

ASTR469: Project #1, Green Bank HI Data!

Due 3 April by class time.

This project will focus your skills with the following concepts:

Radio astronomy; Spectroscopy; HI line emission; Doppler/gas dynamical effects; Regression and error analysis; Unix; Python; LaTeX; Observing basics (coordinates, time).

We will have three in-class sessions (including this one) to work on this assignment. I am here to help. You are welcome to work on your data at home if you have a capable computer, or come outside of class time to work on your data in the computer lab. Remember to shut the door securely if you leave the lab.

Submission: Projects must be written in LaTeX using Overleaf (use documentclass *article*). Submit projects via email to sarah.spolaor@mail.wvu.edu — to share your project with me, click “share” in overleaf, turn on link sharing, and send me the editable link. Do not edit your project after submission (note: change history is tracked in Overleaf files!).

Description: We have been discussing M33, the Triangulum galaxy, and those of us who went to GBT actually scanned the galaxy to make a frequency-resolved map of it using the VEGAS spectrometer. Our scans covered about $1 \text{ deg} \times 1 \text{ deg}$ across the galaxy. We had one spectral window observing around 1420 MHz, so we were able to catch the 21cm neutral hydrogen emission line.

For this first project, I will provide a step-by-step guide. In future projects, you will be increasingly independent.

Project tasks:

1. Download the data:

<https://sarahspolaor.faculty.wvu.edu/classes/astr469>

The file with a “.fits” extension is a standard astronomical data format (fits, Flexible Image Transport System). This file is a 3D “data cube” with two spatial axes and one “redshift” axis. We created it by scanning the telescope across the galaxy with the VEGAS spectrometer. Myself and DJ Pisano calibrated the data.

The units for the cube data are antenna temperature, in K. The “redshift” axis is velocity in m/s.

2. Image the data.

Use a program called “DS9”, which reads fits image files. This should already be installed on your machines. At the terminal type:

```
>> ds9 &
```

then navigate to open one of the files. The velocity slider allows you to step through different parts of the velocity axis while the image shows in the main window. Which way is the galaxy rotating? **Make images showing the fastest receding HI gas and fastest approaching HI gas.** By drawing and moving around a small region via click+drag, you also can see the spectrum of the galaxy in different localized spots in the galaxy.

3. **Produce a summed spectrum of the whole galaxy.** Draw a large region on the image; this will show you the summed spectrum from the entire data cube, thus giving you all the velocity data across the whole galaxy region. It should look familiar! Save this spectrum using the file menu in the spectrum display. This exports the spectrum as a text file. You can look at it on the command line:

```
>> less filename
```

Save this spectrum using the file menu in the spectrum display. *Note: if the spectrum doesn't automatically pop up after drawing a region, double click on the region, then in the dialog that pops up go to "analysis" then "3D."*

4. **Plot the spectrum in Python.** I suggest making a python script in Emacs, or you can run the below at the python command-line prompt. To import a space-delimited text file to a python list:

```
>> from numpy import genfromtxt
>> m33spec = genfromtxt('filename',delimiter=' ')
>> print m33spec
```

If you run this, it should print the GBTspectrum data imported as a python list. The list is a 2D list (velocity, temperature); here is how you get a plot from a 2D python list, assuming you've imported matplotlib. This plots axis 0 on x-axis and axis 1 on y-axis:

```
>> plt.plot(m33spec[:,0],m33spec[:,1])
```

Remember your other python commands for plotting! **Produce a spectrum for your report — and be sure to add axis labels and units!**

5. **Analyze the spectrum.** Last lecture in the preparatory exercise you did some regression analysis of the Milky Way emission. Include in your report a description of the main features of the spectrum you just plotted. What is the mean velocity and velocity width (the μ and σ of your fitted Gaussian) of the Milky Way emission in this direction? Include the errors on μ and σ and a report of the χ^2_{red} of the fit, as reported by gnuplot/python. By eye, at what velocity range does M33 emit? What is the central velocity of M33 (estimate the center of the galaxy's distribution, or average your max and min line range values)? Compute the red/blueshift of this galaxy based on the observed central velocity. Does your outcome agree with the (red/blue)shift of M33 that you found previously?
6. **Determine the mass of M33.** In class, we spoke about how several effects can cause lines to not look perfect and narrow (gas is hot, galaxy is rotating so traveling at many different velocities, etc.). In this case, M33's HI line looks so broad because it's a big, rotating galaxy. The half-width of the line gives its "velocity half-width." Note that this galaxy is inclined compared to our line of sight, so the true velocity half-width of the galaxy (rather than the observed one) can be found with:

$$v_{\text{true}} = \frac{v_{\text{obs}}}{\sin(i)} \quad (1)$$

Where the inclination angle of Triangulum $i = 55^\circ$.

For HI, there is a well-known relationship between the HI velocity half-width and the galaxy mass. It is called the “Tully-Fisher Relation” (Tully & Fisher, 1977). A plot of this is shown below in Figure 1. Based on this plot, what is the mass of M33? Compare your value with the published value, which is around 50×10^9 solar masses.

