

Name:

## Lab 14

# Galaxy Morphology

### 14.1 Introduction

Galaxies are enormous, “gravitationally bound” collections of billions, upon billions of stars. In addition to these stars, galaxies also contain varying amounts of gas and dust from which stars form, or from which they *have* formed. In the centers of some galaxies live enormous black holes that are sucking-in, and ripping apart stars and clouds of atomic and molecular gas. Galaxies come in a variety of shapes and sizes. Some galaxies have large numbers of young stars, and star forming regions, while others are more quiescent, mostly composed of very old, red stars. In today’s lab you will be looking at pictures of galaxies to become familiar with the appearances, or “morphology”, of the various types of galaxies, and learn how to classify galaxies into one of the three main categories of galaxy type. We will also use photographs/images of galaxies obtained using different colors of light to learn how the appearances of galaxies depend on the wavelength of light used to examine them.

- *Goals:* to learn about galaxies
- *Materials:* a pen to write with, a ruler, a calculator, and one of the notebooks of galaxy pictures

### 14.2 Our Home: The Milky Way Galaxy

During the summertime, if you happen to be far from the city lights, take a look at the night sky. During the summer, you will see a faint band of light that bisects

the sky. In July, this band of light runs from the Northeast down to the Southwest horizon (see Fig. 14.1). This band of light is called the Milky Way, our home galaxy. Because we are located within the Milky Way galaxy, it is actually very hard to figure out its exact shape: we cannot see the forest for the trees! Thus, it is informative to look at other galaxies to attempt to compare them to ours to help us understand the Milky Way's structure.

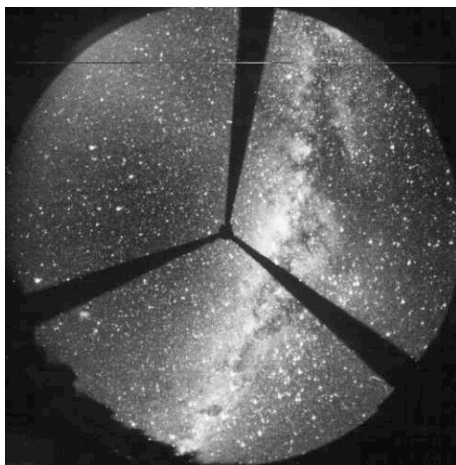


Figure 14.1: A fisheye lens view of the summertime sky showing the band of light called the Milky Way. This faint band of light is composed of the light from thousands and thousands of very faint stars. The Milky Way spans a complete circle across the celestial sphere because our solar system is located within the “disk” of the galaxy.

Galaxies are collections of stars, and clouds of gas and dust that are bound together by their mutual gravity. That is, the mass of all of the stars, gas and dust pull on each other through the force of gravity so that they “stick together”. Just like the planets in our Solar System orbit the Sun, the stars (and everything else) in a galaxy orbit around the central point of the galaxy. The central point in a galaxy is referred to as the “nucleus”. In some galaxies, there are enormous black holes that sit right at the center. These black holes can have a mass that is a billion times that of the Sun ( $10^9 M_{\odot}$ )! But not all galaxies have these ferocious beasts at their cores, some merely have large clusters of young stars, while others have a nucleus that is dominated by large numbers of old stars. The Sun orbits around the nucleus of our Milky Way galaxy (Fig. 14.2) in a similar fashion to the way the Earth orbits around the Sun. While it only takes one year for the Earth to go around the Sun, it takes the Sun more than 200 million years to make one trip around our galaxy!

Note that the central region (“bulge” and nucleus) of the Milky Way has a higher density of stars than in the outer regions. In the neighborhood of the Sun, out in the “disk”, the mass density is only  $0.002 M_{\odot}/\text{ly}^3$  (remember that density is simply the mass divided by the volume:  $M/V$ , here the Mass is solar masses:  $M_{\odot}$ , and Volume is in cubic light years:  $\text{ly}^3$ ). In the central regions of our Milky Way galaxy (within

