The Tully-Fisher Relation

1. OBJECTIVES

After completing this exercise, the student will be able to:

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

2. STUDENT MATERIALS

- Pencil
- Ruler
- Calculator

3. STUDENT REQUIREMENTS

This lab is to be completed individually, without lab partners.

4. INTRODUCTION

Hydrogen is the most abundant element in the universe. Atomic or neutral hydrogen (HI) is also the most abundant element found in a galaxy. The extent of the neutral gas usually extends much farther past the optical extent of the galaxy, so it's a good tracer for how big galaxies actually are.

An HI atom exists in a configuration where the spins of the proton and electron are parallel (just think of spin as energy that points in a specific direction, either up or down). Given enough time, the electron will flip its spin from up to down, which causes the whole atom to lose energy. That difference in energy is emitted from the atom as a photon with a wavelength of 21 cm and frequency of 1420 MHz. Since there is so much hydrogen in a galaxy, it looks like this emission is happening everywhere.

The 21 cm emission line is a great tool for studying galaxies. Since the emission line frequency is very well known, the redshifts of galaxies can be very precisely measured. Since each galaxy is moving away from us, the entire emission line is going to be redshifted by some amount (it will show up as a lower frequency than 1420 MHz).

However, galaxies are large and the extent of the hydrogen that is producing the radiation is even larger. So, 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 profile that's caused by how fast the entire 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 (either towards or away from you), the fastest velocities are on the edges, and if the galaxy is edge-on to our viewpoint, we get spikes on the edges of the profile, which causes the famous "*Batman*" shape of the emission line.

HI emission profiles are always measured with respect to the *noise* level of the spectrum.

Just like how the telescope is receiving radiation specifically from the hydrogen, there is also low energy radiation coming from *the interstellar medium* between us and the object we are observing. This low energy medium along with background energy produced by the electronics in the telescope itself produces low-level fluctuations of energy or "*noise*" in every spectrum. Other devices close to Earth which can emit radio waves such as satellites or GPS systems cause large spikes at specific energies that sometimes appear in the spectra. These spikes are known as Radio Frequency Interference (RFI).

The most important application of the 21cm line is its use as an extragalactic distance measurement method on one of the furthest-reaching rungs of the cosmic distance ladder. The Tully-Fisher distance measurement method (named after Brent Tully and Richard Fisher, who discovered the relation), is a correlation between a galaxy's rotation rate and its absolute magnitude, much like the correlation between a Cepheid variable star's period and its absolute magnitude (The Period-Luminosity relation). Galaxy rotation rates are measured using the broad 21cm emission lines, therefore measuring a rotation rate gives you absolute magnitude, and the normal distance modulus equation lets you calculate the distance.

5. PROCEDURE

Please estimate all measurements to the *hundredth* decimal place. Do *not* round off redshift values.

1) Widths of the Emission Lines

There are 5 spectra that exhibit the HI emission lines from different spiral galaxies. The x-axis and y-axis of each plot show *velocity* in km/s and *flux*, respectively.

Step 1. Measure *the highest point of flux* for both horns, and calculate their *average*.

Step 2. *Divide the average value by 2*, and draw a horizontal line through the emission line at that value on the y-axis.

Step 4. Mark where the horizontal line intersects the sides of the emission line.

Step 5. From the intersection points, draw straight, vertical lines down to the x-axis. Read *the velocity values of where the vertical lines intersected the x-axis*.

Step 6. *The difference between two velocity values* from Step 5 is the observed rotational velocity of that galaxy (W_{50}, or the width at 50% of the flux). *Record your W_{50} values* in the first column of Table 1. Repeat this process for the rest of the galaxies.

Because each galaxy is at *a different inclination* relative to our point of view, in order to get an idea as to how fast the galaxy is actually rotating as if we were observing it completely edge-on, we need to take the inclination of the galaxy into account. In doing this, we correct the W_{50} measurements to the true rotational velocities. To do this, we use:

$$W_{50}(\text{Corrected}) = \frac{W_{50}}{\sin i}$$

where i is the inclination angle, which is listed in Table 1.

2) Luminosity

The Tully-Fisher relation allows you to calculate each galaxy's luminosity using the true rotational velocities, W_{50} (Corrected). The approximation of the relation is:

$$L = W_{50}(\text{corrected})^4$$

where L is the galaxy's luminosity in units of solar luminosities. Record your luminosity values *in scientific notation* in Table 1.

3) Absolute magnitude

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

$$Mv = -2.5\log(L) + 4.82$$

where Mv is the galaxy's absolute magnitude and L is the luminosity you calculated in step 2. Record your absolute magnitudes in Table 1.

