Galaxy Classification and the Hubble Deep Field

A. The Hubble Galaxy Classification Scheme
Adapted from the UW Astronomy Dept., 1999

Introduction

A galaxy is an assembly of between a billion \(10^9\) and a hundred billion \(10^{11}\) stars. In addition to stars, there is often a large amount of dust and gas, all held together by gravity. The Sun and the Earth are in the Milky Way Galaxy (sometimes referred to as "the Galaxy"). Galaxies have many different characteristics, but the easiest way to classify them is by their shape (or "morphology"), and Edwin Hubble devised a basic method for classifying them in this way. In his classification scheme, there are three types of galaxies: spirals, ellipticals, and irregulars.

* Spiral galaxies were the first to be discovered, because the most luminous galaxies near the Milky Way are spirals. These galaxies get their name from the spiral distribution of light seen in photographs. A subclass of spirals contains the barred spirals. Ordinary spirals have a nucleus, which is approximately spherical, while barred spirals have an elongated nucleus that looks like a bar. Spirals are labeled as Sa, Sb, or Sc; barred spirals are designated SBa, SBB, or SBc. The sub-classification (a, b, or c) refers both to the size of the nucleus and the tightness of the spiral arms. The nucleus of an Sc galaxy is smaller than in an Sa galaxy, and the arms of the Sc are wrapped more loosely.

* Elliptical galaxies are classified according to the relative sizes of their apparent major and minor axes. Thus if x and y are these apparent axes, an elliptical galaxy is classed as E\(n\) where

\[
n = 10 \cdot (x-y)/x
\]

Elliptical galaxies typically have \(n\) between 0 and 9.

* Irregular galaxies have no obvious spiral or elliptical structure. It is thought that many irregulars were once spiral or elliptical, but that a close encounter with a larger galaxy disrupted the organization of the material by gravitational forces. Irregular galaxies come in two types: Irr I's are resolvable into individual stars, and Irr II's are not.
Not all galaxies are easily classified. Quasars are the extremely bright cores of very distant active galaxies. These galaxies are so distant that the quasars look like stars in most images. However, their redshifts are so high that we know that they cannot be stars. These quasars are also all moving away from us at extremely high speeds. Quasar 3C273, for example, is moving away from us at 43,700 km/s (over 97 million mph)!

In the late 1920's, Edwin Hubble discovered one of the most fundamental properties of the universe, namely that it is expanding in all directions with a speed proportional to the distance. He used the redshift of spectral lines from distant galaxies, whose distances could be determined by other means (for example, by Cepheid variable observations or measuring the angular sizes of HII regions). He interpreted the observed spectral shift as a Doppler shift, and determined that all galaxies (except a few very close ones that are in the same group of galaxies as the Milky Way) are receding from the Milky Way Galaxy with speeds proportional to their distances:

$$v = H \cdot d$$

where $d$ is the galaxy's distance (in Mpc), $H$ is Hubble's constant (with a current value of about 65 km/s/Mpc), and the speed $v$ is found from the Doppler shift of the galaxy.

**Step 1:** Examine the images of each of the galaxies listed in the table. When there is more than one galaxy in the image, use the finding chart to identify the galaxy in question. Identify each galaxy's type, if possible. Estimate the subgroup of the spirals, and measure the major and minor axes of the ellipticals so that you can calculate $n$ and find the subclass. Use any scale you like to measure the x and y axes, but make sure to measure both axes on the same scale. **Note: you only need to measure the axes for the elliptical galaxies!** Record this information in Table 1.

**Step 2:** Use the Hubble constant and the formula given above to find the distance to each galaxy. Convert the distance from Mpc to light years. ($1 \text{ Mpc} = 3.26 \times 10^6 \text{ ly}$) Converting to light years gives the amount of time (in years) the light spent traveling between leaving the galaxy and the telescope. Record these times in the last two columns of Table 1.

**Step 3:** Check to make sure that all of your answers in the second-to-last column make sense. For example, check that none of the galaxies' light has been traveling for more than the age of the Universe (about 14 billion years). It is often difficult to make astronomical numbers meaningful. For each of the galaxies, we can think about what was happening in the Earth's history when the light left that galaxy. For reference, the dinosaurs became extinct about 65 million years ago, Pangaea split into multiple continents about 200 million years ago, the Earth is about 4.5 billion years old, and the Universe is about 14 billion years old.

