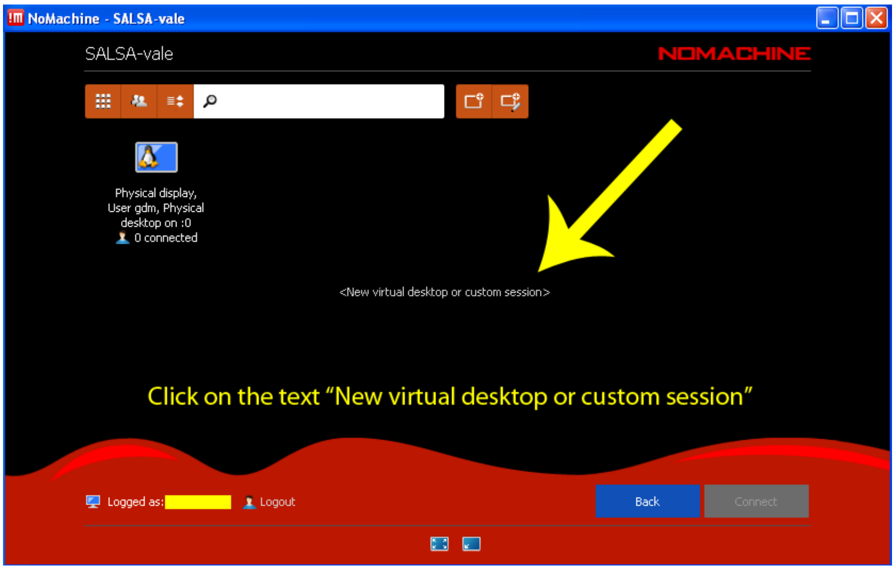

Figure A.7: Click on the text in the middle of the screen *New virtual desktop or custom session.*

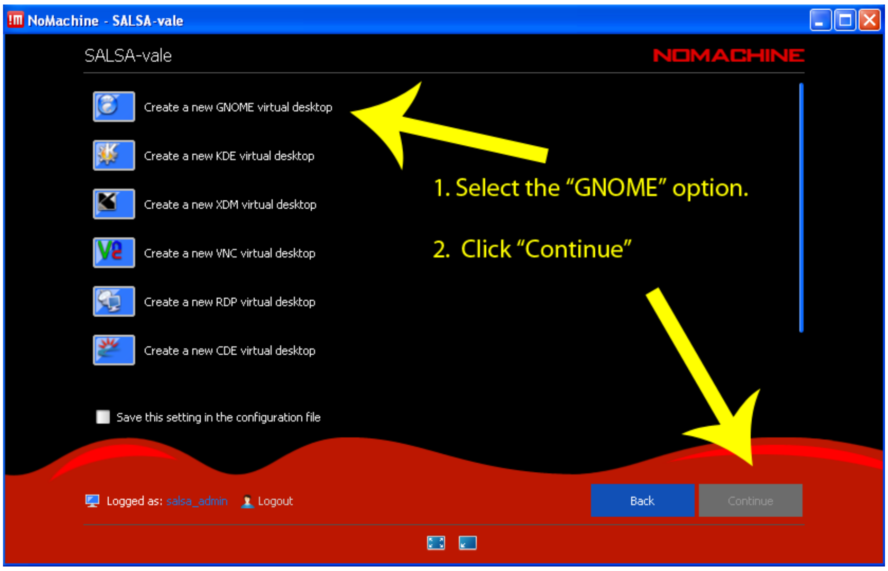

Figure A.8: Select the ”Gnome” option in the list and then click *Continue*. You may now see a few info screens from NoMachine on which you may only click OK.

Figure A.9: Hopefully you will (perhaps after a few NoMachine info screens) see something like this. Congratulations - You are now connected to the SALSA control computer and you may start observing! To start using the telescope, double-click on the shortcut to "SALSA".