Analysing data from SALSA using SalsaJ

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Abstract

This document describes how to analyse FITS files generated by the SALSA Onsala radio telescopes by using the software SalsaJ. We describe step by step how to open the FITS files, improve the analysis by removing receiver artifacts (spectral baseline subtraction), and fit Gaussian intensity distributions to derive velocities and intensities for the observed components (peaks).

Contents

1 Introduction

The SALSA Onsala telescope is a 2.3 m in diameter antenna located at Onsala space observatory outside Gothenburg. The telescopes are designed to detect the faint radiation from cold hydrogen gas in our galaxy, the Milky way. The hydrogen gas emits radiation at a wavelength of 21 cm (or a frequency of 1420.4 MHz). This signal can be detected by the microwave receiver connected to the telescope. The observed spectrum can be exported into a FITS-file, which is the currently most used type of file for astronomical images and spectra. The fits file has two parts: (1) a *header* which includes information about the data such as the velocity resolution, central frequency and many others, and (2) the data itself.

Having completed the observations, the observer may want to process the data further in order to more accurately deduce the kinematics, as well as the amount of hydrogen gas in the Milky Way. There are currently two main ways to analyse data 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.

- **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.

Both SalsaJ and SalsaSpectrum can be downloaded from the webpage at `http://vale.oso.chalmers.se/salsa`.

2 Analysing SALSA data with SalsaJ

In this section we describe step by step how to analyse the FITS files generated by the SALSA Onsala telescopes in the software SalsaJ. We will open the FITS files, switch to velocity, and inspect the data using the pointer. Further analysis, such as removing receiver artifacts (spectral baseline subtraction), and fit Gaussian intensity distributions, is described in Sect. 3. **IMPORTANT:** SalsaJ can only read correctly spectra produced by SALSA after 2015-06-23. If you have older spectra, you cannot use SalsaJ for processing them.

2.1 Starting SalsaJ

Once you have downloaded the file SalsaJ2.jar from the website, open it by double clicking. If this does not work for you, try right-clicking on the file SalsaJ2.jar and chose *Open with* and find *Java*. Once the software open you should see a window looking like Fig. 1.

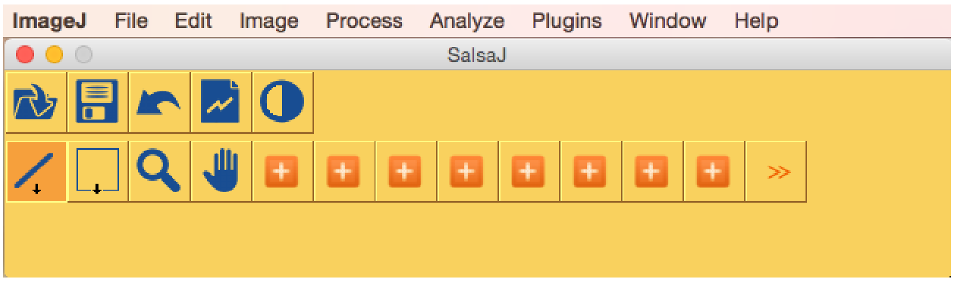

Figure 1: The startup window of the software SalsaJ.

2.2 Opening a spectrum

To open a spectrum, i.e. a FITS file, click the *File* menu, and then *Radio spectrum*. Navigate to the file you want to analyse and click OK. You should now see the spectrum presented as a figure similar to Fig. 2. Note: If you in Mac OS X do not see the *Radio spectrum* option in the *File* menu, make sure you focus the SalsaJ window by clicking on it.

2.3 Set the scale

By default, SalsaJ presents spectra as Intensity vs channel number. For our purposes it is more useful to switch the horisontal axis to velocity. This is done by clicking the button labelled *Set scale*, choose *Velocity*, and click OK. The horisontal axis should now be set to km/s, as in Fig. 3. Note that you can inspect the measured values by moving the pointer over the graph: the

