Imagine the Universe!

Presents

The Hidden Lives of GALAXIES

Written by

Dr. James C. Lochner
NASA/GSFC
Greenbelt, MD

Lisa Williamson
Drew Freeman Middle School
Suitland, MD

Ethel Fitzhugh
Drew Freeman Middle School
Suitland, MD

This booklet, along with its matching poster, is meant to be used in conjunction with the Imagine the Universe! Web site or CD-ROM.

http://imagine.gsfc.nasa.gov/

Table of Contents

National Mathematics and Science Content Standards for the Activities in this Booklet

All Standards are for Grades 9-12

NSES	NCTM
1. How Big is the Universe?	
Standard A: Science as Inquiry	Standard 1: Problem Solving
Standard B: Physical Science	Standard 2: Communication
Standard D: Structure & Evolution of the Universe	Standard 3: Reasoning
	Standard 4: Connections
2. Identifying Galaxies	
Standard A: Science as Inquiry	Standard 1: Problem Solving
Standard B: Physical Science	Standard 2: Communication
Standard D: Structure & Evolution of the Universe	Standard 3: Reasoning
Standard G: History & Nature of Science	Standard 4: Connections
3. Classifying Galaxies Using Hubble's Fork Diagram	
Standard A: Science as Inquiry	Standard 1: Problem Solving
Standard B: Physical Science	Standard 2: Communication
Standard D: Structure & Evolution of the Universe	Standard 3: Reasoning
Standard G: History & Nature of Science	Standard 4: Connections
	Standard 6: Functions
	Standard 8: Patterns
4. Identifying Unusual Galaxies	
Standard A: Science as Inquiry	Standard 1: Problem Solving
Standard B: Physical Science	Standard 2: Communication
Standard D: Structure & Evolution of the Universe	Standard 3: Reasoning
Standard G: History & Nature of Science	Standard 4: Connections
	Standard 8: Patterns

5. Open Clusters versus Globular Clusters

Standard A: Science as Inquiry
Standard B: Physical Science
Standard D: Structure & Evolution of the Universe
Standard G: History & Nature of Science

Standard 1: Problem Solving
Standard 2: Communication
Standard 3: Reasoning
Standard 4: Connections
Standard 6: Functions
Standard 8: Patterns

6a. Evidence for Hidden Mass
6b. Extension: Weighing a Galaxy

Standard A: Science as Inquiry
Standard B: Physical Science
Standard D: Structure & Evolution of the Universe
Standard G: History & Nature of Science

Standard 1: Problem Solving
Standard 2: Communication
Standard 3: Reasoning
Standard 4: Connections
Standard 6: Functions
Standard 8: Patterns
Standard 10: Statistics
Standard 11: Probability

7. Dark Matter Possibilities

Standard A: Science as Inquiry
Standard B: Physical Science
Standard D: Structure & Evolution of the Universe
Standard G: History & Nature of Science

Standard 1: Problem Solving
Standard 2: Communication
Standard 3: Reasoning
Standard 4: Connections

8. The Universe as Scientists Know It

Standard A: Science as Inquiry
Standard B: Physical Science
Standard D: Structure & Evolution of the Universe
Standard G: History & Nature of Science

Standard 1: Problem Solving
Standard 2: Communication
Standard 3: Reasoning
Standard 4: Connections

9. Scavenger Hunt

Standard A: Science as Inquiry
Standard B: Physical Science
Standard D: Structure & Evolution of the Universe
Standard G: History & Nature of Science

Standard 1: Problem Solving
Standard 2: Communication
Standard 3: Reasoning
Standard 4: Connections
Standard 8: Patterns

Preface

WELCOME to the fourth in a series of posters and activity booklets produced in conjunction with the *Imagine the Universe!* Web site. The poster/booklet sets are intended to provide additional curriculum support materials for some of the subjects presented in the Web site. The information provided for the educator in the booklet is meant to give the necessary background information so that the topic can be taught confidently to the students. The activities can be used to engage and excite students about the topic of galaxies in a number of disciplines and ways. The booklet and all activities can be photocopied and distributed for educational, non-commercial purposes.