**Q1:** The velocity of NGC224 is negative. What does this mean?
Q2: 3C273 is one of the brightest radio sources in the sky. But the type of galaxy 3C273 is impossible to find from these images. Does this make sense? Hint: Look at the distance...

Q3: Look again at the color image of NGC5194 (displayed on the computer). What color are the arms? What color is the bulge? Explain the colors that you see.

B. Examining the Hubble Deep Field

Introduction

This is a picture of the Hubble Deep Field (HDF). The “deepest” image of the sky ever taken, it was made in 1996 using the Hubble Space Telescope by effectively leaving the shutter open for 11 consecutive days. Looking at these galaxies is like looking
backward in time: we can see galaxies from near the beginning of the universe. From this picture we will roughly estimate the total number of galaxies in the universe and how much matter there is in the universe. We can use this information to find out the fate of the universe: whether it will expand forever, or collapse with a “Big Crunch” and perhaps then start up again with another Big Bang.

A high-resolution color version of this image can be found at the following web site (warning: image is about 2 MB in size!)

http://imgsrc.hubblesite.org/hu/db/1996/01/images/c/formats/full_jpg.jpg

**Part 1: The Size of the HDF**

First we need to know how big the image is. On Earth, we measure area in square inches, square feet and square meters, or acres and hectares. In space, we measure distances in the sky using angle units, like degrees or arc-seconds. We measure area in the sky using square degrees or square arc-seconds, which we write as (arc-seconds)$^2$. The area of the HDF image is equal to the area of a square with 2.4 arc-minute long sides. (The actual HDF image is not square, but L-shaped because it was taken with 4 separate cameras on the Hubble.) One arc-second is $1/60^{th}$ of one arc-minute, and one arc-minute is $1/60^{th}$ of a degree. So the HDF is only looking at a very small portion of the sky (much smaller than, say, the moon). To help visualize this, we will need to convert from degrees into arcseconds.

The area of the moon is: $0.5$ degrees x $0.5$ degrees = $0.25$ (degrees)$^2$

**Q4:** Convert the area of the moon into (arc-minutes)$^2$

The area of the HDF is: $2.4$ arc-minutes x $2.4$ arc-minutes = $5.76$ (arc-minutes)$^2$

**Q5:** How many HDFs can fit into the moon’s area?

Let’s imagine the size of that. Take a sharpened pencil (or pen with a narrow tip) and hold it at arm’s length. The look at the tip of the pencil: the size of that tip is roughly the same area taken up by the HDF. Now look again at all the galaxies in the HDF. They are all contained within this pencil-lead sized part of the sky! If there are that many galaxies in that small of an area, how many galaxies would there be in the whole sky?

Let’s try to estimate that number. First we need to know how many HDFs we would need to cover the entire sky. Then, we need to count the galaxies in the HDF and multiply that by the number of HDFs in the sky.
There are about $41,000$ (degrees)$^2$ in the entire sky.

**Q6:** Convert the total area of the sky to (arc-minutes)$^2$
Q7: How many HDFs would you need to cover the entire sky?

You should be getting a pretty big number. You have just calculated how many “pencil tip” sized portions there are in the entire sky. Behind every pencil tip held at arm’s length, there is a field of galaxies containing about as many galaxies as we see in the HDF!

Part 2: The Total Number of Galaxies in the Universe

Your next task is to determine the total number of galaxies in the HDF. You *could* count them all… but there are easier (and faster) ways to estimate the number. Here a portion of the HDF is shown that is 1.0 arc-minute long on each side, so it has an area of 1 (arc-minute)$^2$.

Q8: Discuss with your partner(s) a plan for using this smaller field to estimate the total number of galaxies in the total HDF, and describe your method on your answer sheet. Check your method over with the instructor before you continue.
Q9: Next, determine the number of galaxies in the HDF, using the method your group outlined in the previous step. We will assume that the HDF is a fairly common patch of sky in the universe, so we can next use this number combined with our result from Q7 to figure out how many galaxies there are in the entire universe.

Part 3: The Mass and Density of the Universe

(i) The Mass of the Universe

Now, let’s estimate the mass of one galaxy, in terms of the mass of the sun (solar units). We’re going to assume that the Milky Way galaxy, our galaxy, is pretty typical. There are about 400,000,000,000 (400 billion) stars in the Milky Way. For this exercise, let’s assume each star has a mass equal to the mass of the Sun, 2 x 10^{33} grams.