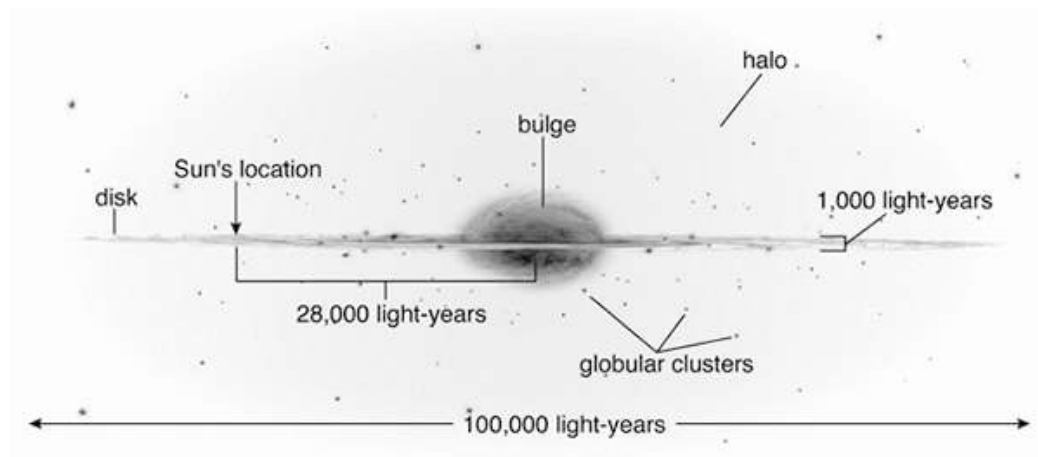


Figure 14.2: A diagram of the size and scale of our “Milky Way” galaxy. The main regions of our galaxy, the “bulge”, “disk”, and “halo” are labeled. Our Milky Way is a spiral galaxy, with the Sun located in a spiral arm 28,000 ly from the nucleus. Note that the disk of the Milky Way galaxy spans 100,000 ly, but is only about 1,000 ly thick. While the disk and spiral arms of the Milky Way are filled with young stars, and star forming regions, the bulge of the Milky Way is composed of old, red stars.

300 ly of the center), however, the mass density is 100 times higher:  $0.200 \text{ M}_{\odot}/\text{ly}^3$ . What does this mean? The nearest star to the Sun is Alpha Centauri at 4.26 ly. If we were near the nucleus of our Milky Way galaxy, there would be 200 stars within 4.26 ly of the Sun. Our sky would be ablaze with dozens of stars as bright as Venus, with some as bright as the full moon! It would be a spectacular sight.

Our Milky Way galaxy is a spiral galaxy that contains more than 100 billion stars. While the Milky Way is a fairly large galaxy, there are much larger galaxies out there, some with 100 times the mass of the Milky Way. But there are an even larger number of very small “dwarf” galaxies. Just like the case for stars, nature prefers to produce lots of little galaxies, and many fewer large galaxies. The smallest galaxies can contain only a few million stars, and they are thousands of times smaller than the Milky Way.

### 14.3 Galaxy Types: Spirals Ellipticals, and Irregulars

Shortly after the telescope was invented, astronomers started scanning the sky to see what was out there. Among the stars, these first astronomers would occasionally come across a faint, fuzzy patch of light. Many of these “nebulae” (Latin for cloud-like)

appeared similar to comets, but did not move. Others of these nebulae were resolved into clusters of stars as bigger telescopes were constructed, and used to examine them. Some of these fuzzy nebulae, however, did not break-up into stars no matter how big a telescope was used to look at them. While many of these nebulae are clouds of glowing hydrogen gas within the Milky Way galaxy (HII regions), others (some of which resembled pinwheels) were true galaxies—similar to the Milky Way in size and structure, but millions of light years from us. It was not until the 1920’s that the actual nature of galaxies was confirmed—they were true “Island Universes”, collections of millions and billions of stars. As you will find out in your lecture sessions, the space between galaxies is truly empty, and thus most of the matter in the Universe resides inside of galaxies: *They are islands of matter in an ocean of vacuum.*

Like biologists or other scientists, astronomers attempt to associate similar types of objects into groups or classes. One example is the spectral classification sequence (*OBAFGKM*) for stars. The same is true for galaxies—we classify galaxies by their observed properties. It was quickly noticed that there were two main types of galaxies, those with pinwheel shapes, “spiral galaxies”, and smooth, mostly round or oval galaxies, “elliptical” galaxies. While most galaxies could be classified as spirals or ellipticals, some galaxies shared properties of both types, or were irregular in shape. Thus, the classification of “irregular”. This final category is a catch-all for any galaxy that cannot be easily classified as a spiral or elliptical. Most irregular galaxies are small, messy, unorganized clumps of gas and stars (though some irregular galaxies result from the violent collisions of spiral and/or elliptical galaxies).

### 14.3.1 Spiral Galaxies

The feature that gives spiral galaxies their shape, and leads to their classification are their spiral arms. An example of a beautiful spiral is M81 shown in Fig. 14.3. A spiral galaxy like M81 resembles a whirlpool, or pinwheel: arms of stars, gas and dust that radiate in curving arcs from the central “bulge”.

Other spiral galaxies, like M51 shown in Fig. 14.4, have less tightly wound spiral arms, and much smaller bulges. Finally, there are spiral galaxies with very tightly wound spiral arms that are dominated by their bulge, like the Andromeda galaxy (M31) shown in Fig. 14.5. The arms are so tightly wound, that it is hard to tell where one ends and the other begins. These types of galaxies also have much less star formation.

