Lab #11:
Large Scale Structure of the Universe

April 30, 2012

Due May 4, 2012

Objectives:

To determine redshifts and use them to map a portion of the nearby universe.

Equipment:

Large Scale Structure of the Universe by Project CLEA

a calculator

Procedure

You will be using the Project CLEA software to measure redshifts of a subset of the galaxies surveyed by the Center for Astrophysics at Harvard in 1985 and recreating their plot of the large scale structure of the (nearby) universe. See `https://www.cfa.harvard.edu/~dfabricant/huchra/zcat/` for the history of this survey.

1) In the A121 folder, create a folder with a name formed by your and your partner's initials and the lab number 11, and then click on Large Scale Structure (may be listed as CLEA_LSS). Log in, then click File → Run.

2) Open the dome, turn on the tracking, and then use "Set Coords" to go to the first object on your list. **MAKE SURE YOU DO THE LIST IN ORDER!**

3) Click "Change view" to access the spectrometer, and use the NSEW buttons (adjusting slew rate if necessary) to center the galaxy in the spectrometer slit (the two red lines).

4) Click "Take Reading", which opens a new window. Click "Start/resume" to begin taking data. Get to AT LEAST a signal/noise ratio (given in the bottom right corner) of 15. MAKE SURE the object name in this window matches the object name on your list!

5) On the spectrum, click and hold down the left mouse button, which will pop up a cross-hair which you can then drag until it's centered on the deepest part of the line. You want to measure the H and K lines (the pair of lines at the left - K is furthest left, as it has the smaller wavelength).

In MATLAB (making sure that you're in the folder you created in step 1), open an m-file and record the object name, the K line wavelength, and the H line wavelength in three separate arrays. **Remember that the K line is the one furthest left (i.e. shorter wavelength) of the pair of lines.** If you want to follow the tutorial for this lab, you can find it at `http://www.astro.umd.edu/~cychen/MATLAB/ASTR121/labLSS/`. (Please note that you should also be following the instructions in this handout to complete the lab. The tutorial is meant as a guide, while the handout for the lab tells you exactly what you need to hand in.)

Note that MATLAB doesn't allow regular string arrays to have entries of varying lengths. If the first entry in the array has, say, 6 letters, then every entry has to have 6 letters (which can be padded with spaces). Since your object names might not all be the same length, you can instead use what is called a "cell array" . Cell arrays allow you to create an array of strings of varying lengths. To create a cell array, use curly braces instead of square brackets when you fill in the entries of the array, as such:
myobjs = {'object1','object2','object3'}
The curly braces, rather then regular parenthesis, mark these arrays as cell arrays rather than a normal string array

To see the first entry in a cell array, type:
>> myobjs{1}
which will return your first object name. Typing:
>> myobjs{2}
will return the name of your second object, and so on.

When you are finished recording the object name and K and H wavelengths, click “Return” in the CLEA spectrum window to go back to the telescope window, and move on to your next object.

6) When you have finished recording the object name and K and H wavelengths for all 27 of the objects on your list, calculate the recessional velocity of the galaxies from the K line, and from the H line, using the formula:

$$v = c\frac{\lambda_{obs} - \lambda_{emit}}{\lambda_{emit}}$$

where λ_{obs} is the array of K or H wavelengths that you measured, $c = 3e8$ km/s, and λ_{emit} is the rest wavelength of the K or H lines (3933.7 Å for K, 3968.5 Å for H).

Also calculate the average velocity by adding the K and H velocities together and dividing by 2. Don’t forget to use “./” and “.*” so that MATLAB treats each entry in the arrays individually rather than doing matrix math.

7) Next we need to save your data to a file so that you can send it to me to combine with your classmates’ data. To do this, we are going to combine the “for” loop command from last week’s lab with a new command, **fprintf**. This command is a very flexible way of writing data of mixed types (strings and numbers) to a file. To use **fprintf**, with the “for” loop, first create a file to write the data to, by adding the following to your m-file:
fout = fopen(‘group1.csv’,‘w’);
where you should substitute your group number as the file name. If the file already exists, the ‘w’ will erase any data previously stored in the file.

