Draft version April 9, 2021
Typeset using LaTeX **twocolumn** style in AASTeX63

ASTR 469 Project #1: Green Bank HI Data

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ABSTRACT

We aim to use data from M33, the Triangulum galaxy, taken from the Green Bank Telescope in 2017 to analyze the HI line. This data was analyzed to determine that the galaxy is spinning counter-clockwise in relation to the observing position while the entire galaxy is moving towards the observer. From this data, the mass of M33 was was determined to be around $10^{11} M_{\odot}$. Moment analysis was also done in order to interpret the nature of the 3-D data.

Keywords: Radio astronomy – Spectroscopy – HI line emission – Doppler/gas dynamical effects – Regression and error analysis

1. INTRODUCTION

The study of galaxies has been a very important field to astronomy. External galaxies have provided us with an better understanding of our own galaxy, and the life-times and life-cycles of such objects. For example, work and topics such as Dickinson et al. (2019). While the study of galaxies can get very in-depth and can be very complicated, for the scope of this introductory project, we focus on fundamental concepts which help expand one's knowledge on the subject and methods which are used for data analysis. For this project, we will be focusing on galaxy displacement, rotation, mass and spectrum analysis.

2. METHODS

2.1. *Imaging the Data*

To image the data, the software package "DS9" was used. With the input of a fits file, the program takes the data and visually represents it in a way that makes it easy to analyze. From this software, a plot is made of a 2-dimensional image at each velocity according to its spacial coordinates. Since this program gives the specific velocity of the galaxy at every point, we are then able to determine the general velocity of the galaxy, and we are also able to determine the direction with which the galaxy is rotating, by looking at which side of the galaxy appears at more negative velocities and which side appears at more positive velocities.

2.2. *Data*

The data used for this project were collected using the Green Bank Telescope during a ASTR469 class trip back on March 13, 2015. The data cover approximately

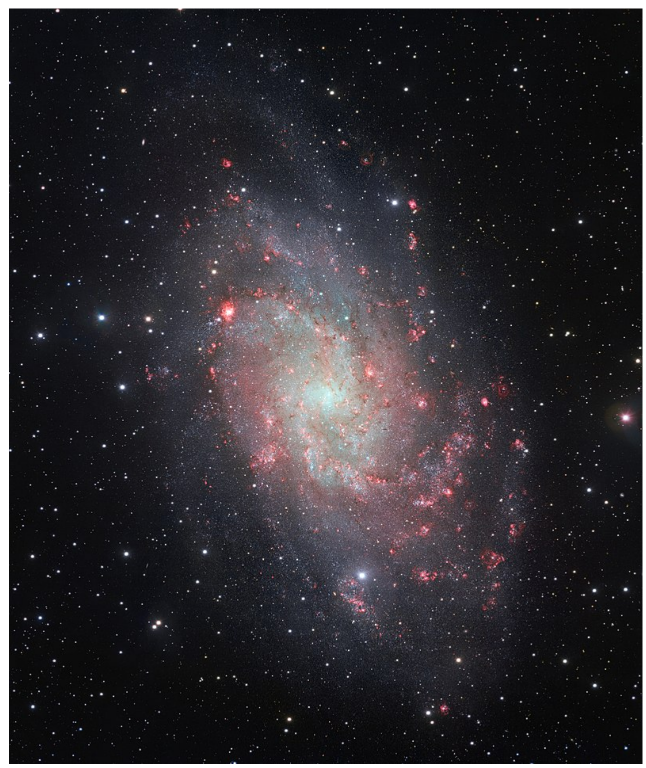

Figure 1. Galaxy Messier 33 in Triangulum.
Credit: VLT Survey Telescope, Atacama Desert, Chile.

