

Name:

## Lab 15

# How Many Galaxies Are There in the Universe?

### 15.1 Introduction

Measurements, calculations, physical principles and estimations (or educated guesses) lie at the heart of all scientific endeavors. Measurements allow the scientist to quantify natural events, conditions, and characteristics. However, measurements can be hard to make for practical reasons. We will investigate some of the issues with taking measurements in this lab.

In addition, an important part about the measurement of something is an understanding about the *uncertainty* in that measurement. No one, including scientists, ever make measurements with perfect accuracy, and estimating the degree to which a result is uncertain is a fundamental part of science. Using a result to prove or disprove some theory can only be done after a careful consideration of the uncertainty of the result.

- *Goals:* to discuss the concepts of estimation, measurement and measurement error, and to use these, along with some data from the Hubble Space Telescope, to estimate the number of observable galaxies in the Universe
- *Materials:* Hubble Deep Field image

## 15.2 Exercise Section

### 15.2.1 Direct Measurement, Measurement Error

We will start out by counting objects much closer to home than galaxies!

How many chairs do you think there are in your classroom? You have one minute!

How did you determine this?

How does your number compare with that of other groups? What does this say about the uncertainty in the results?

Now do an exact count of the number of chairs - you have three minutes. Note the advantage of working with a group! By comparing results from different groups, what is the uncertainty in the result?

### 15.2.2 Estimation

Now we extend our measurement to a larger system where practical considerations limit us from doing a direct count.

How many chairs do you think there are in the entire University? You might wish to consider the campus map shown in Figure 15.1.

