Hydrogen Emission Lines and the Orion-Eridanus SuperBubble

Eduardo Herrera

May 6, 2014

Abstract

Examining the emission of Hydrogen (the H1 line) and using the Leushner telescope we were able to take data for about points from the Orion-Eridanus SuperBubble. Using the calibrated data sets for these points, an image of the Super-Bubble could be resolved, albeit at about half the resolution originally intended due to hardware and organization problems leading to lack of time. From an analyzation of this image we can see the different column densities of the Hydrogen where a bubble structure confirms that it has been expanding and we can also see the feautures of the bubble such as thicker clouds of Hydrogen gas around the circumference of the bubble (around 7 cm^2) present there whereas near the center of the bubble a thinner layer of gas is observed as evidenced by the color intensity of the column densities calculated for the bubble. .

Introduction

The Orion Super-Bubble is the remnant of a supernova and the stellar winds that resulted from it. Due to this explosion, a shock from the original supernova pushed dust and gas outward. As a result of there is an empty space that is surrounded by a wall of gas previously mentioned. The surface of this bubble has neutral gas and contains some features that indicate that there is ionized gas that emits synchrotron radiation. Hydrogen emission is critical to revealing the structure of our Bubble, because the 21 cm line for Hydrogen can easily pass through the interstellar medium present between the Bubble and the telescope, additionally, the vast amount of hydrogen present in the Universe makes this method of observing objects the most preffered. For this project, the Orion Super-Bubble, covers latitudes from -10 to -70 degress in galactic coordinates and longitude of 160 to 220 degrees, covering a total of 2800 degrees of sky.

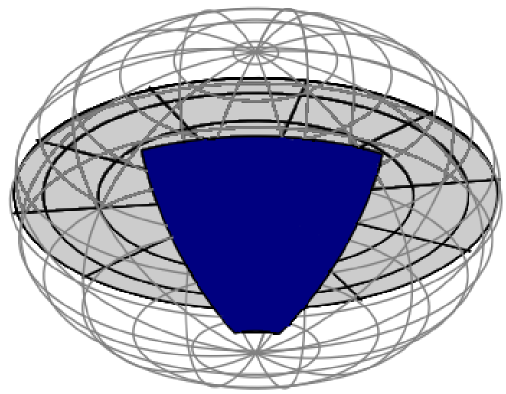


Figure 1: A 3D plot of the total amount of sky that the Orion SuperBubble covered that in turn could be observed by the Leuschner telescope at 2 degree spacings. A 2800 degree area in the sky; taking up about a fifth of the sky this meant the possibility of taking up to 700 pointings.

Due to time constraints caused by the class's groups (procrastination), not all of the 700 pointings could be covered. Results of our observations include a half resolution image of the Super-Bubble. The following section discusses the observer for all of our data, followed by the process by which the raw data was calibrated to produce a final spectrum for the Hydrogen line observed. Then a section on the techniques used to image the SuperBubble and an analyzation of the physical features of the Bubble follows.

The Leuschner Telescope

In regards to the telescope, we used the Leuschner telescope, with a dish diameter of 4.5 meters. Since we are observing the 21 cm hydrogen profile, then the resolution of the dish is $\theta = \frac{\lambda}{D}$, $\theta = \frac{.21m}{3.6m} = .0583$.

Present between the galactic latitudes of -10 to -70 degrees and 160 to 220 degrees longitude, the Orion Super-Bubble spans an area of 2800 square degrees originally it was planned to take measurements at points 2 degrees apart so this meant making 700 pointings for which we would need data. Hardware issues on the telescope as well as a lack of organization could only allow about half of these pointings.