$1^{\circ} \times 1^{\circ}$ of the M33 galaxy, otherwise known as the Triangulum galaxy with J200 coordinates of right ascension: 133.610278, and declination: -31.330903 (Skrutskie et al. 2006). HI, atomic hydrogen, was observed at 1420 MHz, which is where the HI emission line lies. This line is caused when the electron flips from spin-aligned with the proton to spin anti-aligned. Although this occurs very rarely in a single atom, the observation

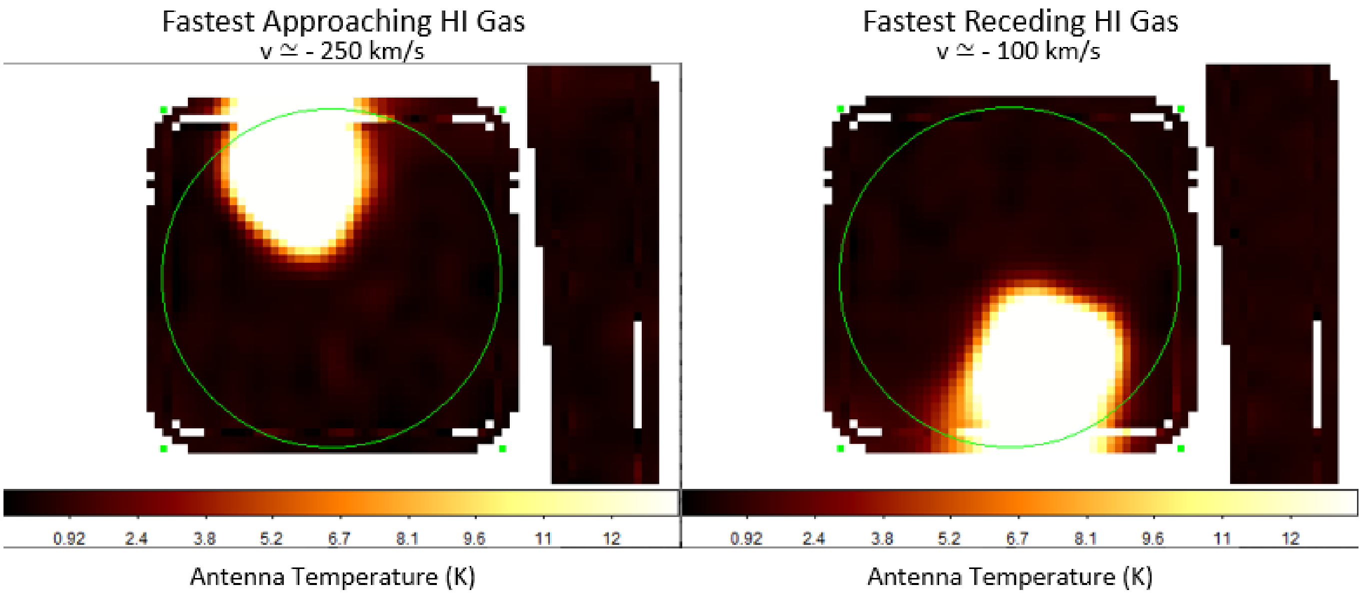

Figure 2. The above data shows the fastest receding HI gas and the fastest receding HI gas from the M33 Galaxy.

line is very strong due to the sheer abundance of hydrogen. For this project, the data were obtained from the "Projects" folder in the course Overleaf document, as a file name "M33_CUBE_K.FITS". The data were created by scanning the Green Bank Telescope across the location of the galaxy and created a 3D data cube with two spatial axies for right ascension and declination as well as a frequency axis. As the telescope scanned the sky, it observed at a single spatial location and each spatial location was then be combined to create a data cube. The data were acquired in units of "antenna temperature" in Kelvin and was initially taken in frequency-space which was then converted to velocity using the formula for Doppler shift:

$$\frac{\Delta\nu}{\nu} = \frac{v}{c} \tag{1}$$

Where negative velocities mean that the gas is blue-shifted and moving towards the observer while positive values mean that the gas is red-shifted and moving away from the observer.

3. RESULTS

3.1. *Galaxy Displacement*

After analyzing the data in "DS9" we were able to determine the overall displacement of the galaxy. By understanding that the galaxy as a whole has a negative velocity of approximately -200 km/s which is close enough to the current most accurate measurement of -179.2[1.7] km/s (McConnachie 2012), this means that the values for the gas is blue-shifted and therefore that the galaxy as a whole is moving towards the earth.

