Orion-Eridanus Superbubble Imaging

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Abstract

In this lab we work with the 3.6 m dish from Leuschner Observatory, measuring the 21 cm line emissions from atomic hydrogen (HI), an abundant element in our galaxy. Analysing features of this line, we create an image of the Orion-Eridanus Superbubble, by using the total flux from HI lines to measure the thickness of a Hydrogen column, and evidenciating the bubble shell from the center to the edges. The methods for tracking, recording and treating the data are presented and the choices justified. The final result is the image of Fig.?, made with ≈ 500 points, mapping the sky from galactic latitude -60° to -10° ($b = -10^\circ \rightarrow -70^\circ$ (JD)), and galactig longitude from 160° to 220° ($l = 160^\circ \rightarrow 220^\circ$ (JD)).

1 Introduction

In Radioastronomy, one of the greatest advantages is the hability of radio antennas on observing the hyperfine energy transition of neutral Hydrogen (HI), known as the 21 cm line, or 1420.4 MHz. This feature is largelly explored due to the fact that this element is present in the whole universe, and many structuers are comprised of molecular hydrogen. We explore this fact using the Leuschner dish (Fig.1) to measure the spectra of a large scale structure, and identify the HI lines to obtain a direct measurement of the quantity of this element.

Figure 1: A picture of the 3.6 m Leuschner dish used for this lab. Credits: Casper website.

Severall codes were developed, and the steps to obtain an image of the bubble are presented in this article on the following steps:

On Section 3 we introduce the physical concepts and some of the equations underlying the physics of our measurements and data aquisition.

On Section 4, an overall overview of the developed codes is presented. We show the steps from data aquisition untill the data calibration, before heading to the imaging task.

On the remaining sctions the image is presented and its features discussed.

2 The Physics of The Bubble

The Orion-Eridanus Superbubble is a large cavity inside a huge hydrogen cloud, formed by stellar winds and the supernovae from Orion OB1 association, a group of several hot giant stars of spectral types O and B. Its position in the sky, in galactic coordinates, ranges from $-10° to -10°$ in galactic latitude b, and from $160° to 220°$ in galactic longitude l. Because the column density of H atoms of this structure is directly proportional to the intensity of the 21 cm line, we use this transition to map the and build an image of its clouds. The equation used to measure the intensity of the lines was

$$N_{H1} = 1.8 \times 10^{18} \int T_B(v) dv\ cm^{-2}, \tag{1}$$

where N_{H1} is the column density of H atoms, T_B is the brightness temperature of this transition, being a function of the velocity of the clouds v produced by the Doppler effect. We use the approximation $N_{HI}\ approx \sum T_B(v) \cdot \Delta v$, where Δv is defined as follows for the 21 cm line:

$$\Delta = -c\frac{\Delta \nu}{\nu} = 0.31\ kms^{-1}. \tag{2}$$

With that, our task is to collect the spectra of a region in the sky that contains the Superbubble, integrating at a certain time the signal from points within a certain range, and also taking noise measurements to calibrate the data before calculating the column denstity. This work is described on the next section.

3 Points in The Sky

In order to build an image of the region of interest in the sky ($b = -10° \rightarrow -70°$ (JD), $l = 160° \rightarrow 220°$ (JD)), we define the measurement spots with a $\Delta b = 2°$ degrees spacing within the galactic latitude values, giving a total of 30 points in latitude, and, for the longitudinal measurements, we define our spacing in terms of the b values as follows:

$$\Delta l = \frac{2°}{cos(b)}, \tag{3}$$

a foreshortening for observers of latitudes different than zero, since we can go over a full circle by fewer steps (if $b = 0°$, no step is needed!). This will give us different number of longitudinal points per latitude value, ranging from around 11 points for $b = -70°$ and 30 $b = -10°$. The choice of 2° spacing is to achieve a good resolution by sampling 2 times per HPBW (Half-Power Beam Width), also known as the Full Width at Half Maximum (FWHM), which is $\sim 4°$ for this dish. About the observation time spent at each point, it followed the sequency: 2 observations of 1 *min* and 20 *sec* to collect information about the HI spectra, and 2 other observations of 10 *sec* to collect noise measurements in order to calibrate the data. More information about calibration is presented on the following sections.