Spiral galaxies are classified by how tightly their arms are wound, and how large their central bulges are. There are three main types of spirals: Sa, Sb, and Sc. Sa spirals have large bulges and tightly wound arms, while Sc’s have very loosely wound arms, and small bulges. Sb’s are intermediate between Sa’s and Sc’s (of course, like M31, there are galaxies that fall halfway between two classes, and they are given names like Sab, or Sbc). The spiral classification sequence is shown in Fig. 14.6.

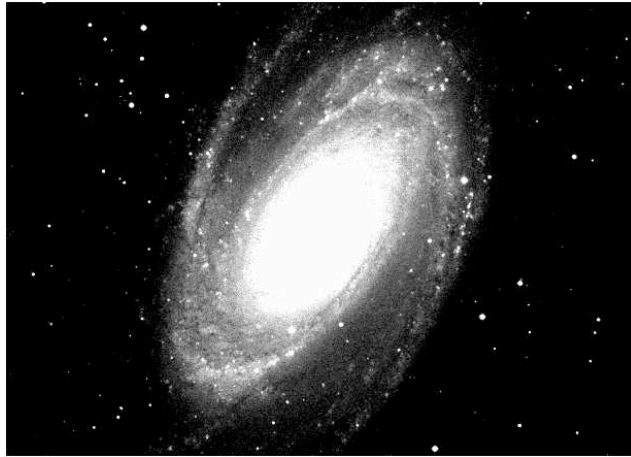


Figure 14.3: The Sb spiral galaxy M81. Notice the nice, uniform spiral arms that are wound tightly around the large, central bulge. Inside the spiral arms, there are large regions of glowing gas called HII regions—where stars are being born. These stand out as knots or clumps in the spiral arms. The dark spots, lanes, and arcs are due to dust clouds that are associated with these star forming regions.



Figure 14.4: The Sc spiral galaxy M51. Notice the large, clumpy spiral arms that are loosely wound around the small, central bulge. Inside the spiral arms of M51 there are very many large HII regions—M51 has many young star forming regions. Notice that there is also a lot more dust in M51 than in M81.

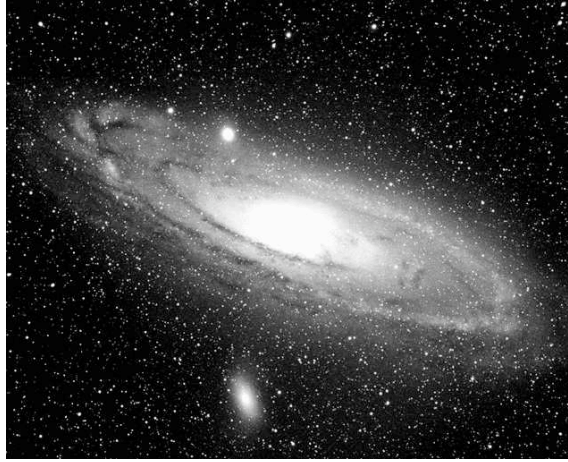


Figure 14.5: The Sab spiral galaxy M31. Notice the very large bulge, and very tightly wound spiral arms. Like the Milky Way, the Andromeda Galaxy has several small galaxies in orbit around it (just like planets orbit the Sun, some small galaxies can be found orbiting around large galaxies). Two of these galaxies can be seen as the round/elliptical blobs above and below the disk of the Andromeda galaxy shown here. Both are elliptical galaxies, discussed in the next section.

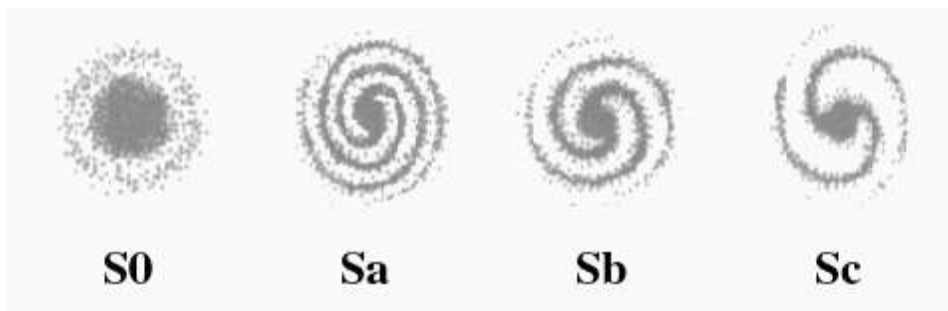


Figure 14.6: The classification sequence for spirals. S0 spirals are galaxies that show a small disk that is composed of only old, red stars, and have no gas, little dust and no star forming regions. They are mostly a large bulge with a weak disk, with difficult-to-detect spiral arms. They actually share many properties with elliptical galaxies. Sa galaxies have large bulges, and tightly wound spiral arms. Sb's have less tightly wound arms, while Sc's have very loosely wound arms, and have tiny bulges.