3.2. *Galaxy Rotation*

By isolating the values only for the galaxy itself, we were also able to determine how the parts of the galaxy are moving with respect to the itself as shown in figure 2. It is then possible to determine that the galaxy rotates counter-clockwise with respect to the observing position as we observe that the top left of the image has a more negative value for velocity which signifies a relative blue-shift in the gas at that position, therefore meaning that this part of the galaxy is moving towards the earth at a velocity of approximately -250 km/s. It is then observed that the bottom right of the galaxy is red-shifted and moving away from the earth at around -100 km/s, therefore indicating the counter-clockwise rotation which is demonstrated in figure 3.

4. DISCUSSION

4.1. *Spectrum Analysis*

By analyzing the spectrum given in figure 4, we notice the "double horned" peak which indicates the typical spectrum shape that we expect to see for a galaxy such as M33. This shape is indicative of the velocity of the different parts of a galaxy. The first peak represents the first spiral arm of the galaxy which is moving towards the observer, the middle part indicates the entirety of the galaxy which is overall moving towards the observer and the last peak represents the gas that is rotating away from the observer however still moving towards the observer as a whole. The clear peak towards 0, represents the gas in our own galaxy. We know this because it is not moving away or towards us, which indicated that it

Figure 3. Direction of Rotation of Galaxy M33 in Triangulum.

is not an object with a separate motion than the Milky Way.

By eye, it appears that M33 emits in the velocity range of -250 km/s to -100km/s, with a central velocity of 200 km/s which agrees with the accepted value of -179.2[1.7] km/s (McConnachie 2012). The blue-shift can then be calculated using equation 2.

$$z = \frac{v}{c} \tag{2}$$

$$z = \frac{-200km/s}{c} \tag{3}$$

$$z = -6.6 \times 10^{-4} \tag{4}$$

4.2. *Galaxy Mass*

It is possible to determine the galaxy's mass from the data we have taken. First, we start by estimating the width of the HI in M33 from figure 4. By eye, it is estimated that the width of the H1 from the M33 galaxy is of approximately 200 km/s. However, this is not the true velocity since the galaxy is inclined with respect to our line of sight. In order to correct for this, we use the formula:

$$v_{true} = \frac{v_{obs}}{sin(i)} \tag{5}$$

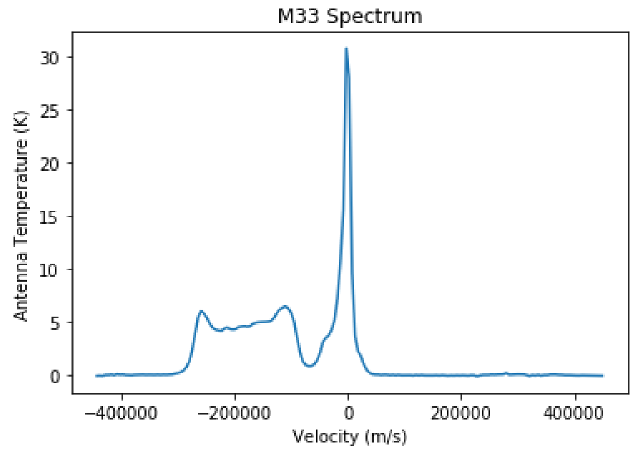

Figure 4. Spectrum of M33 plotted in Python

Where i = 55°

$$v_{true} = \frac{200,000m/s}{sin(55°)} \tag{6}$$

$$v_{true} = 244,154.92m/s \tag{7}$$

We can then use the relationship between HI velocity width and galaxy mass known as the Tully-Fisher Relation (Tully & Fisher 1977) to find the mass of the galaxy. From this relationship, we are able to determine that the mass of the M33 galaxy is around $10^{11} M_\odot$ which is larger than the accepted value of $5 \times 10^{10} M_\odot$ (Corbelli 2003). This disagreement in the values is most likely due to the estimation of the width of the galaxy's velocity rather than using an exact value. Because this estimation could be off by tens of thousands of meters per second, it is most likely the biggest cause of error in the calculation of the mass. Another source of error could be due to the human nature of looking at the graph of the Tully-Fisher Relation and manually aligning the data to find the mass. Because of the manual nature of this process, error could have easily been introduced, and the estimation could be off by up to an order of magnitude. It is also possible that the data taken by the GBT were not processed in the most efficient way which would result in a certain amount of error being introduced in the data. Any other error such as any type of noise and radio frequency interference would be negligible compared to the size of the potential error introduced above.

