Intensity Mapping of The Smith Cloud

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Introduction
The Smith Cloud was first discovered by Gail Bieger, née Smith in 1963. It is a high velocity cloud of hydrogen gas that contains enough mass to form a million suns. The cloud is a 11,000 light-years long, 2,500 light-years wide, and is moving towards the galaxy at a speed more than 62 mile/s or 100 km/s. (http://www.nrao.edu/pr/2008/smihcloud)

How does Radio Astronomy Work?
Radio astronomy uses large dishes, called Radio Telescopes, to observe electromagnetic radiation from objects in outer space. When observing, there are many different ways of locating where these objects are in the sky. One way is Galactic Longitude and Latitude. The galaxy has its own longitude and latitude, similar to how Earth has longitude and latitude.

Longitude (l) runs along the plane containing the center of the galaxy and the Sun. Latitude (b) runs perpendicularly to the latitude and goes through the sun. Using these coordinates, we can tell the telescope where to point. Once the telescope is pointing there, it is set to look at a certain frequency. We can change the frequency, almost like changing the station on your radio. Essentially, it represents how strong the signal is in the area. Additionally, we can also calculate the velocity of the gas that corresponds to the area by using the Doppler Effect Equation: \( V_{\text{vel}} = \frac{c \cdot f - f_{\text{local}}}{c} \) /1420.41. This equation gives us the velocity at a certain frequency. We can change the frequency, almost equally to the latitude and goes through the sun.

What is \( V_{\text{LSR}} \)?
\( V_{\text{LSR}} \) is a velocity relative to the Local Standard of Rest. This is important because if your data is not corrected to \( V_{\text{LSR}} \) then your data cannot be compared to other data at another time or to another telescope on our planet. If you observe an object one day, and then take the same observations the next day, you will get different velocities when you do your calculations. So to compensate, \( V_{\text{LSR}} \) is a standard to which you can compare your data no matter when it is taken.

Objective
Our objective is to refine our method of calculation and expand our area of observation into lower density regions that are much more difficult to analyze. This will push our equipment and methods of analysis closer to their limit of sensitivity and will give us a better understanding of our capabilities with this telescope moving forward. Finally, we will map our results against data taken from The Green Bank Telescope to check for accuracy.

Procedure
We used a 20-meter Radio telescope at the Green Bank Observatory, Green Bank WV, to collect data. We accumulated data in 360 second intervals, recording 4096 different frequencies at a time. Since the Smith Cloud is composed mostly of hydrogen, scans were run around the 21cm band, centered on the 1420.41 MHz frequency. When an observation is run with the telescope, it scans a 0.5 by 0.5 degree block in the sky.

This year, our observations occurred in a 16 block ring from (l 37, b -12) to (l 39, b -14). This is a 1 block outward expansion upon last year's data in a 9 block box from (l 37.5, b -12.5) to (l 38.5, b -13.5). The area observed last year was mostly a high density area of The Smith Cloud. This made it easy to see if our data was correct, as it would have a very high intensity to match. This year, we expanded one block outward. Our new area contains equally dense blocks as before, but also contains blocks that are almost off, or are completely off the cloud.

Pictured above is a graph of partially processed data from the telescope. These sets are already calculated from frequency into velocity, and corrected for \( V_{\text{LSR}} \). On the right graph, the signature of the Smith Cloud is easily visible and provides simpler analysis. This graph is more analogous to what was observed last year. The graph on the left is of a block located almost completely off The Smith Cloud. It is almost impossible to visually see the signature of The Smith Cloud, so our analysis has to be spot on. This necessitated the improvement of our calculation.

Part of the calculation method is subtracting out the background radiation of the Milky Way, only leaving the Smith Cloud intensity. In order to do this, we cut out the signature of the Smith Cloud, graphed the remaining data points, and generated a best fit line from the data to get a quadratic equation. This background equation is then subtracted from the remaining data and would isolate the Smith Cloud. However, this ended up not being the most accurate method. Limiting the background radiation equation to a quadratic function does not give it enough parameters to properly fit the data. This can be seen above as the best fit line sweeps above a section of real data points.

To determine what the next best equation was, we took a set of real data and used Excel's LINEST function to generation equations of 5th, 4th and 3rd order polynomials. It was determined that a 5th order equation gave the best fit for the background and allowed for higher precision work on lower density regions. Additionally, we were careful with the danger of over-fitting in choosing such a high order equation to generate. While analyzing the equations, we took the derivatives through Wolfram's Mathematica programs and checked for inflection points. The equations only had one inflection point, which meant the generated line was not over-fitting, and was not oscillating back and forth with the data. All of the data, both new and old, was refit using the new background equations.

Conclusion
From our results, we were able to deduce that the method of mapping that we used this year was an improvement on the method we did last year as we are able to analyze lower density regions. Additionally, through analyzing such lower density regions we were able to find a sensitivity limit of 12.3 K for the 20-Meter radio telescope.

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References