New to this poster/booklet set is the availability of color images for some of the activities. These are available for download from the *Imagine the Universe* Web site at

http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/transparencies/

At the time of printing this booklet, a limited number of hardcopies of the transparencies are available upon request by writing to us at itu@heasarc.gsfc.nasa.gov.

Also note that words in **boldface** are found in the glossary near the end of this booklet.

For additional materials and information, visit the *Imagine the Universe!* Web site at http://imagine.gsfc.nasa.gov/. We also look forward to hearing your opinions about this poster/booklet set. Our email address is itu@heasarc.gsfc.nasa.gov

Foreword

The Story of Andromeda

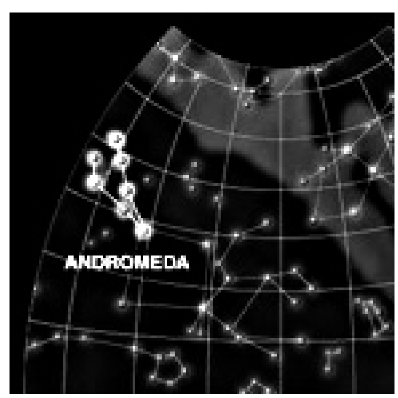
In Greek mythology, Andromeda was the daughter of Queen Cassiopeia and King Cepheus of Ethiopia. Andromeda's mother claimed she was more beautiful than the sea nymphs, the Nereids. The Nereids felt insulted by this and complained to the sea god Poseidon.

Poseidon threatened to send a flood and a sea monster, Cetus, to destroy the kingdom of Ethiopia. The king consulted the oracle of Ammon who advised him to sacrifice his daughter. Andromeda, dressed only in jewels, was chained to a sea-cliff. At this time, Perseus, a Greek hero was traveling along the coast of Africa to the north. He noticed the beautiful woman chained to a rock and instantly fell in love with her.

Perseus offered to rescue Andromeda in return for her hand in marriage. Andromeda had already been promised to a man named Agenor. However, hoping to save their daughter from the approaching sea monster, King Cepheus and Queen Cassiopeia consented in bad faith to Perseus' request.

Perseus was a valiant warrior and possessed some powerful weapons, including the head of the Gorgon Medusa, which had the capability to turn everything into stone. With the aid of the Gorgon's head, Perseus slew Cetus and freed Andromeda. On Andromeda's insistence, the wedding was then celebrated. Her parents, who had forgotten their promise to Perseus, informed Agenor of the wedding. He interrupted the ceremony with an armed party.

A violent fight took place with King Cepheus and Queen Cassiopeia siding with Agenor. Perseus prevailed, using the Gorgon's head to petrify his opponents. Finally, Andromeda left her country to live with Perseus, who later became the king of Tiryns and Mycenae. The goddess Athena placed the figure of Andromeda among the stars as a reward for keeping her parents' promise.



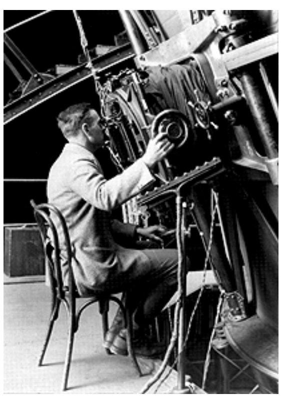
The constellation Andromeda

The Hidden Lives of Galaxies

Looking up at the sky at night, we see a small display of stars which are a part of our Milky Way Galaxy. A galaxy consists of a multitude of billions of stars. Our sun is part of a solar system, which belongs to a large family of more than 100 billion stars. According to the **Big Bang** theory, when the universe was created, all the matter in the universe was distributed uniformly, but within that uniformity, there existed clumps of matter. Through the action of **gravity** these clumps grew. Galaxies began when large clouds of gas and dust started to shrink as a result of their gravity. As the cloud shrinks, stars form from the gases.

