Lab 9 – The Tully-Fisher Relation

ASTR 1020

Name:

Overview

In this activity, you will explore the relationship between the rotation rate of spiral galaxies and their intrinsic luminosity, and how to utilize that relation for distance measurement.

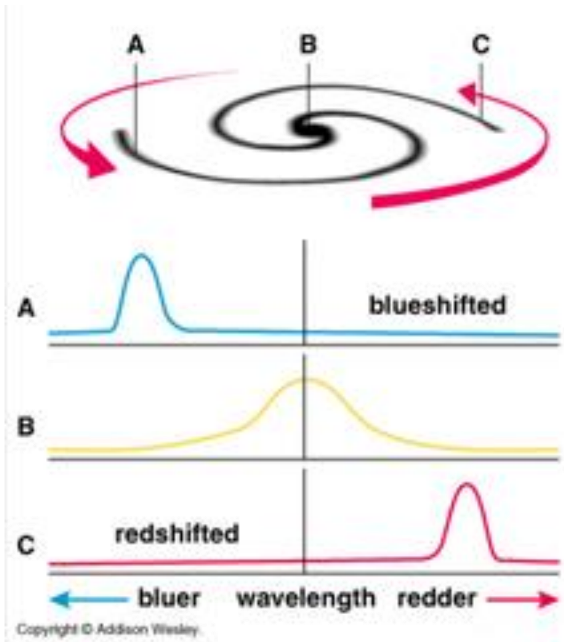
Objectives

After completing this activity students will be able to:

- Recognize the profile of an HI emission line from a spiral galaxy
- Measure the width of an HI emission line
- Calculate galaxy luminosity by using the Tully-Fisher relation
- Calculate distances using the absolute magnitude from the Tully-Fisher relation

Definitions

- **HI** – neutral hydrogen; the most abundant element in spiral galaxies, and the best tracer for spiral galaxy size
- **Emission Line** – an increase in flux at a specific wavelength or frequency in a spectrum
- **W_{50}** – the width of an emission line at 50% of the flux
- **Redshift** – the amount of increase in wavelength (or decrease in frequency) of a photon due to its velocity away from the observer
- **Blueshift** – the amount of decrease in wavelength (or increase in frequency) of a photon due to its velocity towards the observer
- **Radial Velocity** – the measure of the amount of a celestial object's velocity that is in the line of sight of the observer
- **Noise** – low-level fluctuations of energy in a spectrum or image due to weak radiation from space and background energy produced by electronics in the instrument
- **Radio Frequency Interference** – RFI; large energy spikes in a spectrum caused by near-Earth objects that emit in the radio portion of the spectrum (GPS, satellites, etc.)



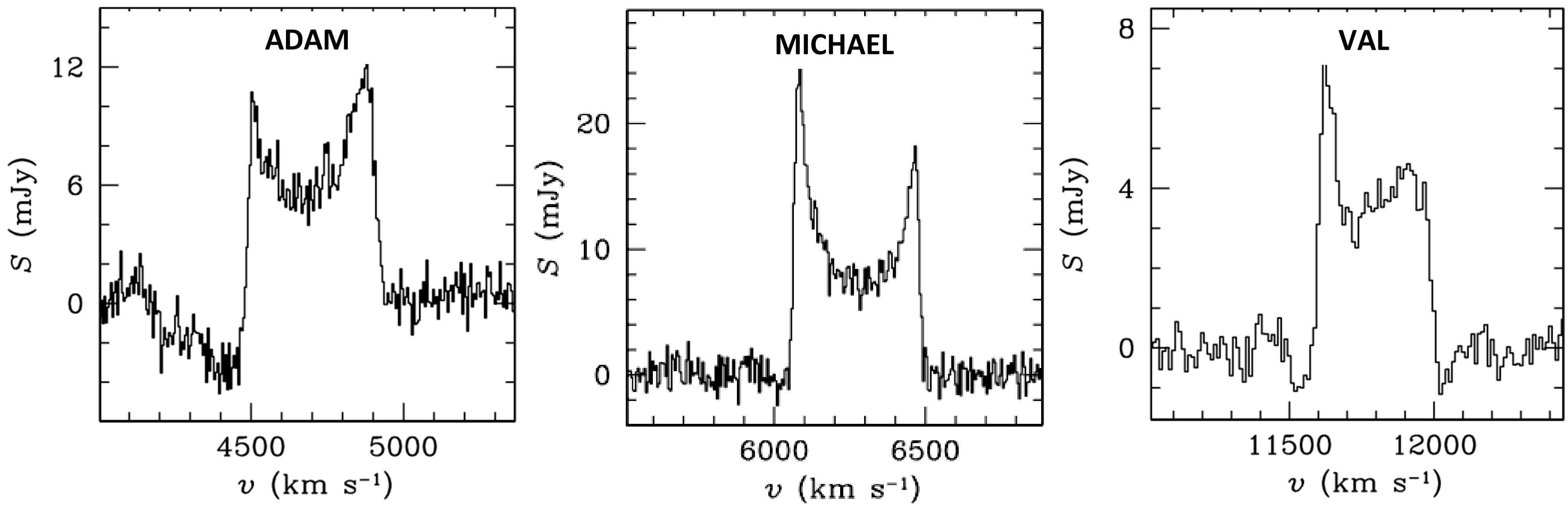
- **Apparent magnitude** – *m*; the apparent brightness of a celestial object as measured from Earth.
- **Parsec** – equal to 3.26 light-years; the distance an object must be to have a parallax angle of 1 arcsecond.
- **Absolute magnitude** – *M*; the brightness of a celestial object as measured from 10 parsecs.
- **Distance Modulus** – *m-M*; the difference between an objects apparent and absolute magnitudes.