7. **Write up your project.** Your writeup should include basic observation details (the target, its coordinates, the observing date, the telescope, frequency range, and number of frequency channels used to observe it). Like any real astronomical publication, the write-up should generally describe your process: include relevant equations and figures with captions (I’ve noted in bold in the above which figures I expect to appear, at a minimum). Include sections like *Introduction*, *Observations/Data*, *Analysis/Results/Conclusions* (create your narrative as you see fit). Interpret the results to the best of your ability. Don’t worry overly about LaTeX formatting for this assignment; I will mostly grade on whether you included all the components above and the correctness of what you write. We can work on making things pretty for later assignments. For the ambitious: optional bonus points will be given for additional creative analysis insights and other aspects like making the spectrum’s x-axis with in more sensible units (km/s), and properly using LaTeX citations. **Excluding figures, a suitable length for the words in this project in `\documentclass{article}` format would be 1–2 pages.** Before you turn in your project, ask yourself:

- Did I include at least plots of the full spectrum, and at least two galaxy velocity images?
- Do my plots actually show up in the compiled Overleaf pdf file?
- Did I address all questions asked in each point above?
- Did I include an equation for at least the redshift calculation that I did?

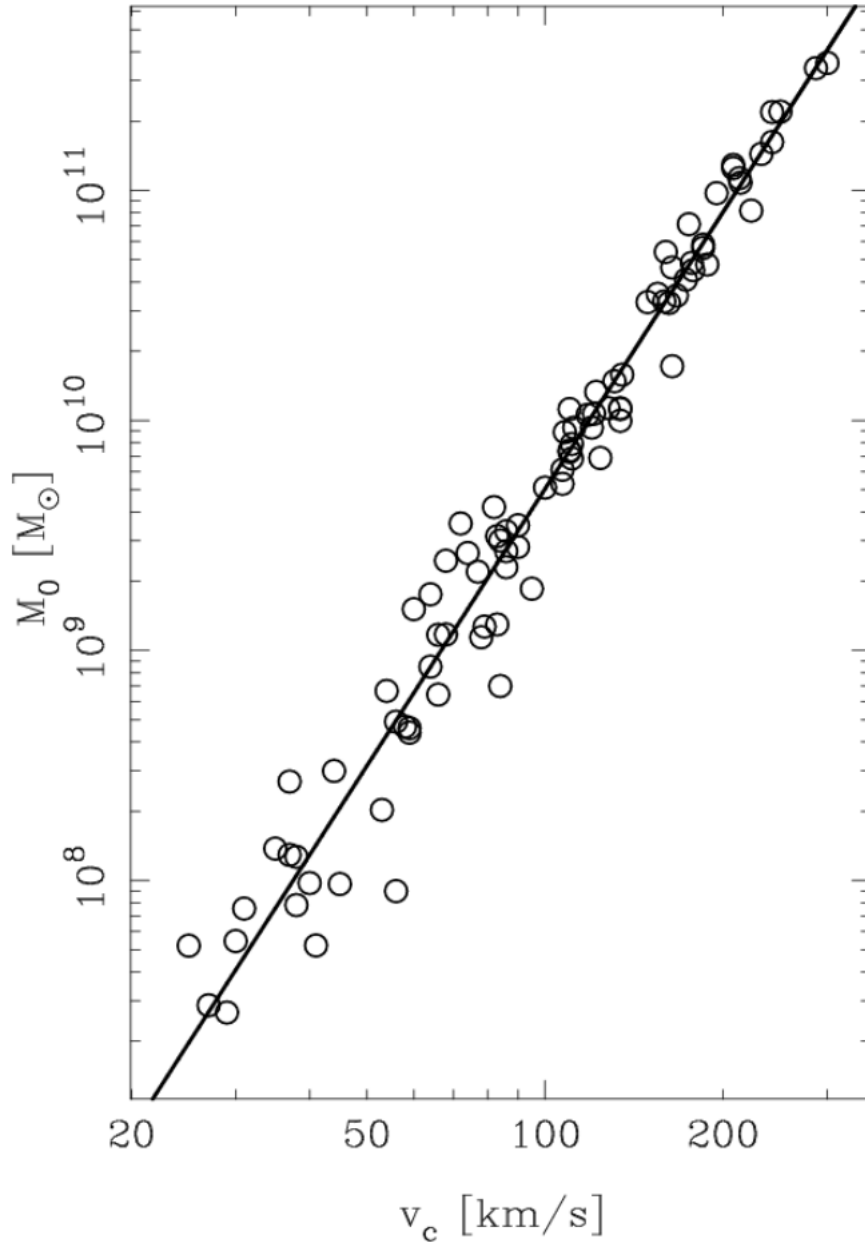


Figure 1: The Tully-Fisher relation that relates galaxy stellar mass to the HI half-width velocity of the galaxy. Here is a link to the paper if you'd like to read it (you can access the PDF if you're connected to WVU internet): <http://adsabs.harvard.edu/abs/1977A%26A...54..661T>