Introduction

In the 19th century, astronomers thought that the Milky Way was the only galaxy in the universe. The introduction of **telescopes** to the study of astronomy opened up the universe, but it took some time for astronomers to realize the vastness of the universe. Telescopes were used to make dim objects in the sky look brighter and small objects look larger. There are two types of telescopes: a refractor, which uses a lens to collect light, and a reflector, which uses a mirror to collect light. Telescopes revealed that our night sky was not only populated with stars, but with other objects which appeared like faint, patchy clouds. These objects were **nebulae** that seemed to be within our Galaxy, the Milky Way, and thus believed to be relatively close. But as telescopes became more powerful, it was possible to see different structures in the nebulae.



Edwin Hubble

Astronomers debated the nature of these nebulae. The question arose whether these objects were within the Milky Way, or were they communities distinct from our Galaxy. It wasn't until the 1920s that the American astronomer Edwin Hubble ended the debate by discovering that some of the nebulae were composed of stars. Hubble also determined the distances to these particular nebulae, and found that they were far outside our Galaxy. These were thus found to be individual galaxies. Scientists now estimate that there are about 200 billion galaxies of various shapes in the universe.

Activity #1 – How Big is the Universe?

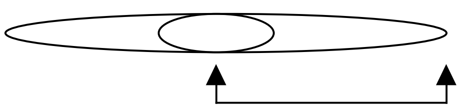
Objectives:

- Student will be able to estimate the size of the visible universe.
- Student will be able to convert from centimeters to kilometers.

Directions:

Calculate the approximate size of the universe given the following scenario: The Milky Way has a radius of approximately 50,000 **light years**. The visible universe has a radius of approximately 15 billion light years or 300,000 times the size of the Milky Way. If the Milky Way is an 8 centimeter wide coffee cup, how big would the rest of the universe be in kilometers?

A



50,000 light years

B

C

8 cm

The Milky Way has a radius of about 50,000 light years.

What is the total size of the Milky Way Galaxy?________

The visible universe has a radius approximately 15 billion light years or 300,000 times the size of the Milky Way.

So if an 8 cm wide coffee cup represents the Milky Way, the visible universe would be a sphere approx.________km in radius.

Show your calculations.

I. The Lives of Galaxies

A. The Characteristics of Galaxies

Like all galaxies, the Milky Way is held together by gravity. Gravity also holds the stars, planetary bodies, gas, and dust in orbit around the center of the galaxy. Just as the planets orbit around the sun, the sun orbits around the center of the Milky Way.

Galaxies come in a variety of shapes.In the 1920s Edwin Hubble was the first to study the **morphology** of galaxies. Using the 100-inch Hooker reflector telescope at Mount Wilson Observatory in California between 1922-1926, Hubble photographed numerous galaxies. He categorized these shapes or basic schemes as spiral, barred spiral, elliptical, irregular, and peculiar.This system was known as the Hubble morphological sequence of galaxy types. First, he noted that some galaxies, like the M31- Andromeda Galaxy, appeared as disks and had arms of stars and dust which appeared in a spiral pattern. Like M31, these galaxies appeared nearly uniform in brightness. In addition, Hubble observed that in some of these types of galaxies the arms were more tightly wound around the galaxy. He called these spiral galaxies. Our Galaxy, the Milky Way, is an example of a spiral galaxy. Secondly, he noted that some spirals had a bright bar of gas through the center, and called these barred spirals. Thirdly, Hubble discovered galaxies that were slightly elliptical in shape, while others were nearly circular, such as M32. He called these elliptical galaxies. The fourth type of galaxy observed was neither spiral nor elliptical, but was irregular in shape. These galaxies were called irregular. An example of this is the Magellanic Clouds. Finally, there were some galaxies that fit none of these descriptions. These were called peculiar galaxies, one example of which is Centaurus A.