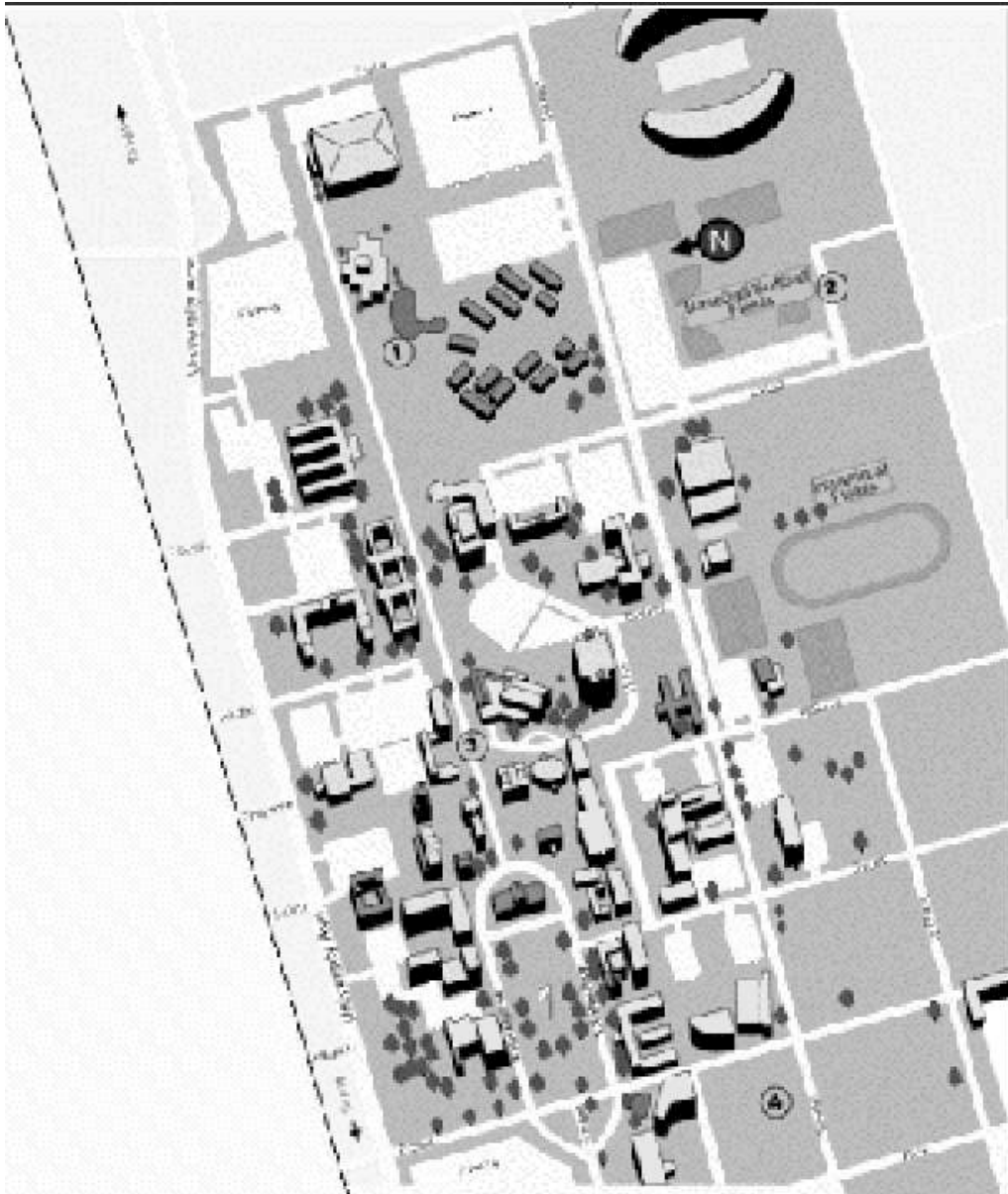


Figure 15.1: A map of the NMSU campus from the NMSU WWW site

How did you determine your number?

How accurate do you think your number is?

How might you estimate the uncertainty in your number?

### **15.2.3 How many galaxies are there in the Universe?**

Considering how you estimated the number of chairs in the classroom and on campus, consider and write down several alternative ways of estimating the number of galaxies in the Universe.

Let's consider the issue by looking at a picture of the sky taken with the Hubble Space Telescope. This telescope is the most capable of existing telescopes for viewing very

faint objects. In an effort to observe the faintest galaxies, astronomers decided to spend 10 entire days training this telescope on one small region of the sky to observe the faintest galaxies and learn about them. The image that was obtained is shown in Figure 15.2.

First, let's figure out how long it would take for the Space Telescope to take pictures like this over the entire sky.

To do this, we need to talk about how we measure distances and areas on the sky, concepts that we will need in some of our other labs as well. When one measures, for example, the distance between two stars as seen from Earth, one measures what is known as an angular distance. A standard unit of this angular distance is the familiar unit of the degree; there are 360 degrees in a full circle. As an example, the distance between an object which is straight overhead and one which is on the horizon is 90 degrees. However, when one makes astronomical observations with big telescopes, one usually sees an area which is only a small fraction of a degree on a side. To make things easier to write, astronomers sometimes use units known as arcminutes and arcseconds. There are 60 arcminutes in a degree, and 60 arcseconds in an arcminute.

1. We can now use this information to calculate how many pictures the Space Telescope would have to make to cover the entire sky. The picture from the Space Telescope covers a region that is about 1 arcminute on a side. Our first conversion is from arcminutes to degrees (this has been partially done for you): *(3 points)*

$$1 \text{ arcminute} \times \frac{1 \text{ degree}}{60 \text{ arcminutes}} = \underline{\hspace{2cm}} \text{ degrees} \quad (15.1)$$

2. The *area* of the entire picture is measured in square degrees, so we take the number of degrees found in question 1 and square it to get: *(3 points)*