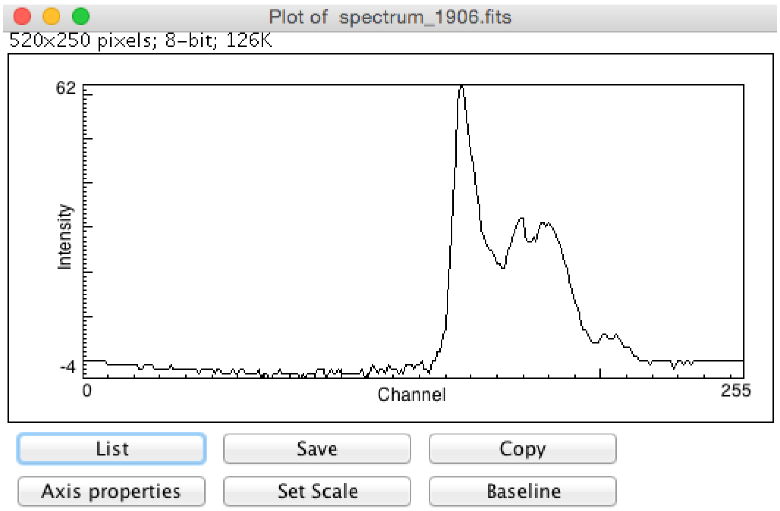

Figure 2: A spectrum has been opened and is by default presented with channel index on the horisontal axis. We want to change to velocity.

intensity and velocity are reported in the lower part of the window. If you are only interested in rough estimates of velocities, you can note down the values you find by visual inspection and consider yourself finished with this spectrum. However, if you want to get the best possible results you may want to consider the baseline subtraction and gaussian fitting described in Sect. 3 below.

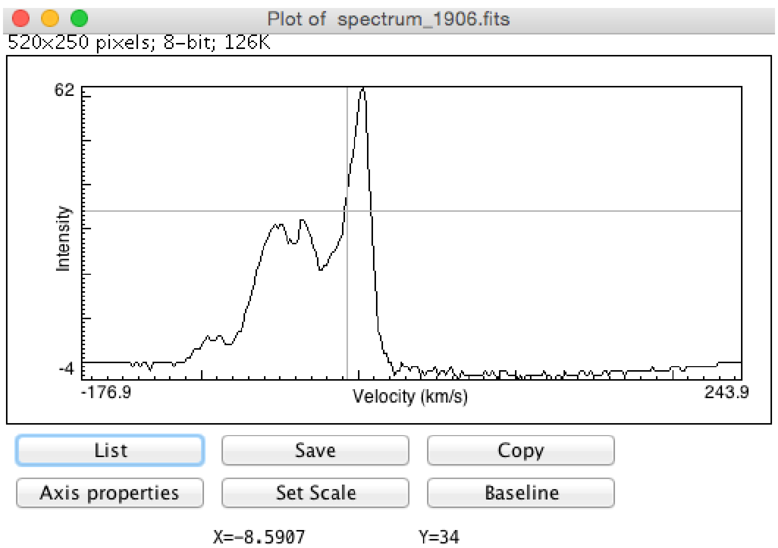

Figure 3: The spectrum is now shown with velocity on the horisontal axis. You can now inspect the spectrum directly by hovering with the pointer over the peaks. The current value marked by the cross is displayed in the bottom part of the window.

3 Advanced processing

You can get pretty good estimates of the observed velocities by moving the pointer over the graph: the intensity and velocity are reported in the lower part of the window. However, if you want to get the best possible results you may want to consider the baseline subtraction and gaussian fitting as described below. Note that this can be tedious work if you have many spectra, in this case consider using the Matlab program SalsaSpectrum if you have access to Matlab.

3.1 Spectral baseline subtraction

The spectra presented in Fig. 3 is pretty good already from the start, but looking carefully we can see that the zero-level is not flat. Instead, it is curved due to residual effects from the receiver which were not subtracted during the observation. For accurate results, we need to remove this effect. This removal is called *baseline subtraction* and is started by clicking the button *Baseline* in the SalsaJ window. From quickly inspecting the graph with the pointer, we note that we have no line emission in the velocity regions [-170 to -130] and [50 to 240] km/s. We enter the boundaries of the two regions and chose poynomial order 2, see Fig. 4.

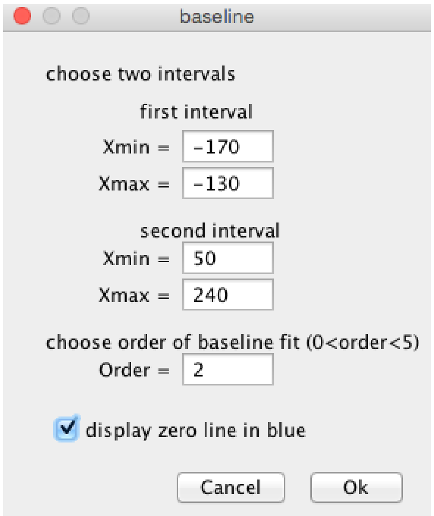

Figure 4: The input window for baseline subtraction, where we have defined two regions of the spectra with no line emission and chosen a degree of polynomial to fit to the data.