Astronomers now have decided that the morphology classification should consist of only two types of galaxies: the spirals and the ellipticals. Barred spirals are a subclass of spirals. Irregulars may be either spiral or barred spiral. Peculiars are not fundamentally a different type. They are simply galaxies in the act of colliding; the collision distorts their shape and makes them appear “peculiar”.

Activity #2 – Identifying Galaxies

Objectives:

1. Using the "Hidden Lives of Galaxies" poster, the student will gain knowledge ofgalaxymorphology.
2. Student will observe different images of galaxies from the Hubble Space Telescope deep survey image.
3. Student will be able to identify the basic types of galaxies (spiral, elliptical, barred spiral, peculiar, or irregular) from the Hubble Space Telescope deep survey image.

Directions:

1. List the five types of galaxies shown on the "The Hidden Lives of Galaxies" poster and write a brief description of each. (see Transparency #1: Types of Galaxies, http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/transparencies/)

Title____________________________

A.____
B.____
C.____
D.____
E.____

2. Observe the Deep Survey Image by the Hubble Space Telescope taken between December 18 – 28, 1995. (See Transparency # 2: Deep Survey Image, http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/transparencies/). Identify the types of the ten galaxies labeled on the Deep Survey Image.

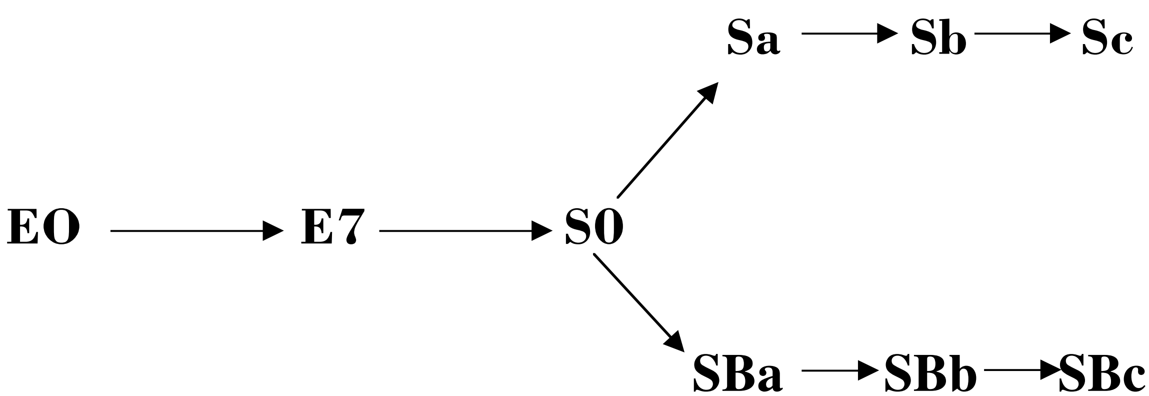
A.________________________ F.________________________
B.________________________ G.________________________
C.________________________ H.________________________
D.________________________ I.________________________
E.________________________ J.________________________

Assessment:

What inferences can you make from observing the Deep Survey Image?

This classification sequence has become so widely used that the basic types, spiral, barred spiral, elliptical, irregular, and peculiar, are still used by astronomers today to classify galaxies according to their visible appearance. Spirals are denoted by "S", and barred spirals by "SB". Letters "a", "b", "c" denote how tightly the spiral arms are wound, with "a" being most tightly wound. The Andromeda Galaxy is an Sb. Elliptical galaxies are denoted by "E", with a number from 0-7 indicating how circular it appears (0 being most circular, 7 being more elongated). An example of this would be M87, which is an E0 galaxy. Irregulars, such as the Small Magellanic Cloud, are denoted by "Irr". Peculiar galaxies, such as Centaurus A, are denoted by "P".

To show how the various classes relate to each other, Hubble organized them into a diagram. A simplified version of Hubble's Fork Diagram is shown below. Note that this diagram does not represent how galaxies form. Note that this diagram does not represent how galaxies form.