4.3. *3-D Data*

In order to visualize 3-D data, we must find a different method which is able to look at things differently and describe the data in a way which is comprehensible for humans. This is why we use the moment analyses. We first start with "Moment 0", which is the integrated

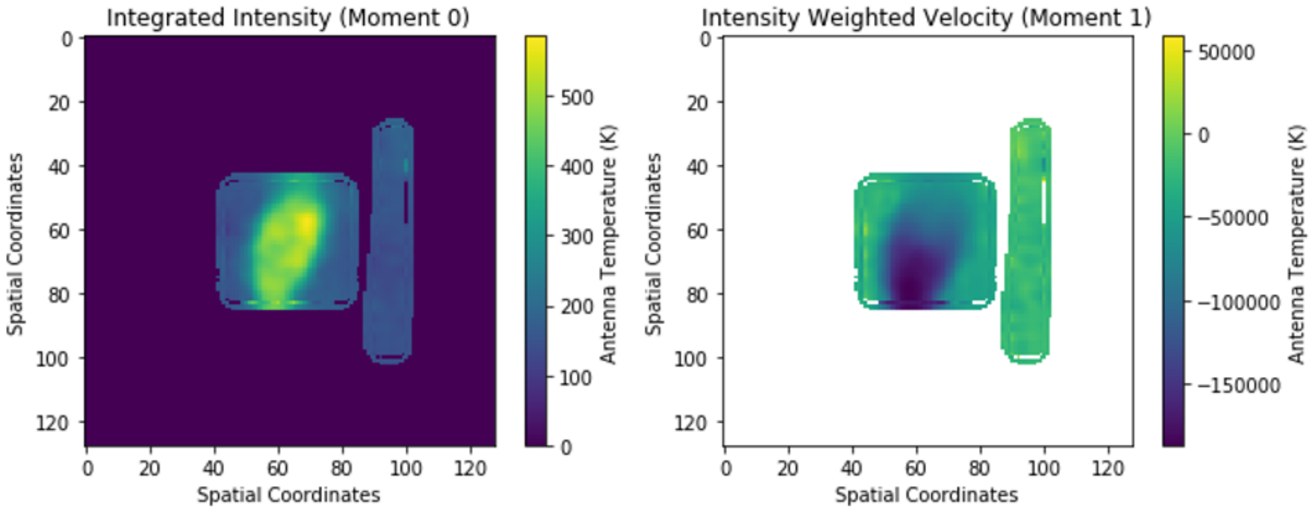

Figure 5. Figure 5 shows the integrated intensity of the M33 galaxy in the left panel, and in the right panel shows the intensity weighted velocity.

intensity. This means that we are taking all of the intensity for the observation and creating an image indicating the total summed intensity for every single velocity. The units on both axis of the graph are spacial coordinates, while the color in the graph indicated integrated antenna temperature in kelvin as shown in figure 5.

It is then also possible to look at the data by plotting the intensity-weighted velocity. This means that the plot shows the highest intensity of velocity at each spatial location. Therefore indicating the fastest moving point at each location in the sky. The units on both axis of the graph are spacial coordinates, while the color in the graph indicates the antenna temperature in kelvin at the highest intensity velocity as shown in figure 5.

5. CONCLUSION

From our results, we conclude that it is possible to determine the overall movement of the M33 galaxy, as well as it's relative rotation. From this data, the mass of the galaxy was also determined to be higher than previously thought, however, as our methodology is not as rigorous as previous studies, still lies within the margin of error. Overall, we have successfully analysed the HI data in order to reach the goals set out by this project.

6. ACKNOWLEDGEMENTS

This work was supported in part by my parents who are paying my tuition.

APPENDIX

Facilities: Green Bank Observatory

Software: numpy (Harris et al. 2020), matplotlib (Hunter 2007), pandas (Wes McKinney 2010; Reback et al. 2021)

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