

# **Large Scale Structure of the Universe Lab**

## **Introduction:**

Since the mid-1980's astronomers have gathered data allowing, for the first time, a view of the structure of the Universe in three-dimensions. You might speculate that an image of this structure could be determined by photographing stars to see if they form some kind of pattern. An example of a star is our own Sun. Although the Sun is extremely bright for earth's inhabitants, it would not appear to be bright at all if it were 100,000 times farther away from us. And if it were a billion times farther away, the Sun would be extremely faint, visible only through telescopes. But to get something like a picture of the whole Universe, stars near and far must be photographed. The difficulty in observing dim images of stars is overcome by taking advantage of the fact that a single star is usually part of an extremely large aggregation of stars called a *galaxy*.

A typical galaxy contains 100 billion stars, so it is obviously much brighter than a single star. So our original question of whether or not the stars form some kind of pattern changes to the question of whether or not the galaxies form some kind of pattern. In this lab, you will answer this question by downloading and plotting the same data used by professional astronomers.

## **Stars and Galaxies:**

- Goals:
- Observe galaxy images
  - Compare star distances to galaxy distances

## **Large Scale Structure (LSS):**

- Goals:
- Download and plot astronomical data for galaxies
  - Take measurements on the plots to characterize the LSS

## **Two-Point Correlation Function for Cities**

- Goals:
- Plot and analyze two-point correlation function for mid-west cities
  - Compare to two-point correlation function plot for galaxies

## Stars and Galaxies

Before making a plot that reveals the Large Scale Structure, it is necessary to understand the distances to stars, and the distances to galaxies. And it is useful to know how galaxies look when seen through a powerful telescope.

### Directions

1. Visit the web site

[https://en.wikipedia.org/wiki/List\\_of\\_nearest\\_stars\\_and\\_brown\\_dwarfs](https://en.wikipedia.org/wiki/List_of_nearest_stars_and_brown_dwarfs)

and click on the table link to get a list of the brightest stars. Record distances to five of these stars, from the top, middle and bottom of the table, and record these distances in the table below. Be sure to include Sirius A, the brightest star in the night sky that you have probably seen.

2. Calculate how many times farther each star is from the earth compared to the earth-sun distance. The distance between the earth and Sun is 150 billion meters. This distance can be converted to another measure of distance, the light-year. A light-year (ly) is the distance that light travels in 1 year.

Earth-sun distance = 150 billion meters = 150,000,000,000 meters = 0.0000159 ly

Name of Star	Distance to Star in light years (ly)	How many times farther than Sun

3. Visit the web site

<http://messier.seds.org>

and click on the link to the list of galaxies. Click on individual links to five galaxies, and in the table below record their distances, found in the upper left corner of the screen. Be sure to include M100 because it resembles the galaxy that we live in, the Milky Way.

4. Calculate how many times farther each galaxy is from the earth compared to the earth-sun distance (given above).

Name of Galaxy	Distance to Galaxy in Million light years (Mly)	How many times farther than Sun

## Questions

1. Briefly describe the appearance of a spiral galaxy, and compare it to the appearance of an elliptical galaxy.
2. What is the range (smallest and largest) of distances to the stars closest to the earth?
3. What is the range (smallest and largest) of distances to the galaxies that you have recorded?
4. Complete the sentence below to explain to a lay person how much farther galaxies are from the earth compared to nearby stars.

Galaxies are approximately a \_\_\_\_\_ times farther away from the earth than nearby stars.

5. Explain why galaxies are visible through telescopes even though they are so far away from earth compared to the nearby stars.
6. What kind of pattern do you think the galaxies will form. Make that pattern below using dots, keeping in mind that one dot represents one galaxy.

## Large Scale Structure (LSS)

You are now ready to see what type of pattern (if any) the galaxies form. This pattern provides evidence to astronomers who are trying to understand how the Universe has evolved over time. Astronomers have gathered the data that you will access by observing almost a million galaxies over the last eight years using a telescope in New Mexico dedicated to what is called the Sloan Digital Sky Survey (SDSS).

### Directions

1. Visit the web site that gives you access to the server where the SDSS data is stored:

<http://cas.sdss.org/dr7/en/tools/search/sql.asp>

2. You should be on a web page labeled SQL Search. SQL (Structured Query Language) is a computer language used to access databases. Replace the text in the white window with the following SQL text.

```
SELECT STR(z,10,6) z, ra, dec
FROM specObj
WHERE specClass=2 AND dec BETWEEN -3 AND 3 AND ra BETWEEN 0 AND 360
AND z BETWEEN 0 AND 0.05
```

3. After typing this text, click the HTML button, then Submit. Position data for 9660 galaxies will appear in a browser window. Three columns of data should appear labeled z, ra, and dec to give the position of each of the galaxies. The z (called the redshift) tells how far the galaxy is away from earth; we will convert this to Mega (million) light years. And ra and dec give the angular position of the galaxy in the sky. Notice from the SQL above that dec ranges only from  $-3^\circ$  to  $+3^\circ$ , while ra ranges from  $0^\circ$  to  $360^\circ$ . So you will plot only a small slice of the Universe on an x-y plot.

