Chapter 24 Normal and Active Galaxies

Hubble's Galaxy Classification

Figure 24.1 shows a piece of space about 100 million pc from the Earth. Just about every point of light you see is a galaxy. We have photographed millions of galaxies in groups like this. Even through a small telescope a galaxy looks nonstellar. Some of them look like a blob while others look just like the Andromeda galaxy. Edwin Hubble was the first to look at the different types of galaxies out there. He classified them as *spirals*, *barred spirals*, *ellipticals*, and *irregulars*. When all was said and done he produced the *Hubble classification scheme*.

Spirals

We have seen several examples of spirals, such as the Andromeda Galaxy. These galaxies all contain a flattened disk with a dense, nuclear bulge and an extended halo of old stars. The spiral galaxies are denoted by the letter S and the individual galaxies are classified by a, b, and c. A Sa galaxy has a large nuclear bulge and a Sc has the smallest bulge. Figure 24.2 Just like the Milky Way the halos and nuclei contain red and yellow stars, which are the oldest. Most of the light comes from the A – G type stars in the disk. These disks are rich in dust and gas, which makes them prime for star formation. They contain newly formed O and B class stars. That gives them a bluish color. Sc galaxies contain the most dust and gas while the Sa galaxies contain the least. Most of these galaxies are not seen face on, but they are tilted as seen from Earth. We don't need to see the spiral arms to classify the galaxy as a spiral. The disk with its dust and gas and young stars is enough. Figure 24.3 is definitely a spiral because of the clear line of obscuring dust in the galaxy. A variation of the spirals is called the *barred spirals*. Figure 24.4 There is a bar running through the nucleus and the arms come off the arms. They are designated by SB and then the a, b, and c. Recent studies shows that the nucleus of the Milky Way is elongated which suggests that we are a barred spiral.

Ellipticals

Elliptical galaxies have no disk or spiral arms. They often show almost no structure at all. As you go toward the center the stellar density increases as you would expect. These galaxies are designated by the letter E. the most perfectly spherical is classified by E0 and if it flattened slightly it is an E1 galaxy. This goes all the way to E7. Figure 24.5 there is a large range in both size and numbers of stars that are found in ellipticals. Giant ellipticals may be a few megaparsecs across and contain trillions of stars while the dwarf ellipticals may be 1 kpc and contain less than a million stars. The dwarfs are the most common of the ellipticals, outnumbering the giants by 10:1. Ellipticals contain little or no dust and cool gas unlike the spirals. There are no dust lanes to be seen. They are made up of mainly old reddish stars. Just like the halo of the spirals, the motion of the elliptical galaxy's stars is random. One big difference is that there are large amounts of hot gas; millions of K that emits in the X-rays. Some giant ellipticals are exceptions to many of the rules about ellipticals. Some have been found with disks of dust and gas where stars are forming. Astronomers think these are due to collisions between galaxies. There is a classification between E7 and Sa called the *S0 galaxies*. If a bar is present they are called *SB0 galaxies*. Figure 24.6 They are known as *lenticular galaxies* because of their lens shape.

Irregular Galaxies

This class of galaxies has no set shape. Most of them look as though they are being torn apart by some type of force. We have 2 of this type as our companion galaxies. They are called the *Large and Small Magellanic Clouds*. Figure 24.7 They are usually smaller than the spirals, containing between 100 million and 10 billion stars. The smallest are the *dwarf irregulars* which are the most common. The Magellanic Clouds are about 50 kpc from us. The distances have been determined by using Cepheid variable stars. The Large Cloud contains about 6 billion M_{sun}. Both clouds contain lots of dust and gas and young stars so we know that star formation is still going on today. Radio studies show us that there is a bridge of hydrogen gas connecting the Milky Way to its companion galaxies.

The Hubble Sequence

When Hubble put together his galaxy sequence, he used a tuning fork as his model. It puts the ellipticals on the handle of the tuning fork starting at E0 down to E7 and then to S0. The 2 parts of the fork are the spirals and barred spirals from a to c. This is nice to look at, but it just isn't so. There is no evidence that ellipticals that have no dust and gas become spirals full of dust and gas. And there is no evidence that it goes the other way. Isolated galaxies just don't evolve that way.

The Distribution of Galaxies in Space

Let's look at how galaxies are spread throughout space. We will see that this distribution is not even.

Extending the Distance Scale

Astronomers think that there may be as many as 40 billion galaxies out there. Some are close enough for us to see Cepheid variables in them. We have been able to see and measure Cepheids out to 25 Mpc. This allows us to calculate the distance fairly accurately. But what do you do beyond 25 Mpc? We use what are called *standard candles*. These are objects that we know their luminosities accurately. If we can determine the apparent brightness from its luminosity and we know the absolute brightness, we can do a distance calculation. This provides the distance to the galaxy that it resides in. A standard candle must have a narrowly defined luminosity and be bright enough to be seen at large distances. We have learned how to use a number of different things such as novae, Type I supernovae and even galaxies themselves. But each of these objects has not been equally useful due to some uncertainties. In recent years, planetary nebulae and Type I supernovae have become particularly useful. They have been measured out to many hundred of Mpcs. In the 1970's astronomers found a very important relationship between the rotational speed of the galaxy and the luminosities of the galaxy. The Tully-Fisher relation allows us to accurately determine the luminosity of a galaxy by measuring the speed of rotation. We can determine the rotation rate by doing a Doppler study. One side of the galaxy comes towards you while the other side moves away from us. This can be used out to about 200 Mpc. The preferred line that we use to do this is the 21 cm wavelength. Figure 24.12 shows the distance ladder that has been put together so far.