### 14.3.2 Elliptical Galaxies

Elliptical galaxies do not have as much structure as spiral galaxies, and are thus less visually interesting. They are smooth, round to elliptical collections of stars that are highly condensed in their centers, that slowly fade out at their edges. Unlike spiral galaxies, where all of the stars in the disk rotate in the same direction, the stars in elliptical galaxies do not have organized rotation: the individual stars orbit the nucleus of an elliptical galaxy like an individual bee does in a swarm. While they have random directions, all of the billions of stars have well-defined orbits around the center of the galaxy, and take many millions of years to complete an orbit. An example of an elliptical galaxy is shown in Fig. 14.7.

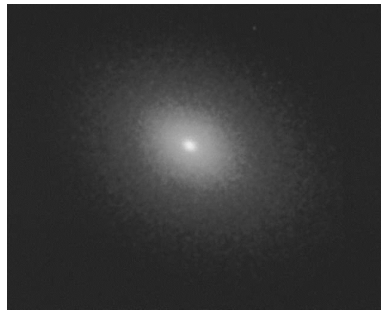


Figure 14.7: A typical elliptical galaxy, NGC205, one of the small elliptical galaxies in orbit around the Andromeda galaxy shown in Fig. 14.5. Most elliptical galaxies have a small, bright core, where millions of stars cluster around the nucleus. Just like the Milky Way, the density of stars increases dramatically as you get near the nucleus of an elliptical galaxy. Many elliptical galaxies have black holes at their centers. NGC205 is classified as an E5.

Elliptical galaxies can appear to be perfectly round, or highly elongated. There are eight categories, ranging from round ones (E0) to more football-shaped ones (E7). This classification scheme is diagrammed in Fig. 14.8.

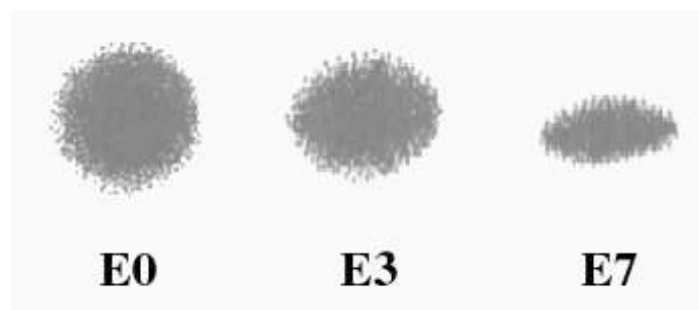


Figure 14.8: The classification scheme for elliptical galaxies. Elliptical galaxies range from round (E0), to football shaped (E7).

It is actually much easier to classify an elliptical galaxy, as the type of elliptical galaxy can be determined by measuring the major and minor axes of the ellipse. The definitions of the major and minor axes of an ellipse are shown in Fig. 14.9. To determine which type of an elliptical galaxy you are looking at, you simply measure the major axis (“a”) and the minor axis (“b”), and calculate:  $10 \times (a - b)/a$ . You will do this for several elliptical galaxies, below.

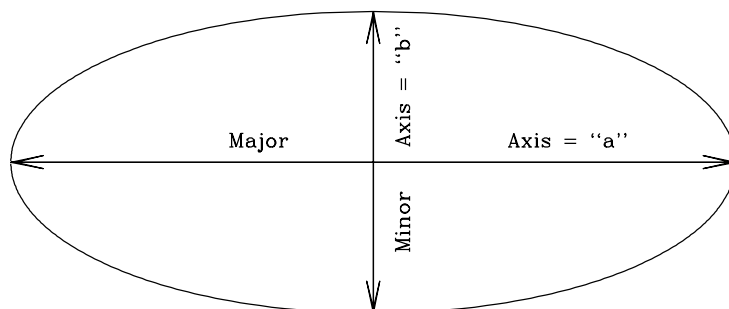


Figure 14.9: The definition of the major (“a”) and minor (“b”) axes of an ellipse.

### 14.3.3 Irregular Galaxies

As noted above, the classification of a galaxy as an “irregular” usually stems from the fact that it cannot be conclusively categorized as either a spiral or elliptical. Most irregular galaxies, like the LMC shown in Fig. 14.10, are small, and filled with young stars, and star forming regions. Others, however, result when two galaxies collide, as shown in Fig. 14.11.