4. Copy all of the data from the browser window, starting from the z, ra, dec heading, then paste the data into a Microsoft Excel worksheet.

5. Type Mly at the top of Column D on your spread sheet, and in the cell D2 type  $=3.26*(3000.0*A2 - 607.8*A2^2 - 156.3*A2^3 + 138.3*A2^4)/0.71$  then hit enter to convert the z-value to Mega (million) light years. Your instructor will show you how to convert all of the z-values in Column A to Mly values in Column D.

6. Type x at the top of Column E on your spread sheet, and in cell E2 type

$=D2*\text{COS}(B2*\text{PI}()/180)$

then hit enter to convert the ra-value to the x-position of the galaxy. Get the x-values for the entire column.

7. Type y at the top of Column F on your spread sheet, and in cell F2 type  
 $=D2*\text{SIN}(B2*\text{PI}()/180)$

then hit enter to convert the ra-value to the y-position of the galaxy. Get the y-values for the entire column.

8. Select columns x and y, then make the plot by choosing the scatter plot under the Chart Wizard. Double click on one of the points in the plot and when the Format menu comes up choose a Style of point like this - , and make the size 2. After clicking on OK, you can begin to see the pattern formed by the galaxies, but the pattern is distorted unless the x and y-axes are adjusted so that they are the same length.

### Questions

1. Was the shape that you drew in question 5 in the Stars and Galaxies correct, incorrect, or indeterminate?
  
2. Describe the pattern formed by the galaxies?
  
3. What explanation would you propose for this pattern if you were an astronomer?
  
  
4. The point where the two pie-shaped wedges touch is where earth is located. How do the distances of the galaxies in the SDSS survey compare to the distances of the galaxies that you found before?
  
5. Estimate the diameter of the voids (where there are no galaxies) in Mly using the scale of the x and y-axes.

## Two-Point Correlation Function for Cities

The two-dimensional plot of galaxies is just a slice of a three-dimensional plot of the LSS. Such a plot must be analyzed so that a mathematical function can be found that describes it. In the absence of gravity the probability of finding one galaxy in volume  $dV_1$  near another galaxy in volume  $dV_2$  within a total volume  $V$  is

$$dP_1 dP_2 = \frac{n_1 n_2}{N^2} dV_1 dV_2,$$

but when gravity is included the probability that the two galaxies are near each other is enhanced:

$$dP_1 dP_2 = \frac{n_1 n_2}{N^2} (1 + \xi(r)) dV_1 dV_2.$$

The function  $\xi(r)$  is called the two-point correlation function. It is calculated by finding distances between all possible pairs of galaxies and comparing these distances to all possible pairs if the galaxies were randomly distributed in the same space. A large  $\xi(r)$  value represents strong clustering, while a  $\xi(r)$  near 0 represents no clustering. It is also possible for  $\xi(r)$  to be negative, representing a “repulsion.”

One method of calculation is represented symbolically by

$$\xi(r) = \frac{\langle DD(r) \rangle}{\langle RR(r) \rangle} - 1$$

where  $\langle DD(r) \rangle$  is the number of galaxy-galaxy pairs at separation  $r$ , and  $\langle RR(r) \rangle$  is the number of pairs at separation  $r$  for a random distribution of galaxies. Instead of performing this calculation for galaxies, however, you will find the analogous two-point correlation function for the cities displayed on the next page, a much simpler calculation.

### Directions

1. Label column A in Microsoft Excel `dat.txt`, and copy the file of the same name into that column. Label column B `datR.txt`, then copy that file into that column. The files `dat.txt` and `datR.txt` correspond to  $\langle DD(r) \rangle$  and  $\langle RR(r) \rangle$  respectively.
2. Make a formula in column C (label it `datPlus`) to add 1 to all of the values in column A. Also make a formula in column D (label it `datRPlus`) to add 1 to all of the values in column B.
3. In column E (label it `pixDist`), generate integer values 0 through 2001. These are pixel distances. To convert to miles, make a formula in column F (label it `miDist`) that multiplies all of the `pixDist` values by 0.492.
4. Calculate  $\xi(r)$  by making a formula in column G (label it `xi`):  $(\text{datPlus}/\text{datRPlus}) - 1$ .
5. Select columns `miDist` and `xi`, then make a plot by choosing the scatter plot under the Chart Wizard. Double click on one of the points in the plot and when the Format menu comes up choose a Style of point like this - , and make the size 2. Adjust the miles axis to read from 0 to 500 miles.