3. Now there are  $4.13 \times 10^4$  square degrees in the sky. From this you can figure out

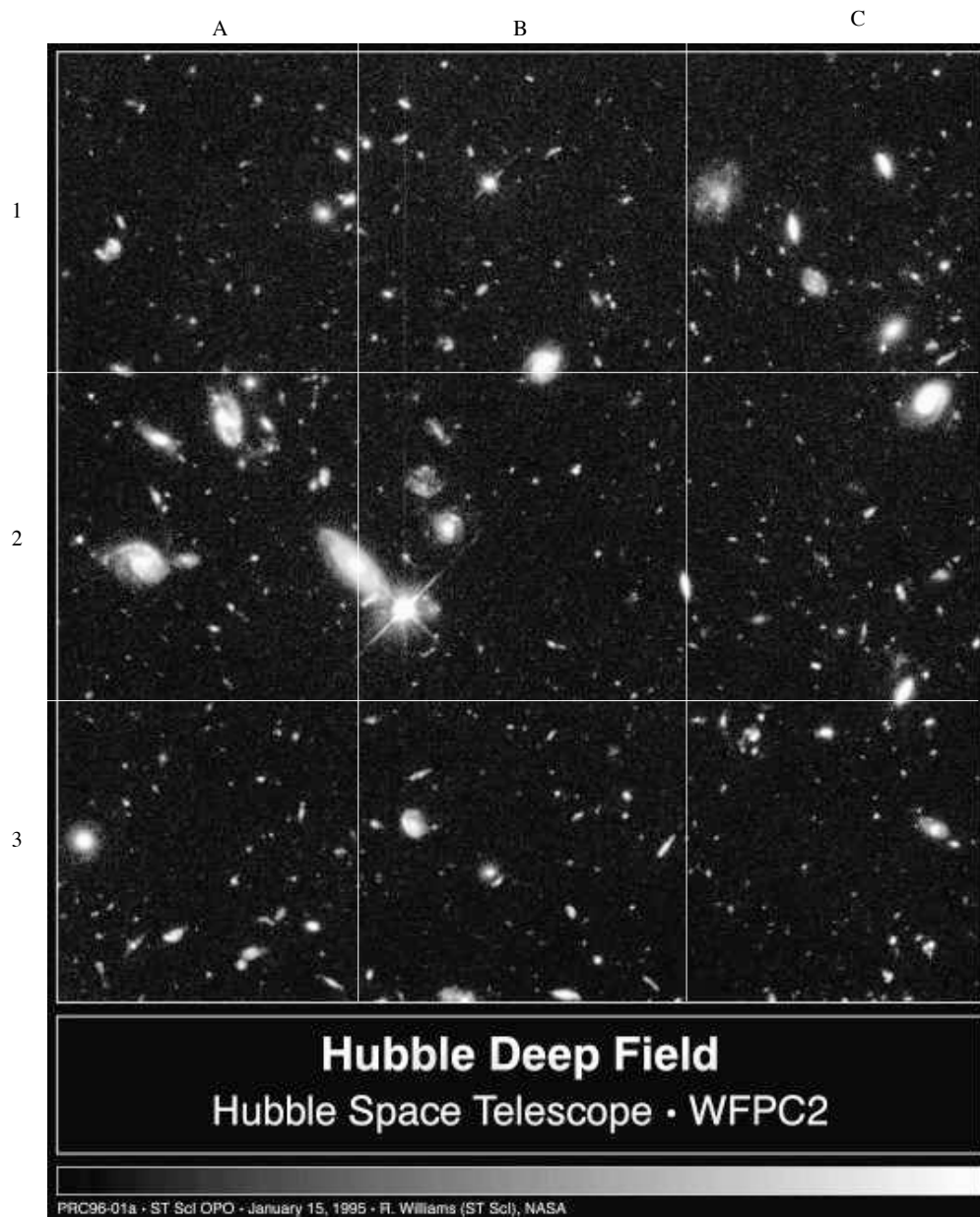


Figure 15.2: A reproduction of the Hubble Deep Field image.

how many pictures you would need to take to cover the whole sky: (*5 points*)

4. Finally if it takes 10 days for each picture, we can figure out how long it would take to cover the whole sky with similar pictures: (*4 points*)
  
5. With a unit conversion of 365 days/year, we can determine the number of years it would take: (*4 points*)

Clearly, this is a very long time! This is an interesting point to note: astronomers can only take deep pictures of a small fraction of the sky. So it is not practical to count galaxies by taking pictures of the entire sky.