Clusters of Galaxies

Figure 24.13 shows the position of major astronomical objects within about 1 Mpc of us. If you look closely you will find that there are about 45 galaxies in our neighborhood. All of these galaxies together are called the *Local Group*. The combined gravity of all of these galaxies holds them together. This type of group is called a *galaxy cluster*. The next large group beyond the Local Group is called the Virgo Cluster. It is about 18 Mpc from us and contains about 2500 galaxies. Most of the galaxies that we see belong to some cluster. Figure 24.15 shows us a cluster that lies about 1 billion pc from us. About 20 % of the galaxies do not belong to any cluster, but are rather isolated systems in space.

Hubble's Law

Now that we have seen some of the galaxies and galaxy clusters, let's look at how they move through space.

Universal Recession

In 1912 Vesto Slipher at Lowell Observatory was working on the motions of the galaxies. What he found was that everything he had measured had a red shift. That meant that they were all moving away from us. We now know that except for some of the galaxies in the Local Group, everything is moving away from us. Figure 24.16 shows the spectra of several galaxy groups and how they are moving. You can see that as we look farther out, the faster they appear to be moving. If we look at Figure 24.17 we see the 5 galaxy groups in figure 24.16 plotted out and then we see numerous galaxies plotted out. The 2 lines are basically the same. The farther you go out, the faster they are moving. This is the *Hubble Law*. This means that the universe itself is expanding. Space itself is expanding, which is why our galaxy is not expanding. This universal recession is sometimes called the *Hubble flow*. Any redshift caused by the Hubble flow is called a *cosmological redshift*.

Hubble's Constant

When looking at the proportionality between the velocity and Hubble's law we have the *Hubble's constant*. It is written as H_o. Recessional velocity = H_o x distance The number for the Hubble constant is around 70 km/sec/Mpc. That means that for every megaparsec an object is from us, it is moving at 70 km/sec. Most astronomers use a range of 50 – 80 km/sec/Mpc. We will accept 70 as the number.

The Top of the Distance Ladder

The Hubble constant is the top of the distance ladder. It is useful beyond 100 million parsecs. Many of the galaxies that we are looking at are moving at speeds that are a significant part of the speed of light. The most distant objects seen have redshifts that equate to 9000 Mpc, which is close to the limits of the observable universe.

Active Galactic Nuclei

Probably 75% of the galaxies have normal nuclei in them. Our galaxy has a luminosity of about 2 x 10^{10} L_{sun}. A small number of galaxies don't fit well into the scheme. They are brighter than the rest of the galaxies. When we say bright we mean 10^{10} times the solar value. These galaxies may have luminosities thousands of times brighter than the Milky Way are called *active galaxies*. They look like most galaxies, but at other wavelengths they are quite different.

Galactic Radiation

As you can see from Figure 24.19 there is quite a difference between a normal galaxy and an active galaxy. An active galaxy emits more energy in more wavelengths. Many luminous galaxies with nonstellar emissions are called *starburst galaxies*. Here something has caused a large number of stars to be born at one time. We will talk about active galaxies whose abnormal activity is found in the nucleus. These are called *active galactic nuclei*. There is considerable variation in these objects. Figure 24.20 shows a galaxy with a very bright nucleus and a large amount of star formation. WE will speak about 3 basic types of objects. 1)Seyfert Galaxies, 2)radio galaxies, and 3)Quasars.

Seyfert Galaxies

IN 1943 Carl Seyfert found a class of galaxies that look to be pretty normal except for the fact that most of its energy is emitted from the nucleus. It is 10,000 times brighter than the nucleus of the Milky Way. Most Seyferts emit most of their energy in the infrared. Astronomers think that the higher energy wavelengths are absorbed by dust in or near the nucleus. The spectra show that material in the nucleus is moving rapidly with velocities as high as 5000 km/sec. Figure 24.21 shows another Seyfert galaxy. Also a Seyfert can vary its output significantly in less than a year. All of this evidence says that violent, nonstellar activity is occurring in the core.