The Orion-Eridanus Superbubble stays visible in our sky (Longitude: $-122°09.4'$ East, Latitude: $37°55.1'$ North, Leuschner location) from around 11 *pm* until 9 *pm*, when all our target points set, so our observation schedules respected this window of time, calculateed by a developed *Python* code. Besides that, our timing had to respect some altitude limits above the horizon due to some obstacles as threes and mountains, ilustrated on Fig.2.

Our object in the sky should be represented by around 694 points, but due to timing issues this aimed numbers were revised, and altough this range is displayed on the images presented on this article, the actual number of samples had to be redefined, and also the range of observation. To begin with, since we knew where to find the main features of the Orion-Eridanus Superbubble, we neglected observations in latitudes in the range $b = -70° \rightarrow -60°$, and $b = -12° \rightarrow -10°$. Also, since we aimed a full cover of the structure, we unfortunately had to downsample our observations to 4° spacing on longitude values, by skiping each calculated point of observation, and this resulted in a poor resolution image. However, the integration time for the spectra aquisition was the same throug all observation and remained as previously stated. A scheme of the final checked and unchecked points (and also the skipped ones) in our grid is presented by Fig.3. The green dots are representing the points we completelly ignored, so we didn't try to collect any information about that region.

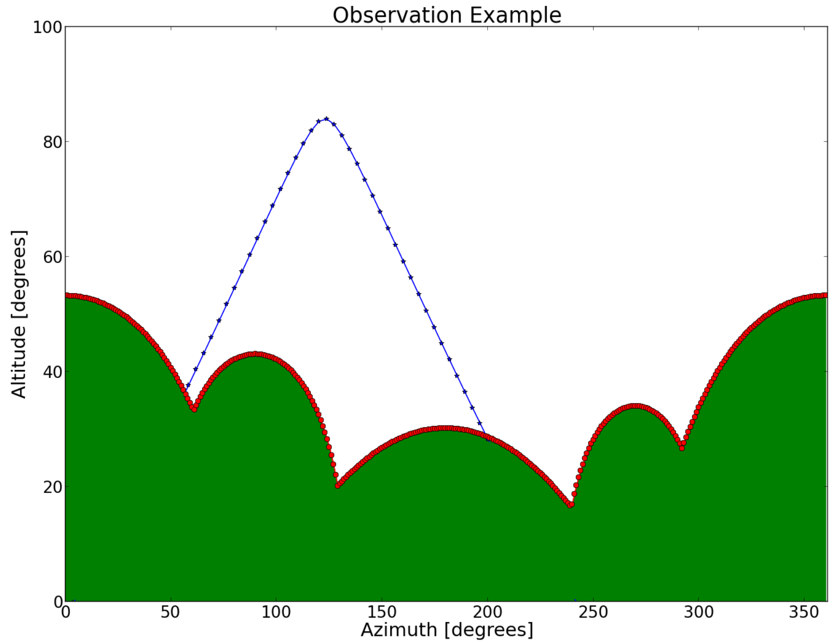

Figure 2: An Example of a day of observation, where the red dots mark the limit due to some local obstacles (at Leuschner Observatory) The star indicates the evolution of an aimed point in our grid in the course of a day.