After you press OK, a baseline will be fitted and plotted, see Fig. 5. If you are happy with the fit, click *Subtract baseline*. If the fit looks bad, click *reset* and redo the subtraction with different intervals or polynomial orders until you get a good fit to the line-free parts of the spectrum. After subtracting a baseline, the line-free parts should be flat, as in Fig. 6.

3.2 Measuring velocities: fitting Gaussians

Because of noise it can be hard to measure exactly the center velocity of peaks by simple manual inspection. A good way is to fit Gaussian intensity distributions to the peak, which can be done by clicking the button *Gaussian fit* in SalsaJ. For the fitting we first need to note down starting guesses for the peaks we want to fit. Here visual inspection suggest four peaks roughly at positions -90, -52, -35, and 0 km/s. Hence we want to fit four Gaussians to the spectrum, but SalsaJ can

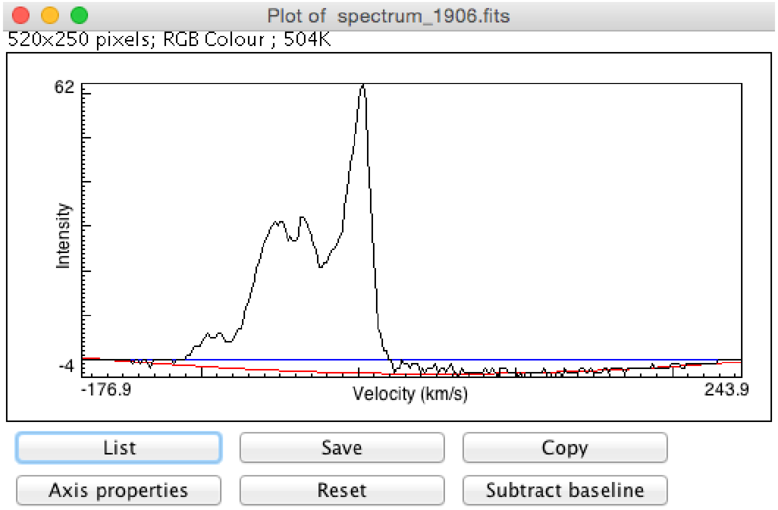

Figure 5: A baseline has been fitted based on the input in Fig. 4. The fitted baseline is shown in red, and the zero-level in blue.

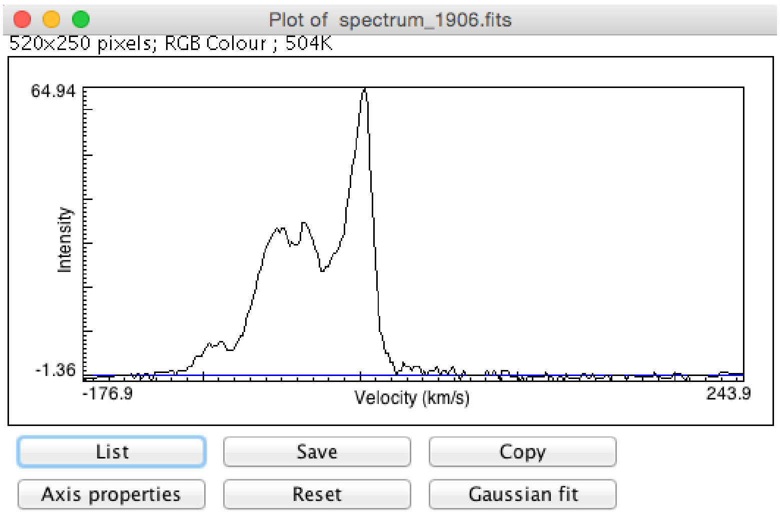

Figure 6: The baseline fitted in Fig. 6 has been subtracted and the line-free regions are flat with noise around zero. We are now ready to measure velocities and intensities.

only handle one at the time (the SalsaSpectrum Matlab class can fit multiple Gaussians at once). Let us start with the brightest peak around 0 km/s.

After clicking the button *Gaussian fit* we need to give an interval of data to use for fitting this peak, specified by Xmin and Xmax. Usually a range of 10km/s above and below the peak center works fine, in this case -10 to +10. Then we need to give initial guesses for the fitting to start. This does not have to be very accurate, but the closer to the real value the better. We guess an amplitude of 30 (which is far below the real one), a center at 0 as noted for the peak positions in the previous paragraph, and a width of 20. Then we click OK. The fitted Gaussian is shown in red, see Fig. 8.

NOTE: If your fit goes wrong, for example if you specify an interval of the data where there is no peak, then you can remove the previous fitted gaussian by checking the box *erase the last*.