Q10: Calculate the mass of the Milky Way galaxy in grams, using the information in the above paragraph.

Q11: Now multiply your result from Q10 by the total number of galaxies in the universe to find the total mass of all galaxies in the universe.

Now we know how much observable matter there is in the universe. We will use this number to say something about the fate of the universe. For example, is there enough matter in the universe for it to eventually collapse? Another way to ask the question is: Is the gravitational force between all the galaxies large enough for the universe to eventually pull itself back together? Well, the gravitational force depends on the mass AND the distance between the masses.

(ii) The Size of the Universe

We do not know the size of our current universe very accurately, but we can estimate it. We know that light travels at 3.0 x 10^{10} centimeters per second (cm/s). If we assume that the light from the most distant galaxies was emitted roughly ten billion years ago, we can calculate the distance.

Q12: How many centimeters are there in one light year? Another way to think about this question is: how far (in centimeters) can light travel in one year if the speed of light is 3 x 10^{10} cm/s?

Q13: The farthest galaxies are 10 billion (10,000,000,000) light years away. Express this distance in centimeters.

(iii) The Density of the Universe

The formula for the volume of a sphere in terms of its radius, r, is: \( V = \frac{4}{3}\pi r^3 \).
Q14: Assuming that the universe is roughly spherical, and its radius is the distance to the farthest galaxies, calculate the volume of the entire observable universe in units of centimeters-cubed (cm$^3$).

Q15: Finally, determine the density of the universe in grams per centimeter-cubed (g/cm$^3$). The density is the total mass (which we figured out in Q11) divided by the volume (from Q14).

The critical density of the universe is about $5 \times 10^{-30}$ g/cm$^3$. If the universe is more dense than this, then the gravitational attraction of all the galaxies will pull the universe together, reversing the expansion of the universe and creating a so-called “Big Crunch.” Less dense, and the universe will continue to expand forever.

Q16: Is your observed density of the universe smaller or larger than the critical density? Based on your calculation, what is the fate of the universe? Will it expand forever or contract?

Part 4: How reliable is your answer?

We did some sound calculations in this exercise, but we also made several assumptions and included a range of “educated guesses.” Let’s consider some of our assumptions.

Q17: One of our assumptions is that the light collected in the HDF image reveals the presence of all the mass (in the form of galaxies) within that particular field of view. How valid is this assumption? Can you think of some types of mass that might not have been visible in the HDF?

Q18: List at least 3 other assumptions we made in this exercise.

Q19: Discuss how your results would be different if some of the assumptions we made were not in fact correct. (For example, what if there were large quantities of mass that exist, but were not detected in the HDF? What would that mean for our results?)
Galaxies Worksheet

Table 1: Galaxy Classification

<table>
<thead>
<tr>
<th>Galaxy Name</th>
<th>x (ellipticals)</th>
<th>y (ellipticals)</th>
<th>Type</th>
<th>Velocity (km/s)</th>
<th>Distance (Mpc)</th>
<th>Light Travel Time (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 1381</td>
<td></td>
<td></td>
<td></td>
<td>1630</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 1398</td>
<td></td>
<td></td>
<td></td>
<td>1299</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 224</td>
<td></td>
<td></td>
<td></td>
<td>-59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 3031</td>
<td></td>
<td></td>
<td></td>
<td>95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 3384</td>
<td></td>
<td></td>
<td></td>
<td>642</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 4374</td>
<td></td>
<td></td>
<td></td>
<td>854</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 4435</td>
<td></td>
<td></td>
<td></td>
<td>793</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 4486</td>
<td></td>
<td></td>
<td></td>
<td>1180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 4565</td>
<td></td>
<td></td>
<td></td>
<td>1122</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 4594</td>
<td></td>
<td></td>
<td></td>
<td>963</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 4763</td>
<td></td>
<td></td>
<td></td>
<td>329</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 5055</td>
<td></td>
<td></td>
<td></td>
<td>587</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 5194</td>
<td></td>
<td></td>
<td></td>
<td>565</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 5236</td>
<td></td>
<td></td>
<td></td>
<td>337</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 7331</td>
<td></td>
<td></td>
<td></td>
<td>1105</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3C273</td>
<td></td>
<td></td>
<td></td>
<td>43,700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>