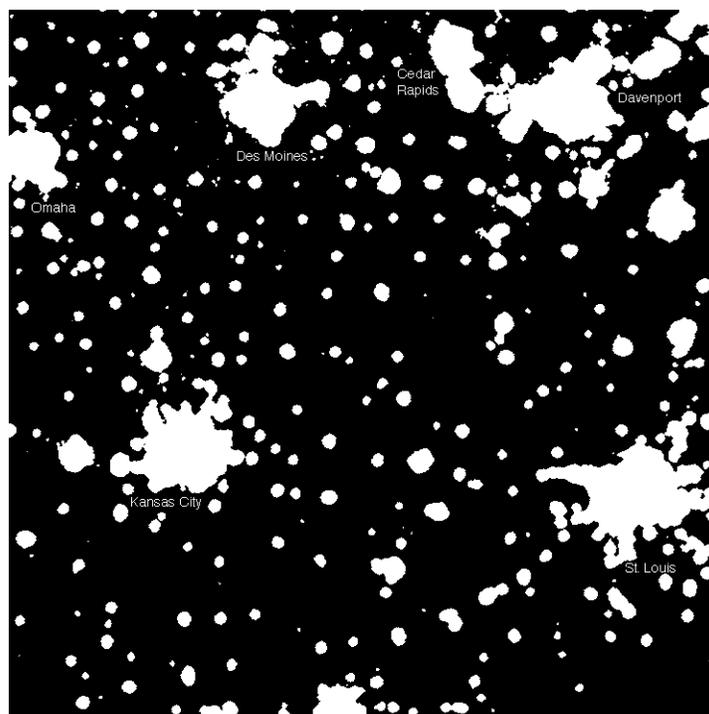
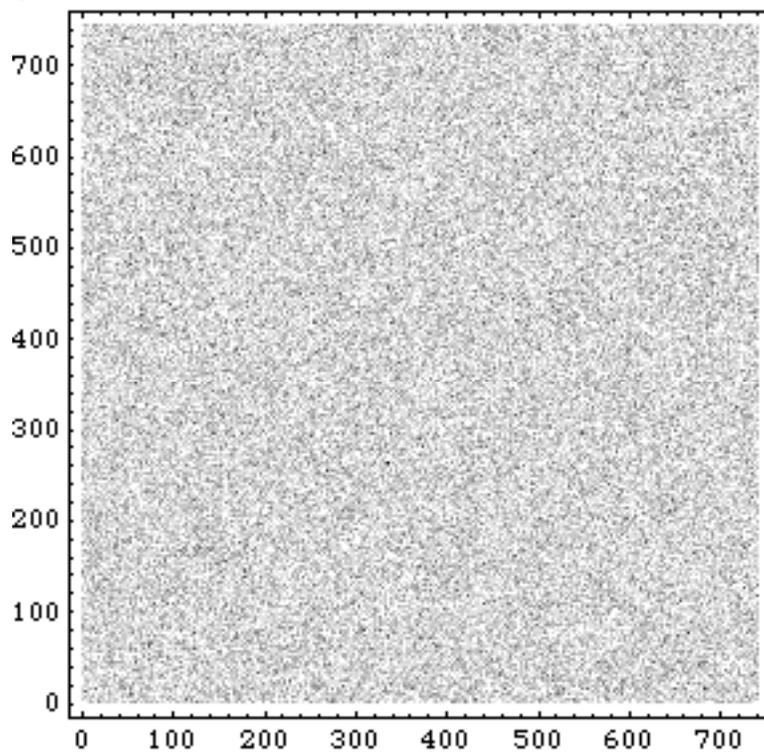


Fig. 1. Midwestern cities (Omaha, Des Moines, Cedar Rapids, Davenport, Kansas City, St. Louis) at night.

Fig. 2. Lights from the cities above distributed randomly.



## Questions

1. From the graph, what is your estimate for the radius of a city and its suburbs?
2. Also estimate the distance between cities from the graph.
3. The graph below was calculated for 57,378 galaxies from the Sloan Digital Sky Survey. Notice the similarity to the graph that you have plotted. Estimate the size, in light years, of a cluster of galaxies from the graph.  $1\text{pc} = 3.26\text{ ly}$ .