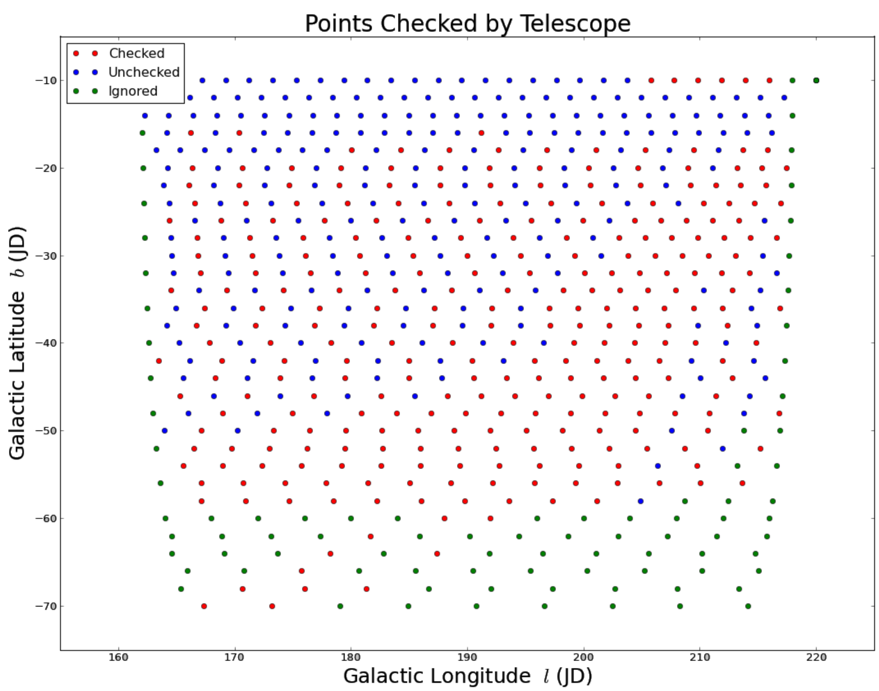

Figure 3: A grid of the points checked in the sky as a result of our observations. The blue ones correspond to the points we were about to check, but we didn't manage to collect the spectra of these positions. The red ones we were able to collect, and the green ones we ignored in order to optmize the information about the bubble collected in our observation time. As a result, our grid had around 400 points about the Orion-Eridanus Superbubble.

4 Controlling Leuschner

The whole data aquisition was made by *Python* scripts that tracked, set the telescope functions and saved the data files. A telescope control code worked together with a rotation matrix function, that changed the *Galactic Coordinates* of our points into *Horizontal Coordinates*, so that the dish could track, since the telescope function inputs must be *Altitude* and *Azimuth*. The codes and the math behind it was previously developed for the *Interferometry Lab*, and the details for the matrices contruction and how they were applied is well described by the article on the following link: git hub account, lab_interf folder. With the need of a conversion from Galactic Coordinates, an aditional step was added, making use of the following matrix provided by the casper website:

$$\mathbf{R}_{(\alpha,\delta)2000\rightarrow(l,b)} = \begin{bmatrix} -0.054876 & -0.873437 & -0.483835 \\ 0.494109 & -0.444830 & -0.746982 \\ -0.867666 & -0.198076 & 0.455984 \end{bmatrix}, \tag{4}$$

which is a conversion for the *epoch 2000*. The *PyEphem* and *radiolab* module were used to perform some calculations.

In fact the inverse of the previous matrix was used, and the following matrix operations were applied to get the desired points in the sky:

$$\mathbf{R}_{(l,b)\rightarrow(az,alt)} = \mathbf{R}_{(ha,\delta)\rightarrow(az,alt)} \cdot \mathbf{R}_{(\alpha,\delta)\rightarrow(ha,\delta)} \cdot \mathbf{R}_{(l,b)\rightarrow(\alpha,\delta)}. \tag{5}$$

For the antenna control, besides these modules, the following ones were used: *dish*, *dish_synth* and *takespec*. The first one was used to perform the movements of the telescope, as the tracking and homing, just turning the the noise diode of the telescope on and off, for purposes of measuring the instrumentation noise for data calibration. Only one homing was necessary (in the beginning of each observation), and the tracking was made after finding the position in Altitude and Azimuth, in degrees, for each point of interest. The second one was used to set some values to the dish, as amplitude and frequency for the Local Oscsilator. The LO (Local Oscilator) frequency was 1272.4 MHz, and the amplitude was 10 dBm. The last module takes the data and save in *.log* files, later written with the module *readspec_mod*. At the end of each pointing procedure, we ended up with 4 different files later used to perform the calibration, discussed in the next section. All the codes for tracking and controlling the Leuschner dish can be found here.

5 Data Calibration

In order to measure the column density by anylising the HI line profiles, we first treat the data using the 4 files created for each point. They were the *Noise_On*, *Noise_Off*, *Spectra_On* and *Spectra_Off*, meaning that we took 2 spectra profiles: one 'On' our target line, and another 'Off' by -4 MHz. Together with these 2 spectra measurements, we recorded a noise for both instances, hence *Noise_On* (recording the noise 'On' the spectra) and *Noise_Off* (for the case we are off by 4 MHz).

The math to calibrate the data is presented on the handout provided by the Radiolab instructors, *Calibrating the Intensity and Shape of Spectral Lines*, by Carl Heilies. Severall steps were performed by using the so called *cool method*. Basically, with all these measurements, if we plot them on a same figure we end up with 2 distinct peaks, and they are off by the value set on the data aquisition for the LO (4 MHz), where the 'On' measurements are around the value of 1420.4 MHz, as expected. Besides them, we have 2 spectra of the same profiles but with much higher intensity values. These are the noise values, used to calibrate the HI profile by correcting the instrument temperature.

5.1 Final Image

6 Conclusion