Hubble's Fork Diagram of Galaxy Classification

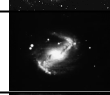
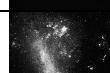
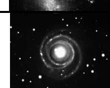
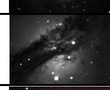
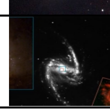
Activity #3 – Classifying Galaxies Using Hubble's Fork Diagram

Objectives:
- Student will gain knowledge of Hubble's Fork Diagram of Galaxy Classification.
- Student will be able to use his/her knowledge of the Hubble Fork Diagram to explain how the five galaxies in the "Types of Galaxies" section were classified.
- Student will be able to create a chart that displays the basic scheme and classification of galaxies using the Hubble Fork Diagram.

Directions:

1. Review Hubble's Fork Diagram of Galaxy Classification (see Transparency #3 – Hubble Fork Diagram).
2. Using the Galaxy Classification Chart, observe the images of each of the galaxies. Determine the scheme and classification of each galaxy. (see Transparency #4 – Galaxy Classification Images).
   Transparencies available at http://imagine.gsfc.nasa.gov/docs/teachers/transparencies/.

Galaxy Classification Chart

Galaxy	Image	Scheme	Classification
Andromeda		**Spiral**	**Sb**
M84, NGC4374			
NGC 2997			
NGC5383			
Large Magellanic			
NGC4622			
M83			
Centaurus A			
M59, NGC4621			
NGC1365			

Assessment:

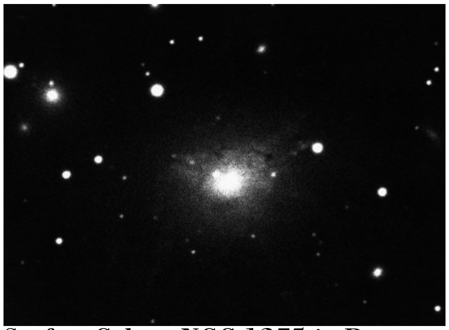
1. With a partner, brainstorm ideas of how you classify objects in your everyday life (Pair/Share).

2. How does classifying help organize your life? List five examples.

____

____

____


Seyfert Galaxy NGC 1275 in Perseus

Later, astronomers added other classifications. One of these astronomers was Carl Seyfert. In 1943, he discovered galaxies with very bright central regions. Seyfert studied the **spectra** of these galaxies. The spectra indicated that the central region was bright at all wavelengths. This indicated some enhanced activity, and **"Seyfert" galaxies** became the first of a range of **active galaxies** that have been studied at all wavelengths since then.

B. How Galaxies Get Their Names

Catalogues are used to list galaxies. One of the earliest catalogues of objects in the sky was made by Charles Messier, who denoted objectsby using the letter "M". Messier, a comet-hunter in the 1700s, kept finding galaxies and nebulae in the sky because many of them looked like comets. Eventually, he created a catalogue of these objects, listing their positions so he wouldn't be fooled again into thinking they were comets. Although he categorized many brilliant objects in the night sky, his cataloguing system was completed in a random manner.

Another common cataloguing system is the NGC (New General Catalogue) which dates from the 19^{th} century. The NGC numbers objects from west to east across the sky. All objects in the same area of the sky have similar NGC numbers. Several other cataloguing systems are: ESO (European Southern Observatory), IR (Infrared Astronomical Satellite), Mrk (Markarian), and UGC (Uppsala General Catalog). The numbers following the letter designation may indicate either the order in the list or the location of the galaxy in the sky. Some galaxies are given descriptive names (e.g. "Andromeda", "Whirlpool") if they are particularly distinctive in location or appearance.

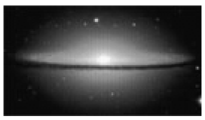
Activity #4 – Identifying Unusual Galaxies

Objective:

- Student will be able to identify different types of galaxies by their distinctive appearance.