How Information Reaches the Telescope

When the telescope is pointed to a source, photons from the source will get to the telescope and be reflected by the dish and into its detector. The telescope measures the intensity of the object, meaning that a time interval between observations over some area of the sky. In tensity is measured by Energy per time per area. The intensity at which the telescope gathers data is $I(\nu) = \frac{2k_B T}{\lambda^2}$ because $\frac{h\nu}{k_B T} << 1$. Our hydrogen, when excited, is at a relatively high temperature compared to other things reacting to heat. One important aspect of specific intensity when observing a source is that $I(\nu)$ is constant along the ray's path. This has the consequence that the specific intensity of the 'lens' of the telescope is equal to that of the source, independent of distance, $I_{scope} = I_{source}$. Since the sources in the sky have some differences in their frequencies there is a temperature dependence as well, so we can then define intensity in terms of a temperature, a *brightness temperature*, $T_B = \frac{I(\nu)}{2k_B}\lambda^2$ but in general this temperature is not equal to the temperature of the source, the brightness temperature merely characterizes the object from its emitted intensity. Another temperature to take into account is the *antenna temperature*, which when the telescope's beam is larger than the object it attempts to take measurements from, is defined as $T_v(\nu) = T_B(\nu)(\frac{\Omega_{source}}{\Omega_{source}+\Omega_{beam}})$

Coordinates and Pointing Strategy

Again, the use of rotation matrices was key to get the telescope to point at the appropriate sources, but fortunately compared to the last lab, we only had to account (on top of the previous code from the last lab) for galactic coordinates which treats the sun as the origin of its polar coordinate system, a primary direction toward the center of our own galaxy, and its plane in line with the plane of our own galaxy, this system makes finding objects within our own galaxy easier.

In order to keep as much time as possible for the observation of our points, we chose to use the rastering strategy. This involves the telescope sweeping across the sky stopping at its designated observing points when necessary. When the script was at the end of a sweep it would simply go down to the next point below the one it had just taken data for instead of sweeping back over (much like a typewritter). This would then save time for taking on more points.

On a more technical level, we needed to choose two local oscillation (LO) frequencies, one that was at 1272.2 MHz and the other that was shifted off by 4 Mhz at 1268.2 MHz The reason we chose these values was to alias the Hydrogen line making it easier to discern it from the data when we opened it. The reason we shift this frequency is to use the noise diode onboard the telescope to increase the amplitude of our measurements, which are weak sources for the most part. The noise measurements are made for both times when the LO frequency, but because of the noise, there will be large spikes in the data mostly due to the first amplifier present on the telescope, before anything can be done, it must somehow get cleaned.

Treating the Raw Data

In calibrating our raw data, we see 4 continuum spectra with spikes that present the hydrogen line. But this data is riddled with spikes as a result of the amplifier making a lot of noise in the data, making any attempt to add the spectra worthless since the original data with the hydrogen line could be wiped out when added and averaged across other smaples. To get rid of these samples, a box-car average over this data is needed to get rid of the spikes and have some good data to work with for the later step of convolvement into a final spectrum for each data set. Instead of a mean, we take a median between every few points making sure the bin does not exceed the width of the observed Hydrogen spike, otherwise the box car average would interpret the spike as the noise we are trying to measure and flatten it out. As a result of using a good cleaning code is, the following.