So how can we proceed to figure out how many total galaxies there are? We can make an *estimate* by guessing that the number of galaxies in any particular picture will be the same regardless of where we point. We can then estimate the total number of galaxies in the sky by counting the number of galaxies in this one picture, and multiplying it by the number of pictures that it would take to cover the whole sky.

6. Take a look at the image of the Hubble Deep Field given to you by your TA. Almost every one of the objects you see in this picture is a distant galaxy. Count up all the galaxies in each section then add them up to get an estimate of the number of galaxies in this one field. Again, you can proceed quicker by taking advantage of the multiple members of your group; however, you might wish to have everyone in the group count one region independently to get some idea of the measurement uncertainty. (*10 points*)

Region A1: \_\_\_\_\_

Region A2: \_\_\_\_\_



Region A3: \_\_\_\_\_  
Region B1: \_\_\_\_\_  
Region B2: \_\_\_\_\_  
Region B3: \_\_\_\_\_  
Region C1: \_\_\_\_\_  
Region C2: \_\_\_\_\_  
Region C3: \_\_\_\_\_

There are a total of \_\_\_\_\_galaxies in Hubble Deep Field.

7. Now estimate the total number of galaxies in the whole sky, using our calculation of the number of pictures it takes to cover the sky which we did above. (*7 points*)

This is a pretty amazingly large number. Consider that each galaxy has billions of stars, and think just for minute about how many total stars there are in the Universe! It makes you feel pretty small... but, on the other hand, think how cool it is that humans have evolved to the point where they can even make such an estimation!

8. As we've discussed, an estimate of the *uncertainty* in a result is often as important as the result itself. Discuss several reasons why your result may not be especially accurate. You may wish to compare the number of galaxies in any given region which you counted with the number counted by other groups, or consider the variation in the number of galaxies from one region to another. Also, remember a fundamental assumption that we made for getting our estimate, namely, that the number of galaxies we would see in some other portion of the sky is the same as that which we see in this Hubble deep field. (*8 points*)

9. Finally, there's one more caveat to our calculated total number of galaxies. To make our estimate, we *assumed* that the 10 day exposure sees every single galaxy in this portion of the sky. With this in mind, how would the calculation you just conducted compare to the real number of galaxies in the Universe? Back up your answer with a short explanation. (8 points)

### 15.3 The Mass and Density of the Universe (Contained in Galaxies)

In the preceding we have estimated the number of galaxies in the Universe. In the final section of this lab, we now want to explore the implications of this calculation by making an estimate of the matter density of the Universe. In your lecture sections, and some of the earlier labs (like the Terrestrial Planet lab, esp. Table 4.2) you have probably encountered the concept of density:  $\text{density} = \text{Mass}/\text{Volume}$ . Astronomers usually use the unit of  $\text{gm}/\text{cm}^3$  for density. We can now make an estimate for the density of matter contained in all of the galaxies in our Universe. We will start with very large numbers, and end up with an extremely tiny number. It is quite likely that your calculator cannot handle such numbers. To make this calculation easier, we will use some round numbers so that you can do the calculation by hand using the techniques outlined in Lab 1 (if you get stuck with how to multiply numbers with exponents, refer back to section 1.4). This is a challenging exercise, but one that gives you an answer that you might not expect!