Figure 14.10: The Large Magellanic Cloud (LMC). The LMC is a small, irregular galaxy that orbits around the Milky Way galaxy. The LMC (and its smaller cousin, the SMC) were discovered during Magellan’s voyage, and appear as faint patches of light that look like detached pieces of the Milky Way to the naked eye. The LMC and SMC can only be clearly seen from the southern hemisphere.



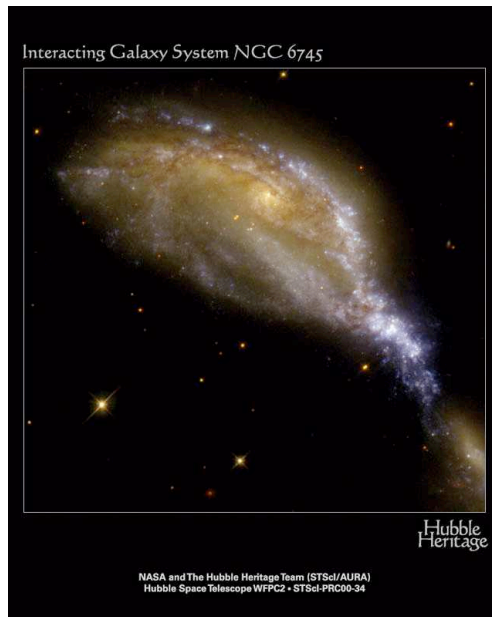


Figure 14.11: An irregular galaxy that is the result of the collision between two galaxies. The larger galaxy appears to have once been a normal spiral galaxy. But another galaxy (visible in the bottom right corner) ran into the bigger galaxy, and destroyed the symmetry typically found in a spiral galaxy. Galaxy collisions are quite frequent, and can generate a large amount of star formation as the gas and dust clouds are compressed as they run into each other. Some day, the Milky Way and Andromeda galaxies are going to collide—it will be a major disruption to our galaxy, but the star density is so low, that very few stars will actually run into each other!

#### 14.3.4 Galaxy Classification Issues

We have just described how galaxies are classified, and the three main types of galaxies. Superficially, the technique seems straightforward: you look at a picture of a galaxy, note its main characteristics, and render a classification. But there are a few complications that make the process more difficult. In the case of elliptical galaxies, we can never be sure whether a galaxy is truly a round E0 galaxy, or an E7 galaxy seen from an angle. For example, think of a football. If we look at the football from one angle it is long, and pointed at both ends. But if we rotate it by  $90^\circ$ , it appears to be round. This is a “projection effect”, and one that we can never remove since we cannot go out and look at elliptical galaxies from some other angle.

As we will find out, spiral galaxies suffer from a different classification issue. When the Sa/Sb/Sc classification scheme was first devised, only photographs sensitive to blue light were used. If you actually look at spiral galaxies at other wavelengths, for example in the red or infrared, the appearance of the galaxy is quite different.

Thus it is important to be consistent with what kind of photograph is used to make a galaxy classification. We will soon learn that the use of galaxy images at other wavelengths besides the visual that our eyes are sensitive to, results in much additional information.

## 14.4 Lab Exercises

For this lab, each group will be getting a notebook containing pictures of galaxies. *These notebooks are divided into five different sections.* Below, there are *five sections* with exercises that correspond to each of the five sections in the notebook. Make sure to answer all of the questions fully, and to the best of your ability.

### Section #1: Classification of Spiral Galaxies

In this section we look at black and white photographs of spiral galaxies. First you will see three standard spiral galaxies that define the Sa, Sb, and Sc subtypes, followed by more classification exercises.

**Exercise #1:** In pictures 1 through 3 are standard spiral galaxies of types Sa, Sb, Sc. Using the discussion above, and Figures 14.3 to 14.6, classify each of the spiral galaxies in these three pictures and describe what properties led you to decide which subclass each spiral galaxy fell into. (*3 points*)

**Exercise #2:** The pictures of the galaxies that you have seen so far in this lab are “positive” images, just like you would see if you looked at those galaxies through

a large telescope—white means more light, black means less light. But working with the negative images is much more common, as it is much easier to see fine detail when presented as dark against a light background versus bright against a dark background. For example, Picture #4 is the negative image for Picture #1. Detail that is overlooked in a positive image can be seen in a negative image. For most of the rest of this lab, we will look at negative images like those shown in Picture #4.

Classify the spiral galaxies in Pictures #5, 6, 7 and 8. In each case, describe what led you to these classifications. *(4 points)*

**Exercise #3:** So far, we have looked at spiral galaxies that have favorable orientations for classification. That is, we have seen these galaxies from a direction that is almost perpendicular to the disk of the galaxy. But since the orientation of galaxies to our line of sight is random, many times we see galaxies from the side view. In this exercise, you will look at some spiral galaxies from a less favorable viewing angle.