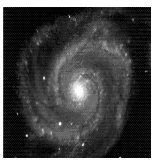
Directions:

Match the unusual galaxy on the left with its distinctive name on the right. Justify your reasoning.

1._____ 

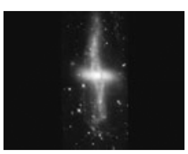
Reason________________________________

____

2. _____ 

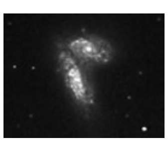
Reason________________________________

____

3. _____ 

Reason________________________________

____

4. _____ 

Reason________________________________

____

a. Polar Ring Galaxy

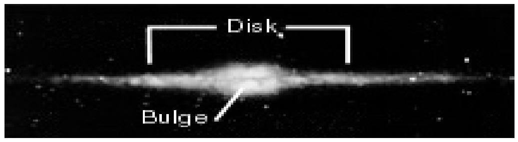
b. Siamese Twins Galaxy

c. Sombrero Galaxy

d. Whirlpool Galaxy

C. The Components of a Galaxy

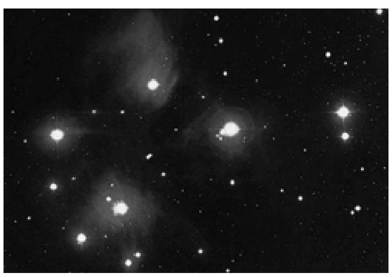
A galaxy is may be made up of two visible components. The two components are the **disk** and the **bulge**. Spiral galaxies have most of their stars in a disk. The



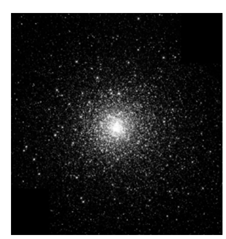
A Near-infrared image of the Milky Way Galaxy

stars may be single stars, double, or multiple stars, or may be part of clusters. In the disk, stars cluster into **open clusters** (also called "galactic clusters") which are asymmetric group of stars. There may be as few as ten or as many as 2000 stars in anopen cluster.

In our Galaxy, the Pleiades is the well known example of an open cluster (see image left), and it contains a few hundred stars. Open clusters tend to be the younger of the type of clusters which appear in a galaxy. The galaxy disk also contains clouds of gas and dust, called nebulae. Some nebulae result from the death of stars, while others are the place where stars are being created. Some nebulae emit light, while others absorb light. The stars, clusters, and nebulae in the disk rotate around the center of the galaxy. In our Galaxy, it takes 200 million years for our sun to go around once. In addition to the disk, spiral galaxies also have a "bulge", which is a large, squashed sphere surrounding the galaxy's center. This region is composed of stars, dust, and gas. In the Milky Way Galaxy, the bulge contributes about 1/5 of the total light of the galaxy. The bulge consists of older stars and not very much gas or dust. Above and surrounding the bulge, stars cluster into **globular clusters** (see image right), which are collections of up to hundreds of thousands of stars bound together in a tight spherical swarm. Since they consist of old stars, globular clusters can be used to determine the age of the galaxy. In globular clusters, the stars move about just as bees swarm near their hive.



The Pleiades



The Globular Cluster M80

Elliptical galaxies consist of just one visible component, the bulge. A good example of this would be M87. Elliptical galaxies contain old stars and a small amount of gas and dust. Stars in these galaxies collect into globular clusters, but not open clusters.