10. In question 7 above, you estimated the total number of galaxies in the sky. If we assume that these galaxies are similar to (though probably somewhat smaller than) our Milky Way galaxy, we can calculate the total mass of all of the galaxies in the Universe. Over the course of this semester you will learn that the Milky Way has about 100 billion stars, and most of these stars are about the mass of the Sun, or somewhat smaller. The mass of the Sun is  $2 \times 10^{33}$

gm. Let's assume that the average galaxy in the Universe has 1/2 the number of stars that the Milky Way has: 50 billion. Fifty billion in scientific notation is  $5 \times 10^{10}$ . To calculate the mass (in gm) of all of the galaxies in the Universe, we need to solve this equation:

$$\text{Mass of Galaxies in Universe} = (\# \text{ of Galaxies}) \times (\text{Average Mass of a Galaxy})$$

You calculated the # of Galaxies in question 7. We need to multiply that number by the Average Mass of a Galaxy. The Average Mass of a Galaxy (in gm) is simply:

$$\text{Average Mass of a Galaxy} = (\# \text{ of stars in a galaxy}) \times (\text{average mass of a star})$$

If the number of stars in a galaxy is  $5 \times 10^{10}$ , and the average mass of a star is  $2 \times 10^{33}$  gm, what is the average mass of a galaxy? (2 points)

$$\begin{aligned} \text{Average Mass of a Galaxy} &= (\underline{\hspace{2cm}}) \times (\underline{\hspace{2cm}}) \\ &= \underline{\hspace{2cm}} \text{ gm} \end{aligned}$$

With this number, you can now calculate the total mass of all of the galaxies in the Universe (2 points):

$$\begin{aligned} \text{Mass of Universe} &= (\underline{\hspace{2cm}}) \times (\underline{\hspace{2cm}}) = \\ &\underline{\hspace{2cm}} \text{ gm} \end{aligned}$$

11. We have just calculated the total mass of galaxies in the Universe, and are halfway to our goal of figuring out the density of galactic matter in the Universe. Since density =  $M/V$ , and we now have  $M$ , we have to figure out  $V$ , the Volume of the Universe. This is a little more difficult than getting  $M$ , so make sure you are confident of your answer to each of the following steps before proceeding to the next. We are going to make some assumptions that will simplify the calculation of  $V$ . First off, we will assume that the Universe is a sphere. The volume of a sphere is simply four thirds "pi"  $R$  cubed:  $V_{\text{sphere}} = 4\pi R^3/3$ . To figure out the volume of the Universe we need to calculate " $R$ ", the radius of the Universe.

So, how can we estimate  $R$ ? In your lecture class you will find out that the most distant parts of the Universe are moving away from us at nearly the speed of light (the observed expansion of the Universe is covered in the Hubble's Law lab). Let's assume that the largest distance an object can have in our Universe is given by the speed of light  $\times$  the age of the Universe. Remember, if a car travels at 50 mph for one hour it will cover 50 miles: Distance = velocity  $\times$

time. We can use this equation to estimate the radius of the Universe:  $R_{\text{Universe}} = \text{velocity} \times \text{time} = (\text{speed of light}) \times (\text{age of Universe})$ .

The speed of light is a very large number:  $3 \times 10^{10}$  cm/s, and the age of the Universe is also large: 13 billion years. To calculate the radius of the Universe in cm, we must convert the age of the Universe in years to an age in seconds (s). First, how many seconds are there in a year? Let's do the calculation:

$$\text{Seconds in year} = (\text{seconds in day}) \times (\text{days in year}) = (60 \times 60 \times 24) \times 365 =$$

$$\underline{\hspace{2cm}} \text{ s/yr}$$

Since this is only estimate, feel free to round off any decimals to whole numbers. Now that we have the number of seconds in a year, we can convert the age of the Universe from years to seconds:

$$\text{Age of Universe in seconds} = (\text{Age of Universe in Years}) \times (\text{seconds in a year})$$

$$= (13 \times 10^9 \text{ yr}) \times \underline{\hspace{2cm}} \text{ s/yr} = \underline{\hspace{2cm}} \text{ s.}$$