In pictures #9, 10, and 11 are three more spiral galaxies. Try to classify them. Use the same techniques as before, but try to visualize how each subtype of spiral galaxy would change if viewed from the side. (Remember that in a negative image, bright white means no light, and dark means lots of light—so dusty regions show up as white!) *(3 points)*

**Section #2: Elliptical Galaxies** As described earlier, elliptical galaxies do not show very much detail—they are all brighter in the center, and fade away at the edges. The only difference is in *how* elliptical they are, ranging from round (E0) to football-shaped (E7). In this section will learn how to classify elliptical galaxies.

**Exercise #4:** In pictures #12, 13, 14, and 15 are some elliptical galaxies. Using Figure 14.8 as a guide, classify each of these four galaxies as either E0, E1, E2, E3, E4, E5, E6, or E7. Describe how you made each classification. (*4 points*)

**Exercise #5:** In our discussion about elliptical galaxy classification, we mentioned that there was a *quantitative* method to classify elliptical galaxies: you use the equation  $10 \times (a - b)/a$  to derive the subclass number. In this equation “a” is the major

axis (long diameter) and “b” is the minor axis (the short diameter). Go back to Figure 14.9 to see the definition of these two axes. For example, if you measured a value of  $a = 40$  mm, and  $b = 20$  mm, then the subclass is  $10 \times (40 - 20) / 40 = 10 \times (20/40) = 10 \times (0.5) = 5$ . So that this particular elliptical galaxy is an E5.

If the measurements for an elliptical galaxy are  $a = 30$  mm and  $b = 20$  mm, what subclass is that galaxy? (Round to the nearest integer.) *(2 points)*

Measure the major and minor axes for each of the galaxies in pictures #12, 13, 14, and 15, and calculate their subtypes. Note: it can sometimes be hard to determine where the “edge” of the galaxy is—try to be consistent and measure to the same level of brightness. *(4 points)*

It is pretty hard to measure the major and minor axes of elliptical galaxies on black and white photographs! Usually, astronomers use digital images, and then use some sort of image processing to make the task easier. Picture #16 is a digitized version of picture #15, processed so that similar light levels have the same color. As you can see, this process makes it much easier to define the major and minor axes of an elliptical galaxy.

**Exercise #6:** Measure the major and minor axes of the two elliptical galaxies shown in Pictures #16 and #17, and classify them using the same equation/technique as

before. (2 points)

**Section #3: Irregular Galaxies** While most large galaxies in our Universe are either spirals or ellipticals, there are a large number of very strange looking galaxies. If we cannot easily classify a galaxy as a spiral or elliptical, we call it an Irregular galaxy. Some irregular galaxies appear to show some characteristics of spirals and/or ellipticals, others are completely amorphous blobs. Many of the most unusual looking galaxies are the result of the interactions between two galaxies (such as a collision). Sometimes the two galaxies merge together, other times they simply pass through each other (see Fig. 14.11). Pictures 18 through 22 are of irregular galaxies.

**Exercise #7:** The peculiar shapes and features of the irregular galaxies shown in Pictures #18, 19 and 20 are believed to be caused by galaxy collisions or galaxy-galaxy interactions (that is, a close approach, but not a direct collision). Why do you think astronomers reached such a conclusion for these three galaxies? (4 points)

**Exercise #8:** In Pictures #21 and 22 are images of two “dwarf” irregular galaxies. Note the general lack of any structure in these two galaxies. Unlike the collision-

caused irregular galaxies, these objects truly have no organized structures. It is likely that there are hundreds of dwarf galaxies like these in our Universe for every single large spiral galaxy like the Milky Way. So, while these dwarf irregular galaxies only have a few million stars (compared to the Milky Way's 100+ billion), they are a significant component of all of the normal ("baryonic") mass in our Universe. One common feature of dwarf irregular galaxies is their abundance of young, hot stars. In fact, more young stars are produced each year in some of these small galaxies than in our Milky Way, even though the Milky Way is 10,000 times more massive! Why this occurs is still not fully understood.

In the two dwarf irregular galaxies shown in Pictures #21 and 22, the large numbers of blue stars, and the high number of *bright* red supergiants (especially in NGC 1705) indicate a high star formation rate—that is lots of new, young stars. Why are large numbers of hot, luminous blue stars, and red supergiants linked to young stars? [Hint: If you have learned about the HR diagram, try to remember how long hot, blue O and B stars live. As their internal supply of hydrogen runs out, they turn into red supergiants.] (*4 points*)

#### **Section #4: Full Color Images of Galaxies**

As we have just shown, color images of galaxies let us look at the kinds of stars that are present in them. A blue color indicates hot, young O and B stars, while a predominantly red, or yellow color indicates old, cool stars (mostly red giants). In this section we explore the kinds of stars that comprise spiral and elliptical galaxies.