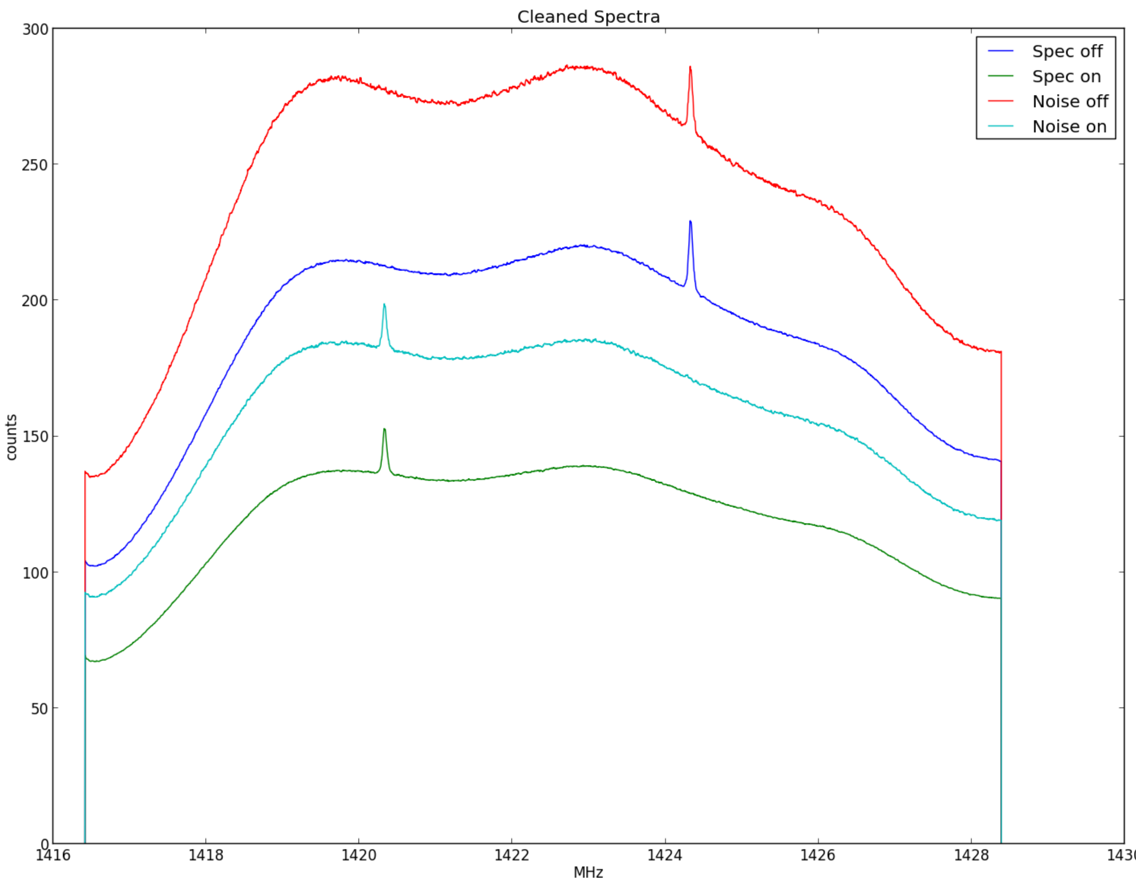


Figure 2: after using a reasonable size for the bin to take the median, we get a spectrum that cuts down significantly on noise, to clarify on lalbels, spec off and on refer to the LO frequencies being on the value we originally chose and shifted off, respectively. As for noise off and on, both mean that the noise diode was turned on for both cases of the LO frequency being either on or off target, no noise diode was ever turned off.

Regarding the calibration time, the Bubble only required about 22 seconds of calibration time, τ, at first it may seem that we need more than that to get a higher resolution for an image. But a look at the radiometer equation shows

$$\sigma_T = \frac{T_{sys}}{sqrt(B\tau)} \tag{1}$$

The important thing to note is that when we measure with the noise diode on, to achieve the same temperature brightness resolution, we do not need to integrate as long since B, the bandwidth takes care of the noise measurement made, now instead of worrying about a bin to bin basis, we use the whole 12 MHz available to us so that our integration time is lowered to meet the same brightness temperature resolution. This should also lower the noise level as we do increase integration time by an inverse factor of $\sqrt(\tau)$.

Calibration

With cleaned data, a calibrated spectra is now possible to get. Because of the noise diode is there to build up the calibrated hydrogen line; to give both the original LO and the shifted LO an increased amplitude. Because we were able to invest the time, our group went for the 'cool' method of getting calibrated spectra out. First, we may assume that the Temperature of the noise diode $T_{noise} = 100$ is a constant. Next we create a Y factor for both the LO frequencies consisting of the sum of noise measurements and on spectrum measurements, which also looks similar for the off measurement frequencies. What the Y factor is though, is the our noise on measurement, which is equal to the temperature of the system plus the temperature created in the telescope by the noise diode, so that $Y_{on} = 1 + \frac{T_n}{T_s}$ and by analogy the o Y factor for the off measurement is similar to the previous equation. With these Y factors, we can then solve for the temperature of the system for both the on and off measurements. One additional thing is the ratio of the gains, equal to the division of the sums of the spectrum of the measurements with the two LO frequencies. With this we must re-define the spectrum measurements by multiplying the original spectrum measurements by the gain ratio. Here we divide the new spectrum measurements while not dividing out the hydrogen line feature, this allows for the flattening of the noise measurements while keeping the structure of the hydrogen lines. Additionally we must add them together and divide by two to get the average of the summed hydrogen lines, and thus we get a calibrated spectrum as shown.