Radio Galaxies

Just like the name suggests, a radio galaxy emits huge amounts of energy in the radio part of the spectrum. These galaxies look nothing like a Seyfert galaxy. If you look at Figure 24.23 you will see the Centaurus galaxy. As you can see this galaxy has 2 huge *radio lobes* coming out of the nucleus. These are clouds of gas expanding out to half a megaparsec. End to end they can span more than 10 times the Milky Way. Centaurus A is an E2 galaxy that has the lobes jutting out perpendicular the dust lane around the galaxy. Figure 24.24 shows a close up of the galaxy. It is a low brightness galaxy that lies rather close to us. Figure 24.25 shows a more powerful emitter called Cygnus A. It is abut 250 Mpc from Earth. IN the visible image you can see that it really is 2 colliding galaxies. The radio lobes of a galaxy like Cygnus A emit 10 times more energy in the radio than the Milky Way does in all wavelengths. Even so, these galaxies emit far more energy in the shorter wavelengths. Not all radio galaxies have the lobes. Some are called *core-dominated radio galaxies*. Figure 24.26 shows a galaxy called M86 and you can see the radio emissions from that galaxy. It is likely that all radio galaxies have lobes, but because of their orientation we can't always see them. Figure 24.27

Common Features of Active Galaxies

Things that we stated about Seyfert galaxies and radio galaxies appear to be pretty common for most active galaxies. There is a large amount of energy generated across the spectrum by these galaxies. It is usually emitted from the central part of the galaxy. Jets are pretty common in these galaxies. Figure 24.28 shows a jet coming out of the galaxy called M87. It is an E1 galaxy about 100 kpc across. You can see a jet that is 2 kpc long coming out of the galaxy. It appears to be a series of blobs that suggests the material was ejected during bursts of activity. If we were aligned perfectly with the jet so that it was coming straight at us, the beam would be both intense and Doppler shifted towards the short wavelengths. It would be called a *blazar* and would shine in the X-rays or gamma rays. All of the galaxies that we have talked about show signs of interactions with other galaxies.

Quasars

In the early 1960's many radio objects were catalogued but no visible object could be found with these sources. In 1960 a faint blue star appeared at the site of 3C 48 and its spectrum was obtained. The spectrum defied explanation. In 1962 another spectrum was obtained with the same characteristics. This object was 3C 273. IN 1963 the mystery was solved. The spectrum of 3C 273 was just the hydrogen lines shifted by 16 % which means that the object was moving at 48,000 km/s. Figure 24.30 Once that was figured out, it was determined that 3C 48 had its hydrogen shifted 37 % which means that it is moving at about 1/3 the speed of light. That means that they are not members of the Milky Way. Using the Hubble constant we arrive at distances of 650 Mpc for 3C 273 and 1400 Mpc for 3C 48. However that doesn't explain what they are. They must be some of the most luminous objects in the universe. The object 3C 273 must have a luminosity of 20 trillion M_{sun}. At this point it was determined that they were not stars, but because of how they look, they were called *quasi-stellar radio sources* or *quasars*. We now know of more than 30,000 quasars. The closest is about 240 Mpc away and the farthest is about 9000 Mpc. That means that the quasars date back to near the beginning of the universe. Figures 24.29, 24.31, and 24.32 show several different things dealing with quasars. A unique thing about quasars is that they are very small, very bright, and very far away. Common sense says that you can have a combination of any 2 of those but not all 3.

The Central Engine of an Active Galaxy

Active galaxies show the following traits:

1) High luminosities
2) Nonstellar
3) Energy output can be variable
4) Often have jets and other signs of explosive activity
5) Rapid internal motion

Energy Production

The energy produced in a quasar could be produced in a giant galaxy of about a trillion stars. So this amount of energy is not unheard of, but this is the kicker: a galaxy like M87 is 100 kpc across and a quasar is less than a parsec in diameter. The fact that the object must produce huge amounts of energy and be very small brings us back to a black hole, albeit a supermassive one. We are talking about one of at least 3 – 4 million M_{sun}. Figure 24.33 shows us what we think the central engine of an active galaxy must be like. We have an accretion disk that swirls down towards the black hole and heats up to millions of K. It would emit in the X-ray region of the spectrum. The amount of mass that is turned into energy would only need to be about 1 M_{sun} of material per decade for a billion M_{sun} black hole. Thus to power a large quasar you need to consume about 10 M_{sun} of mass per year. That is not unreasonable. Why the jets? We really don't know about them yet. One idea is that they are formed by strong magnetic fields. Figure 24.35 shows the spectroscopic data from the center of M87. This shows that it rotates very fast and that the jet is perpendicular to the rotation.

Energy Emission

The energy coming from the central region of this object appears to have been reprocessed. In stead of being in the infrared to X-ray region, most of it is in the infrared. Astronomers think that this occurs in a fat donut shaped ring of dust and gas surrounding the inner accretion disk. Figure 24.36 shows us how this works. If we see this object from the side , we see most of the information in the infrared, but if it points in our general direction we see a broader spectrum of radiation. The jets and radio lobes are places where the magnetic fields are being transported into intergalactic space by the jets and lobes. As electrons are ejected into space they follow the magnetic field lines and they begin to spiral around them. They emit electromagnetic radiation called *synchrotron radiation*. With this type of radiation there is no link between temperature and intensity. The jet or lobe is slowed by the intergalactic medium and it releases virtually all of its energy as synchrotron radiation. This also means that the source of all of this energy is the accretion disk which is a billion billion times smaller than the lobe or jet. The jets are simply the means of transporting the energy.