Ok, we now have the "time" part of the equation  $\text{distance} = \text{velocity} \times \text{time}$ . And we have already set the velocity to the speed of light:  $3 \times 10^{10}$  cm/s. Now we can figure out the Radius of the Universe (3 points):

$$\text{Radius of Universe (in cm)} = (\text{speed of light}) \times (\text{Age of Universe in seconds}) =$$

$$(3 \times 10^{10} \text{ cm/s}) \times \underline{\hspace{2cm}} \text{ s} =$$

$$\underline{\hspace{2cm}} \text{ cm.}$$

In these calculations, notice how the *units* cancel. The units on a distance or radius is length, and astronomers generally use centimeters (cm) to measure lengths. Velocities have units of length per time, like cm/s. So when calculating a radius in cm, we multiply a velocity with units of cm/s  $\times$  a time measured in seconds, and the units of seconds cancels, leaving a length unit (cm).

We are now ready to calculate the Volume of the Universe,  $V = 4\pi R^3/3$ . It may be easier for you to break this into two parts, multiplying out  $4/3 \times \pi$ , and then taking  $R^3$ , and then multiplying those two numbers. [Remember,  $\pi = 3.14$ .]

$$\text{Volume of Universe} = 4/3 \times \pi \times R^3 =$$

$$\underline{\hspace{2cm}} \times \underline{\hspace{2cm}} =$$

$$\underline{\hspace{2cm}} \text{ cm}^3$$

12. Tying it all together: figuring out the average density of the Universe (at least that contained within galaxies—astronomers believe there is more “dark” matter in the Universe than the regular matter that we can see contained in galaxies!). We have just calculated the Volume of the Universe, and we have already calculated the Mass of all of the galaxies in the Universe. Now we take the final step, and calculate the Average Galactic Matter Density of the Universe (3 points):

$$\begin{aligned} \text{Average Density of the Universe} &= M_{\text{Universe}}/V_{\text{Universe}} = \\ &= (\text{_____ gm})/(\text{_____ cm}^3) = \\ &= \text{_____ gm/cm}^3 \end{aligned}$$

13. The mass of a single hydrogen atom is  $1.7 \times 10^{-24}$  gm. Compare your answer for the average density of the Universe to the mass of a single hydrogen atom. [Hint: the average amount of mass (*in gm*) of 1 cm<sup>3</sup> of the Universe is simply the density you just calculated, but you drop the cm<sup>3</sup> of the units on density to get *gm*.] Are they similar? What does this imply about the Universe, is it full of stuff, or mostly empty? (3 points)

## 15.4 Summary

(35 points) Please summarize the important concepts discussed in this lab. Your summary should include a brief discussion of

- direct measurement vs. estimation
- error estimates in both direct measurement and estimation
- Consider the importance of the galaxy counting results discussed in lab. Since the Hubble Deep Field was taken in a presumably empty part of the sky, what is the significance of finding so many galaxies in this picture?

- Use the concepts discussed in this lab to estimate the total number of stars that you can see in the night sky by going out at night and doing some counting and estimating. Describe your method as well as the number you get and provide some estimate of your uncertainty in the number.
- Think back to a time before you did this lab, would you have expected the answer to question #13? Our Universe has many surprises!

Use complete sentences, and proofread your summary before handing in the lab.

## 15.5 Extra Credit

In question #7, you estimated the number of galaxies in the Universe. In question #10 you found that a typical galaxy contains 50 billion stars. Thus, you can now estimate how many stars there are in the Universe. Recently, some mathematicians have estimated that there are between  $7 \times 10^{19}$  and  $7 \times 10^{22}$  grains of sand on all of the Earth's beaches—that is every single beach on every single island and continent on the Earth. Obviously, this is a difficult estimate to make, and thus their estimate is quite uncertain. How would you begin to estimate the number of sand grains on the Earth's beaches? What factors need to be taken into account?

Compare the number of stars in the Universe, with the number of grains of sand on the planet Earth. How do they compare? We still do not know the average number of planets that are found around an average star. It is probably safe to assume that 10% of all stars have at least one planet orbiting them. If so, how many planets are there in the Universe? (5 points)