We proceed in a similar way to fit the other three peaks, the result can be seen in Fig. 9. After fitting you will also get a list of fitted values, see Fig. 10. From this list you can read the galactic coordinates of the spectrum, and the velocities and intensities of the all fitted peaks. The velocities can be used to make a rotation curve or map of the Milky Way as described in the SALSA Milky Way project instructions.

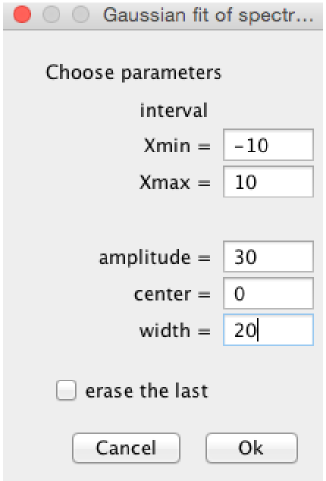

Figure 7: A set of parameters to fit a Gaussian intensity distribution to one of the peaks in the spectrum. The resulting fit can be seen in Fig. 8.

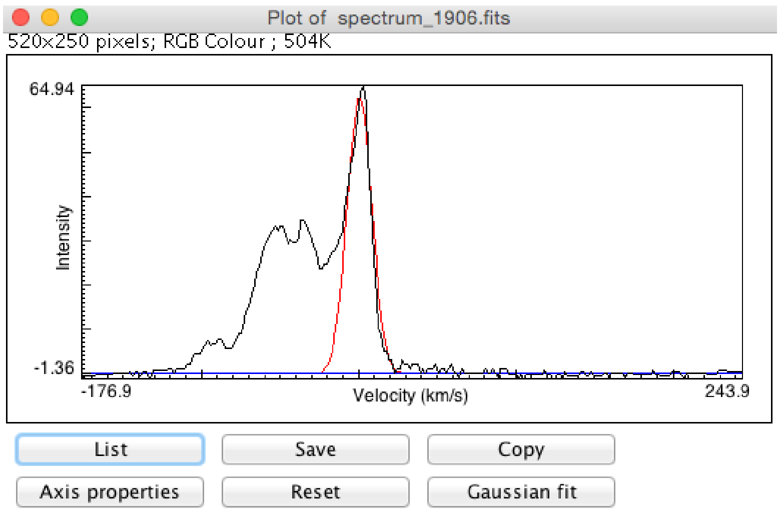

Figure 8: A gaussian has been fitted to the data using the parameters specified in Fig. 7.

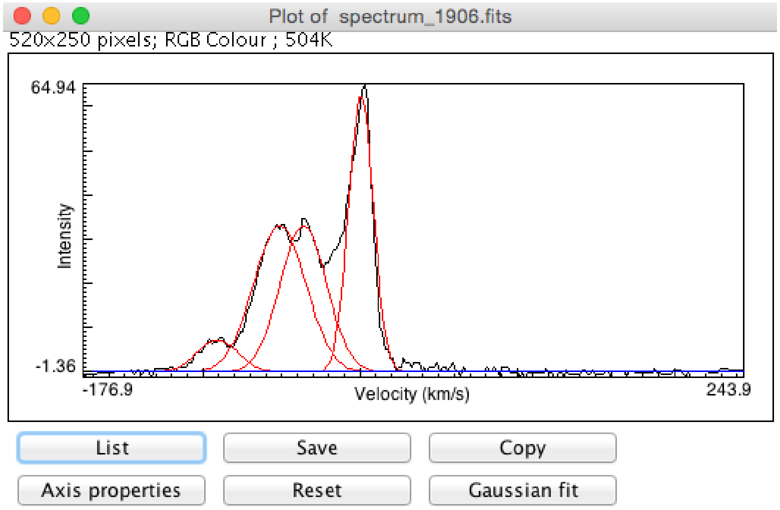

Figure 9: All four peaks have been fitted. The fitted velocities and intensities can be found in the *Gaussian fit results*, see Fig. 10.

Gaussian fit results

File	l	b	Velocity (km/s)	Intensity
spectrum_1906.fits	99.86	-0.03	0.59	62.54
spectrum_1906.fits	99.86	-0.03	-90.85	7.20
spectrum_1906.fits	99.86	-0.03	-51.17	33.08
spectrum_1906.fits	99.86	-0.03	-36.13	33.10

Figure 10: All four peaks have been fitted. In this window you can read the fitted velocities and intensities. These values can be used to make a rotation curve or map of the Milky Way, as described in the SALSA project instructions document.