Part 1. Emission Line Widths

The extent of HI in spiral galaxies usually reaches much further past the regions occupied by bright stars. So, it's a great tool for revealing how big spirals actually are. We can also trace out the galaxy's rotation using the HI emission line. As the galaxy is rotating, one side is always coming towards you and other side is always going away from you. So, on top of the redshift of the whole emission line that's caused by how fast the galaxy is receding from you, one side is receding just a bit faster and one side just a bit slower, so the emission line is broadened depending on how fast the galaxy is rotating. The faster it rotates, the broader the emission line will be. The width of the line, then, is a measure of the galaxy's total rotational velocity. Because all this motion is radial, the fastest velocities are on the edges, and if the galaxy is edge-on to our viewpoint, we get spikes or horns on the edges of the profile.

In Figure 1, there are 5 spectra that exhibit the HI emission lines from different spiral galaxies. Velocity is on the x-axis, flux is on the y-axis. In order to measure how fast each galaxy is rotating, we need to measure the width of the emission lines. To do this:

a. Measure the highest point of flux for both horns and calculate their average.
b. Divide your average by 2 and draw a horizontal line through the emission line at that average value on the y-axis.
c. Mark where the horizontal line intersects the sides of the emission line.
d. From the intersection points, draw straight, vertical lines down to the x-axis. Read off the velocity values of where the vertical lines intersected the x-axis.
e. Subtract the larger velocity value from the smaller value. Your difference is the *observed* rotation rate of that galaxy, or the width of the emission line (W_{50}).
f. Record your W_{50} values in the first column of Table 1.
g. Repeat this process for the other 4 galaxies' emission lines and record your calculations in Table 1 (can be found on Page 6).