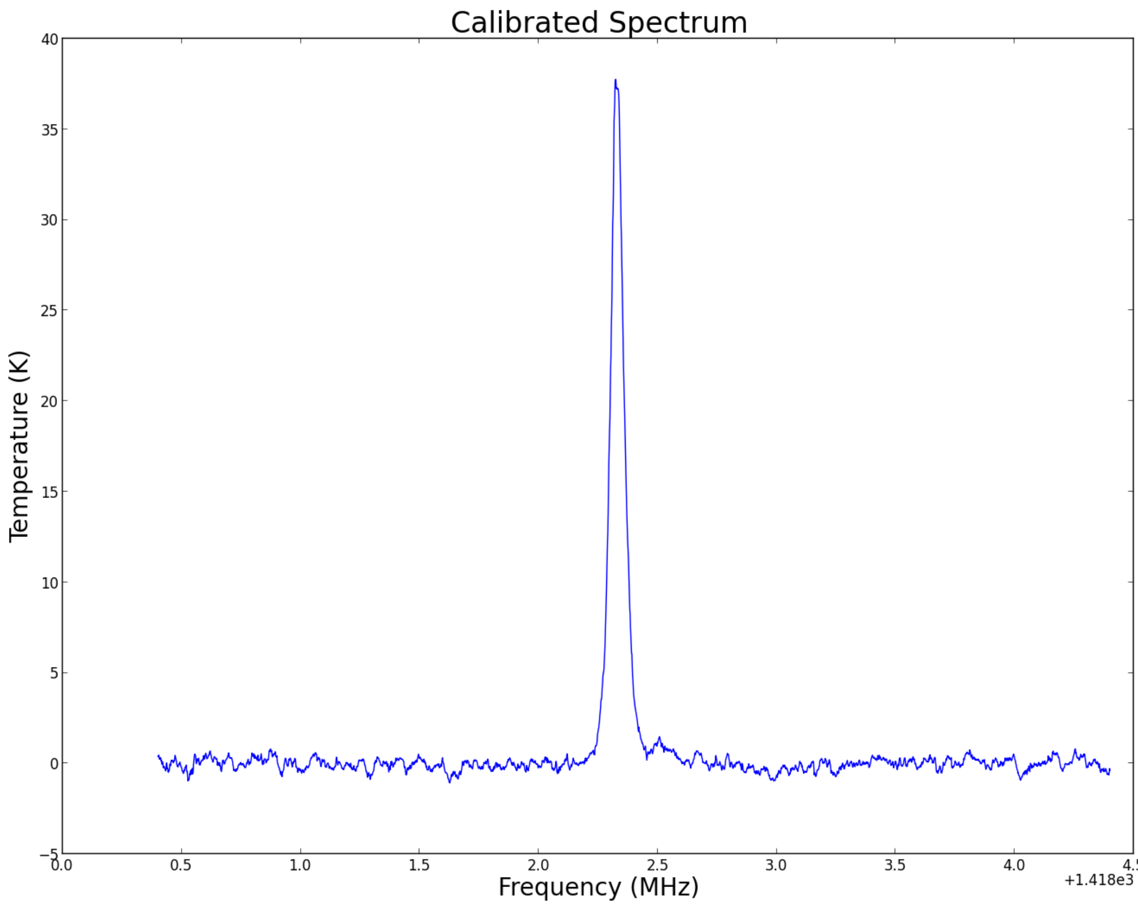


Figure 3: An example of a calibrated spectrum for one data point in the Orion Super bubble, it looks like a sharp spike, most look like this, but there are others that exhibit the feature of a double spike in the calibrated data, this is telling of seeing contributions from both the front and the back of the bubble; a doppler shift of the expanding bubble, showing both a red shifted and blue shifted spectrum on the same line. As for this more common spectrum, a single spike may come from the edges of the bubble where from our point of view the gas is expanding perpendicularly, no shift.