4) Distances

Now that you have your absolute magnitudes (Mv), you can now use the apparent magnitudes (V mag) given in Table 1 to compute the distances using the familiar distance modulus equation:

$$D = 10^{(V-Mv+5)/5}$$

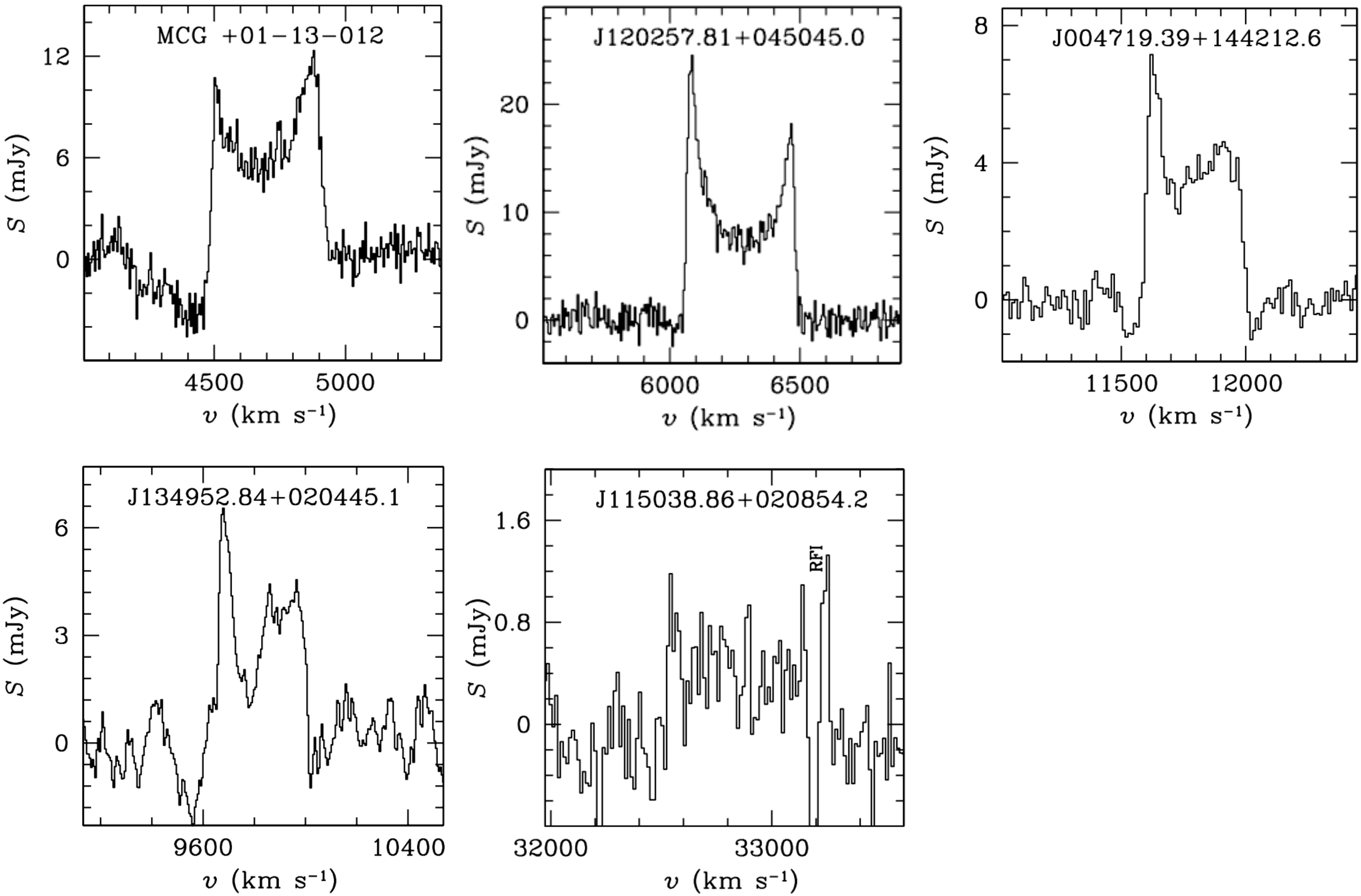
Note that D will be in parsecs, so divide your distance by 1,000,000 in order to convert from parsecs to megaparsecs (Mpc).

Galaxy	W_{50} (km/s)	i (degrees)	W_{50} (Corrected)	Luminosity ($L_{\odot}$)	Mv mag	V mag	Distance (Mpc)
MCG +01-13-012		70.3				12.61	
J120257.81+045045.0		74.1				12.82	
J004719.29+144212.6		54.8				14.00	
J134952.84+020445.1		64.5				15.28	
J115038.86+020854.2		82.2				14.95	

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

2) Some of the profiles exhibit strange shapes between the two horns, what do you think might cause these?

3) 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.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J004719.39+144212.6
J134952.84+020445.1
J115038.86+020854.2
RFI
S (mJy)
v (km s⁻¹)