#### **Exercise #9: Comparison of Spirals and Ellipticals**

In Pictures #23 through 27 we show some color pictures of elliptical and spiral galax-

ies. Describe the average color of an elliptical galaxy (i.e., #23 & #24) compared to the colors of spiral galaxies (#25 to #27). *(3 points)*

Now, let's look more closely at spirals and ellipticals. When examining the color pictures of the spiral galaxies you should have noticed that the spiral arms are generally bluer in color than their bulges. Hot young stars are present in spiral arms! That is where all of the young stars are. But in the bulges of spirals, the color is much redder—the bulge is made up of mostly old, red stars. In fact, the bulges of spiral galaxies look similar to elliptical galaxies. Compare the large bulge of the Sombrero galaxy (Picture #27) to the giant E0 galaxy M87 (Picture #23). *(3 points)*



If the bulges of spiral galaxies are made-up of old, red giant stars, what does this say about elliptical galaxies? *(3 points)*

It is likely that you have learned about the emission of light by hydrogen atoms in your lecture sessions (or during the spectroscopy lab). Hydrogen is the dominant element in the Universe, and can be found everywhere. The brightest emission line in the visual spectrum of hydrogen is a red line at 656 nm. This gives glowing hydrogen gas a pinkish color. When we take pictures of glowing clouds of hydrogen gas they are dominated by this pink light. During the course of this semester, you will also hear about ‘HII’ regions (such as the “Orion Nebula”, see the monthly skycharts for February found in the back of this lab manual). HII regions form when hot O and B stars are born. These stars are so hot that they ionize the nearby hydrogen gas, causing it to glow. When we look at other spiral galaxies, we see many HII regions in them, just like those found in our Milky Way.

Of the spiral galaxies shown in Pictures 25 to 27, which has the most HII regions? Which appears to have the least? What does this imply about M51? *(3 points)*

### **Section #5: Multi-wavelength Views of Galaxies**

We now want to explore what galaxies look like at ultraviolet and infrared wavelengths. “Multi-wavelength” data provides insights that cannot be directly gleaned from visual images.

We have just finished looking at some color images of galaxies. Those color pictures were actually made by taking several images, each through a different color filter, and then combining them to form a true-color image. Generally astronomers take pictures through a red, green, and blue filter to generate an “RGB” color picture. Many computer programs, such as Adobe Photoshop, allow you to perform this type of processing. Sometimes, however, it is best not to combine several single-color images into a color picture—subtle detail is often lost. Also, astronomers can take pictures of galaxies in the ultraviolet and infrared (or even X-ray and radio!), light which your eye cannot detect. There is no meaningful way to represent the true colors of a galaxy in an ultraviolet or infrared picture. Why would astronomers want to look at galaxies in the ultraviolet or infrared? Because different types of stars have different colors, decomposing the light of galaxies into its component colors allows us to determine how such stars are distributed (as well as gas and dust). In Pictures #28 and 29 we present blue and red images of the spiral galaxy M81. As you have just learned, the bulges of spiral galaxies are red, and the spiral arms (and disks) of spiral galaxies are blue. Note how the red image highlights the bulge region, while the blue image highlights the disk. Hot stars emit blue light, so if we want to see how many blue stars there are in a galaxy, it is best to use blue, or even ultraviolet light.

In this part of the lab, we will look at some multiwavelength data. Let’s remind ourselves first about the optical part of the electromagnetic spectrum. It runs from ultraviolet (“U”, 330 nm), to blue (“B”, 450 nm), through green/visual (“V”, 550 nm), to yellow, red (“R” 600 nm) and infrared (“I”, 760 nm and longer). The high energy photons have shorter wavelengths and are ultraviolet/blue, while the low energy photons have longer wavelengths and are red/infrared. If we go to shorter wavelengths than those that can penetrate our atmosphere, we enter the true ultraviolet (wavelengths of 90 to 300 nm). These are designated by UV or FUV (FUV means “far” ultraviolet, below 110 nm). We will now see what galaxies look like at these wavelengths—but note that we will switch back to black and white photos.