To write the data, add the following to your m-file:

```
for i= 1:27
    fprintf(fout,‘%s,%E,%E,%E,%E,%E\n’,myobjs{i},avgvel(i),kline(i),kvel(i),hline(i),hvel(i));
end
```

where avgvel is the array of average velocities, kline is the array of measured K line wavelengths, kvel is the array of velocities from the K line measurements, hline is the array of measured H line wavelengths, and hvel is the array of velocities from the H line measurements. MAKE SURE YOU PUT THE DATA INTO THE FILE IN THIS ORDER.

For more information on fprintf, see the tutorial for this lab, or try **help fprintf** in the MATLAB command window.

Once you write your file, email the file to me at `hsheets@umd.edu`. Be sure to name your file using your group number, and in the email, include your name (and your partner's, if you are working with someone) so I know who has sent what. Only one email per group is necessary.

8) Now, unfortunately, you have to sit and wait for the others to finish collecting their data, so we can combine the data to produce the plot. We need a good number of galaxies to see the structure. At least you haven't had to measure all 216 galaxies yourself!

9) Once I have distributed the combined data set, via ELMS, and you have downloaded it to your folder, re-open the Large Scale Structure program, log in, and then choose Data → Load. DO NOT choose Run! It will not let you load data if you choose Run first. Load the combined data set by entering in "Filename" the path to your file, which should be
c:\users\student\desktop\a121\yourfolder
and pressing the "enter" key, which will update the list of files in the left box. Select the correct file ("all.csv") and hit "OK". Then select Data → Save results for Plot.

10) Select Wedge Plot from the File menu, and inside the Plot Module, File → Open File. DO NOT change anything in the window that pops up! It is already set to find the file where the program has saved the data for plotting. Click OK, and go to Plot → Plot current file. Under Options, play with the color command, point size, and point style until you can read your plot reasonably well.

11) The program is not set up to print, so to make a copy of your plot, you need to use the "Print Screen" key (top right of the keyboard) to copy the screen, and then open Paint (under All Programs → Accessories) and paste in what you copied with the Print Screen. Then click on the button that allows you to select a rectangle, select just your plot, and go to Image → Crop (or use the icons), to get just the plot. Lastly, print this out, and make sure to send it to the HP laserjet, so that it will actually print. If you choose to save the plot from Paint, make sure you put it in your A121 folder.

What to turn in

The write-up consists of printing out a copy of your code for your calculations (don't worry about printing the results of all your calculations, as I already have the file with your velocities), answering the following questions, and including your wedge plot. **Be sure to write your group number and section (morning or afternoon) along with your name on the lab.**

Questions

Carefully examine the wedge diagram you and your classmates have produced. Though you have only plotted 200 or so representative galaxies, the features you see are distinctive. Based on your plot, answer the questions below.

1. Does matter in the universe appear to be randomly distributed on the large scale, or are there clumps and voids?

2. The most densely populated region of the diagram (which appears like the stick figure of a human), is the core of the Coma Cluster of galaxies. What are the approximate Right Ascension and velocity coordinates of this feature (aim for the "chest" of the stick figure)?

3. You can use Hubbles redshift-distance relation, $v = H_0 D$ to determine the distances of objects in the chart. Use a value of 71 km s^{-1} Mpc^{-1} to calculate the distance to the Coma Cluster.

4. Using the redshift-distance relation, how far is the farthest galaxy included in this study? How much smaller (i.e. give me a ratio) is this distance than the limit of the observable universe, which is about 4.6×10^9 pc?

5. Beyond the Coma cluster there is a loose band of galaxies stretching from east to west

across the entire survey volume. It is called the Great Wall.

a. Using the Hubble redshift-distance relation, calculate the distance to the Great Wall .

b. One can use the angular diameter formula to estimate the length L of the Great Wall. If the wall spans an angle of θ radians at a distance D Mpc, then the diameter d of the wall in Mpc is:

$$d = \theta * D$$

Use this formula to estimate the length of the Great Wall (which is just a lower limit, since it may extend beyond the boundaries of our survey.) **Indicate, either here with your answer, or on your plot, what limits in RA you are using for the wall.** Give your answer in Mpc AND light years (3.26 ly = 1 pc, and 1 Mpc = $1x10^6$ pc).

c. You have plotted redshift versus Right Ascension. What other information do you need to confirm that the Great Wall is indeed a wall (i.e. two-dimensional) and not just a line or filament (i.e. one-dimensional) of galaxies?