Imaging the SuperBubble

After all of the individual data points had been calibrated and saved to one file, there still remained to plot the image across the area we had abserved it from in galactic coordinates. To achieve this, we needed to take the data forms of the file; longitude, latitude, and the spectrum. And manipulate the data points so that they would be put on a 1000 by 1000 resolution image. Not only that but since we only have a few points to work with, we would have to interpolate all points with one another by using a gaussian that depended on the points themselves and some arbitrary number of pixels for which the gaussian would convolute over. First by creating two grids, one for which your points will fall into the image and the other for the weights that the gaussian will be convolved with. To plot the points, an array of zeros must be implemented as well with the weights, for every latitude coordinate, set the weights equal to one for points that will otherwise be empty. After populating the other points with your data, then you have a grid with your points surrounded by what seems a sea of blue. The gaussian is set to take in the points that happen to be there so that points containing data points will be more convolved than areas barren with points. After compiling the image one must take note that the axis for the longitude are not exactly accurate, since we are in polar coordinates, the vertical axis must be adapted to fit the curvature.

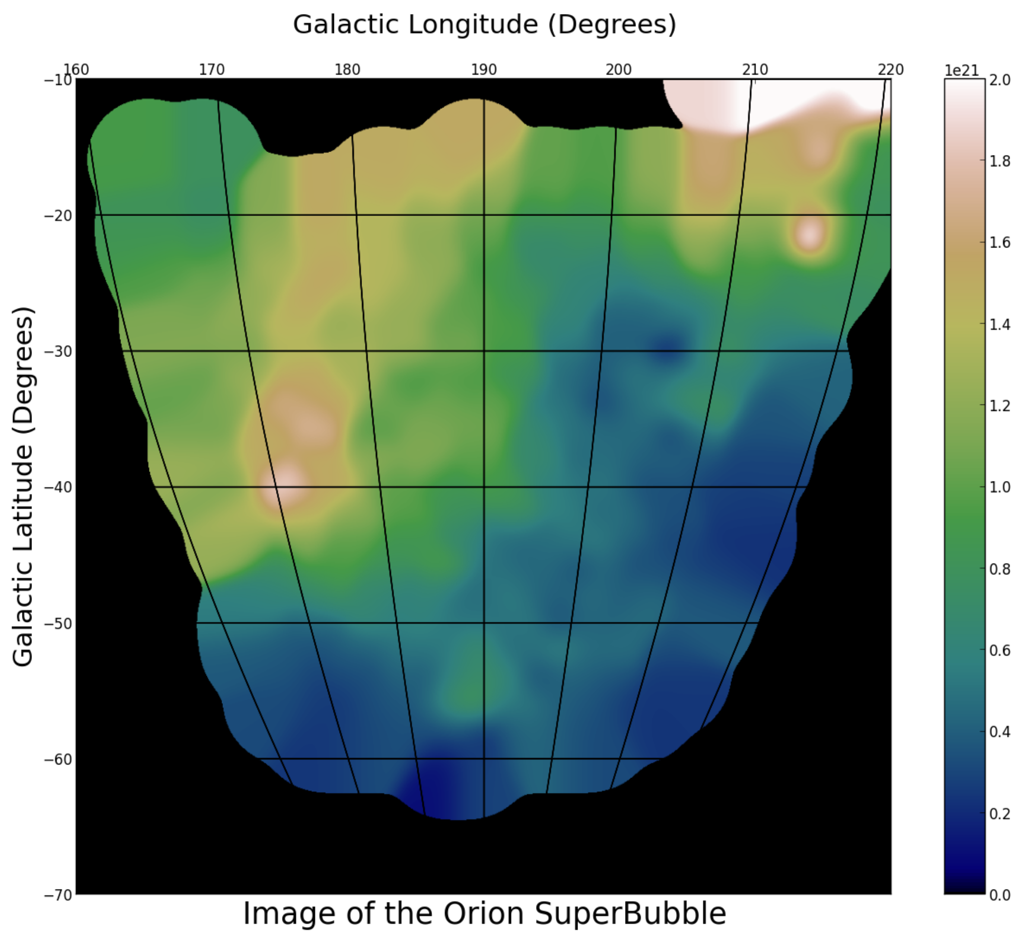


Figure 4: The Final image of the Orion superbubble consistent with other researchers, a hollower area inside with thick walls of hydrogen surrounding the bubble

Comparing the above image to the one taken by 'The Orion OB1 association' headed by A.G.A. Brown, D. Hartmann and W.B. Burton from the Netherlands, we see that they have a wider area of observation with larger resolution. Flipping their image and concentrating on the area corresponding to ours.

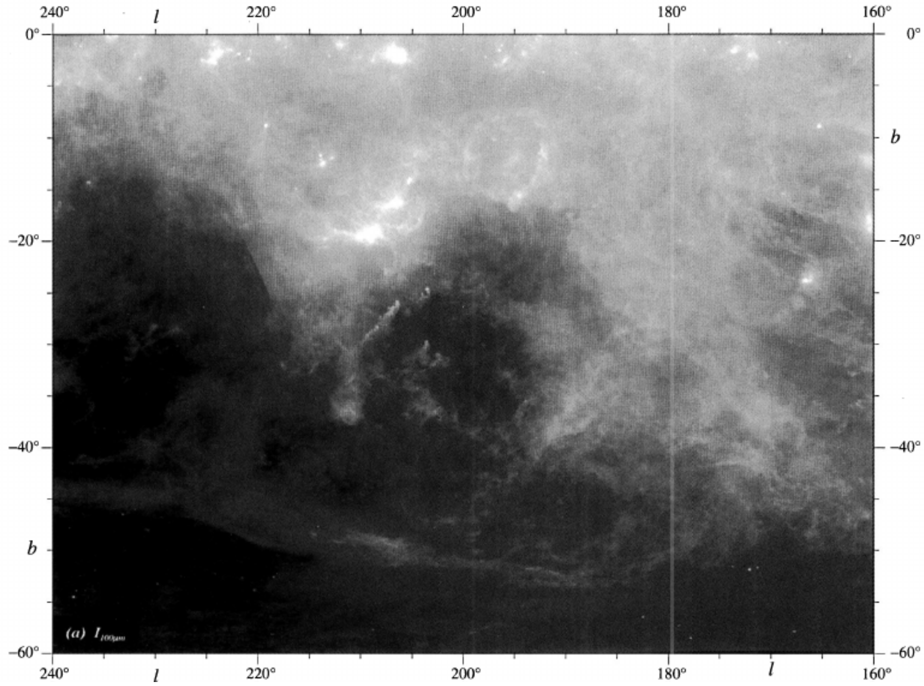
orion.png 

Figure 5: a comparison with an image taken by A.G.A. Brown et al.: 'The Orion-Eridanus Bubble'. As we can see if this image were flipped and concentrated around latitude -30 and -200 degrees, we can see that our image matches up well at least in shape, and we can see a bubble structure surrounded by gas.

The Bubble's Column Density

The column density tells us how much gas there is per square centimeter to have calculated we needed to have every element of the spoectrum be multiplied by $1.8 * 10^{18} * 12000khz/(8129channels * 4.73khz)$ to give us the column density on order of one to two $1e21cm^{-2}$.

1 Conclusion

We can see that the bubble has a lower density around the coordinates of -35 latitude and 200 longitude, as does the the diagram from A.G.A. Brown. Even with less than half resolution, we were still able to make an image that has evidence of a bubble in the middle.

Acknowledgements

A.G.A. Brown et al.: 'The Orion-Eridanus Bubble'