### **Exercise #10: Comparison of Optical and Ultraviolet Images of Galaxies**

In Picture #30 are three separate images of two spiral galaxies. In the lefthand column are FUV, U and I images of the Sc galaxy NGC 1365, and in the righthand column are FUV, U and R images of the Sa galaxy NGC 2841. Remember that images in the FUV, UV, U and B filters look at hot stars, while images in V, R, and I look at cooler stars. The ultraviolet really only sees hot stars! Compare the number of hot stars in NGC 1365 with NGC 2841. Describe the spiral arms of NGC 2841. What do you think is happening in the nucleus of NGC 2841? (*4 points*)

In Picture #31 are FUV, U and R images of two more galaxies: the Sc galaxy NGC 2403, and the irregular galaxy IC 2574. Compare the number of red and blue stars in these two galaxies—are they similar? What is the main difference? (*3 points*)

In Picture #32 is a similar set of images for two elliptical galaxies, NGC 5253 and NGC 3115 (which can also be seen in Pictures #15 and 16) Compare these two galaxies. While NGC 3115 is a normal elliptical galaxy, NGC 5253 seems to have something interesting going on near its nucleus. Why do we believe that? Describe how we might arrive at this conclusion? (*3 points*)

### **Exercise #11: Comparison of Optical and Infrared Images of Galaxies**

Ok, now let's switch to the infrared. Remember that cool stars emit most of their energy in the red, and infrared portions of the electromagnetic spectrum. So if we

want to trace where the cool, red (and old) stars are, we use red or infrared images. Another benefit of infrared light is its power to penetrate through dust, allowing us to see through dusty molecular gas clouds.

In Pictures #33 through #35 are blue (“B”, 450 nm) and infrared (“H”, 1650 nm) images of spiral galaxies. In Picture #33 we have Sa galaxies, in #34 we have Sb galaxies, and in #35 we have Sc galaxies. Compare how easy/hard it is to see the spiral arms in the B images versus the H images. Where are the blue stars? Where are the red stars? Note that while the hot O and B stars are super-luminous (1 million times the Sun’s luminosity), they are very rare. For each O star in the Milky Way galaxy there are millions of G, K, and M stars! Thus, while an O star may have 60 times the Sun’s mass, they are tiny component of the total mass of a spiral galaxy. Thus, what does the infrared light trace? (*5 points*)

Finally, let’s take a look at the Milky Way galaxy. As we mentioned in the introduction, we are embedded in the disk of the Milky Way galaxy, and thus it is hard to figure out the exact shape and structure of our galaxy. In Picture #36 is an optical picture that spans the entire sky—we see that our Milky Way galaxy has a well-defined disk. But in the optical photograph, it is difficult to ascertain the bulge of the Milky Way, or the symmetry of our galaxy—there is just too much dust in the way! Picture #37 is an infrared view that is identical to the previous optical image. What a difference! We can now see through all of that dust, and clearly make out the bulge—note

how small it is. We think that the Milky Way is an Sc galaxy. Make an argument in support of this claim, compare it to the photographs of other tilted spiral galaxies from Exercise #3. [Note: both of these images are special “projections” of the celestial sphere onto a two-dimensional piece of paper. This “Aitoff” projection makes sure the sizes and shapes of features are not badly distorted. For proper viewing, the right hand edge of these pictures should be wrapped around so that it touches the left hand edge, and you would have to be viewing the picture from inside to get a proper perspective. It is hard to take a three dimensional picture of the sky and represent it in two dimensions! A similar problem is encountered when using a rectangle to make a map of our globe (see the Terrestrial planet lab.) *(8 points)*

## 14.5 Summary *(35 points)*

As we have just seen, galaxy classification is relatively straightforward. It simply depends on what the galaxy looks like! But there are problems, and for some galaxies we can never be 100% accurate in their classifications. This is especially true for elliptical or edge-on galaxies. We have also shown how images or pictures taken through different filters or other wavelengths improves our understanding of the kinds of stars found in galaxies, and how stars are formed.

- Describe the process for classifying a spiral galaxy.
- Describe the process for classifying an elliptical galaxy.

- What are the main difficulties in classifying these two main types of galaxies (they may not be the same issues!).
- What kind of information does multi-wavelength data (images) on galaxies provide? How is it useful? What does it tell us?
- What types of stars are found in spiral galaxies? In ellipticals? What does this tell us about elliptical galaxies?
- What types of stars are found in dwarf irregular galaxies?

### Extra Credit

In the introduction we mentioned that many galaxies (including the Milky Way) have large black holes at their centers. These black holes rip apart stars and suck in the gas. As the gas falls in, it gets very hot, and emits a lot of X-rays, ultraviolet and blue light. Compared to the galaxy, this hot gas region is tiny, and shows up as a small bright spot at the nucleus of the galaxy in the ultraviolet. Go back to Pictures 30 to 32 and list which of the galaxies appear to have black holes at their centers. How did you reach your conclusion? (*5 points*)

### Possible Quiz Questions

- 1) What are the three main types of galaxies?
- 2) What are the major components of the Milky Way and other Spiral galaxies?
- 3) How big is the Milky Way, and how many stars does it contain?
- 4) What are O and B stars like? How long do they live? What are red supergiants?
- 5) What are HII regions?
- 6) Draw the electromagnetic spectrum and identify the visual, infrared and ultraviolet regions.

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.