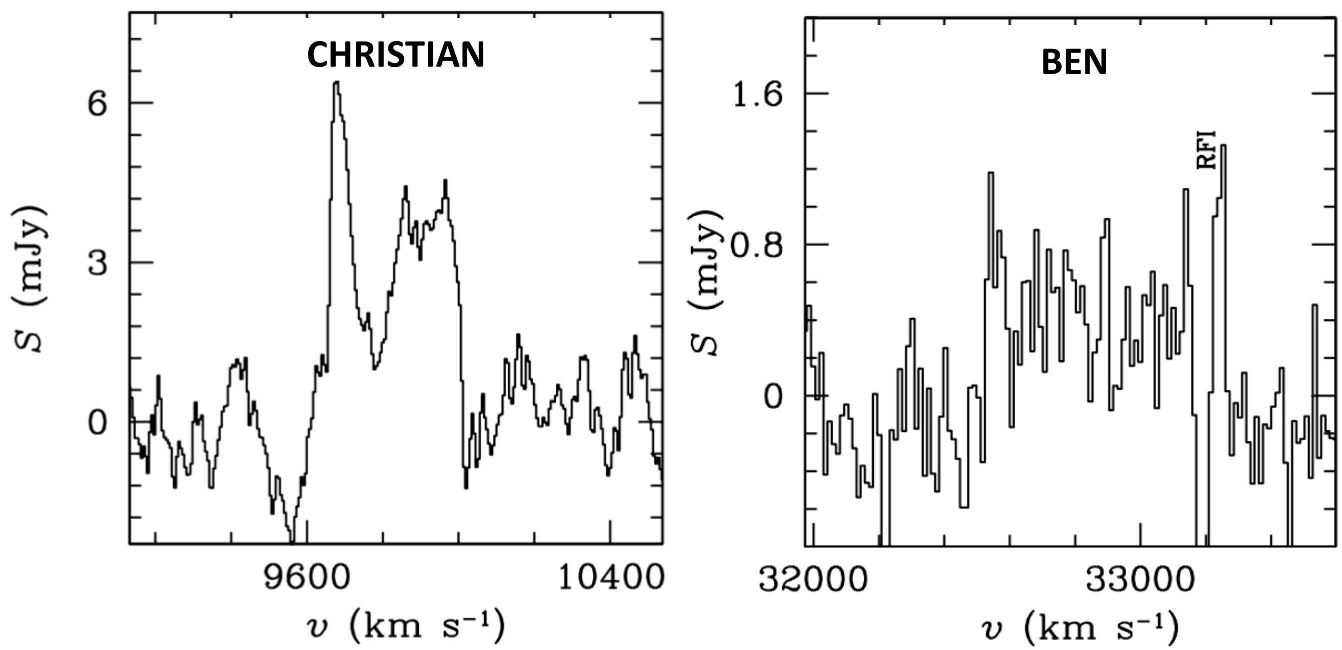


Figure 1: HI emission lines from 5 nearby spiral galaxies

Part 2. True Rotation Rates

Because each galaxy is at a different inclination relative to our point of view, the width of the emission line does not accurately describe how fast the galaxy is *actually* rotating, as shown in Figure 2. So, we need to adjust our measured widths depending on the orientation of the galaxy.

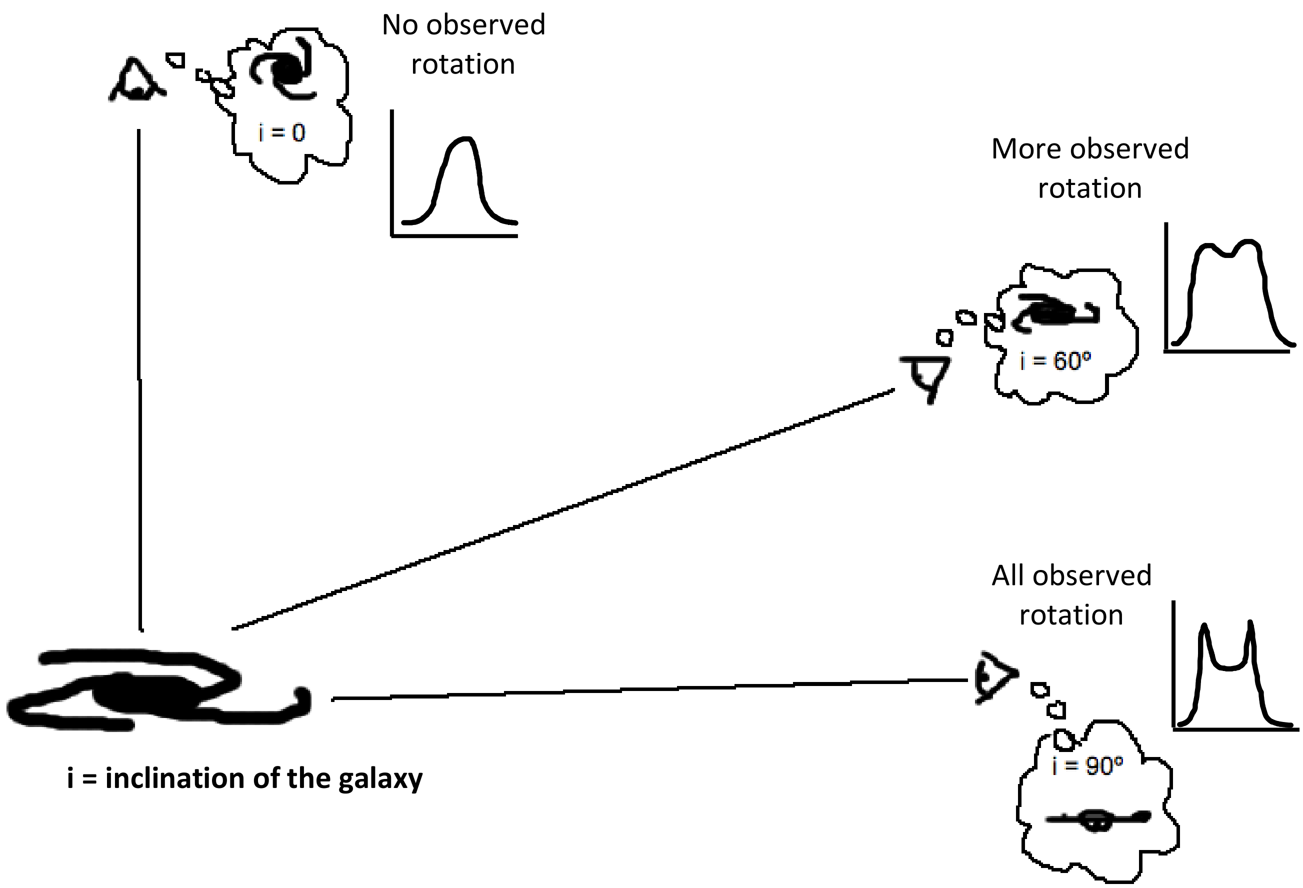


Figure 2: Examples of observing a spiral galaxy at different inclinations

To correct for the galaxies' inclination use Equation 1:

$$W_{50}(corrected) = \frac{W_{50}}{\sin(i)} \qquad (Equation\ 1)$$

where W_{50} is your measured line width from question 1 and i is the inclination of each galaxy, which is listed for you in the 2nd column of Table 1.

2. **Calculate W_{50}(*corrected*) for each galaxy and record your answers in column 3 of Table 1.**

Part 3. From Rotation to Brightness

The most important application of the HI emission line width is its use as an extragalactic distance measurement method on one of the furthest-reaching rungs of the cosmic distance ladder. The Tully-Fisher relation (named after Brent Tully and Richard Fisher) is a correlation between a galaxy's rotation rate and its intrinsic luminosity (how bright it actually is), much like the correlation between a Cepheid variable star's period and its absolute magnitude (Leavitt's Law, or The Period-Luminosity relation). So, the Tully-Fisher relation allows you to calculate each galaxy's true luminosity using your W_{50}(*corrected*) calculations. The relation is shown in Equation 2:

$$L = W_{50}(corrected)^4 \qquad (Equation\ 2)$$

where *L* is the galaxy's luminosity in units of solar luminosities.

3. **Calculate luminosities for each galaxy *in scientific notation* and record them in column 4 of Table 1.**

Now that you have the galaxies' luminosities, you can calculate their absolute magnitudes as follows in Equation 3:

$$M = -2.5log(L) + 4.82 \qquad (Equation\ 3)$$

where *M* is the galaxy's absolute magnitude and *L* is your calculated luminosity from Question 3.

4. **Calculate the absolute magnitudes of your galaxies and record your results in column 5 of Table 1.**

Part 4. Distance!

You now have ½ the pieces you need to calculate a distance. You have absolute magnitudes, and in order to calculate a distance modulus, you also need apparent magnitudes. The writer of this lab was nice enough to give those to you too! The galaxies' *m* values are listed in column 6 of table 1. You can now calculate distances using the distance modulus equation shown in Equation 4:

$$D = 10^{(m-M+5)/5} \qquad (Equation\ 4)$$

Note that *D* will be in parsecs, so divide your distance by 1,000,000 in order to convert from parsecs to megaparsecs (Mpc).

5. **Use the distance modulus equation to calculate distances for all 5 galaxies and record your results in the last column of Table 1.**

Table 1

Galaxy	W_{50} (km/s)	*i* (°)	W_{50}(*corrected*) (km/s)	*L* ($L_\odot$)	*M* (mag)	*m* (mag)	*D* (Mpc)
Adam		70.3				12.61	
Michael		74.1				12.82	
Val		54.8				14.00	
Christian		64.5				15.28	
Ben		82.2				14.95	

6. Some of the profiles have different levels of flux in the two horns, why do you think that is?

7. Some of the emission lines exhibit strange shapes between the two horns, what do you think might cause these?

8. A number of the emission lines contain strong flux and are well above the noise, and some are barely distinguishable from the noise. List some (at least 2) reasons why this may be.

To complete this assignment for grading:

- Save this file: File -> Save As… -> Rename the file 'YourLastName – TFLab'
- Upload your file to 'Lab 9 – The Tully-Fisher Relation' assignment in iCollege (click Add Attachments -> Upload -> upload renamed saved file -> Update).
- Complete the Reflection activity on iCollege
- Have a beverage of your choice in celebration!