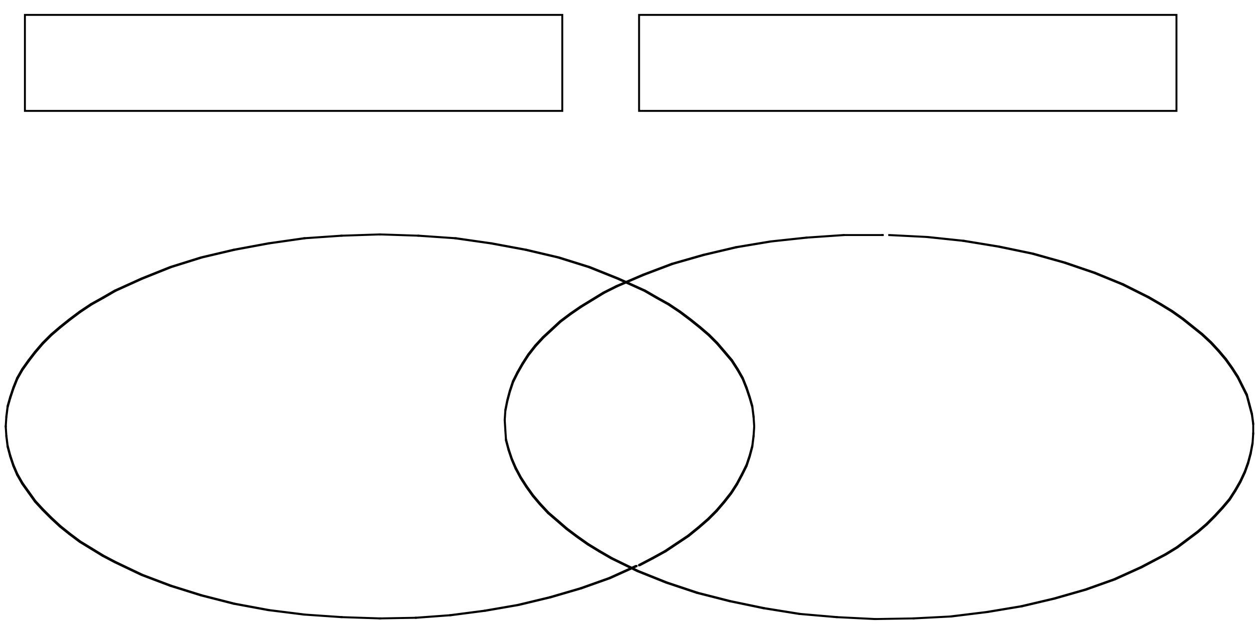
In some irregular galaxies, one can see the individual stars, nebula and clusters, while in other irregular galaxies we cannot see these same objects. Irregular galaxies have a disk, but no spiral arms. However, these galaxies do have a mixture of old and young stars combined with a large amount of gas and dust.

Activity # 5– Open Clusters versus Globular Clusters

Objective:

- Student will be able to show similarities and differences between galactic clusters and globular clusters.

Directions:
Complete the Venn diagram, using Transparency #5: M37/M80 and Section C: The Components of a Galaxy. (See http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/transparencies/ for transparency.)



Assessment:
Compare a swarming beehive to a globular cluster.

D. The Clustering of Galaxies

Like stars, galaxies often appear together in groups and clusters. Groups may consist of a few galaxies and are often a part of larger **galaxy clusters**. Galaxies also often have small companion galaxies. Our Milky Way Galaxy is accompanied by the Large and Small Magellanic Clouds, which are both irregular galaxies visible from the southern hemisphere. The Andromeda Galaxy has two small companion elliptical galaxies, M32 and M110.

Our nearest neighbor galaxies form the Local Group, which consists of about two dozen galaxies of various types - spiral, elliptical, and irregular. The nearest large cluster of galaxies is the Virgo Cluster. It covers a region in the sky about six degrees across in the **constellation** Virgo. It consists of over one hundred galaxies of many types, including spiral, elliptical, and irregular galaxies. The center of the Virgo Cluster is twenty million **parsecs** from Earth. Other clusters are farther, and some have asymmetric distribution of galaxies.

Some clusters are members of **superclusters**. The Local Group and Virgo Cluster are part of a supercluster that contains one hundred other clusters and is one hundred **megaparsecs** across. The study of these superclusters leads to understanding the very structure and evolution of the Universe.

II. The Hidden Lives of Galaxies

A. Hidden Objects

Observation of galaxies at wavelengths other than optical light reveals other objects and components. Some are also seen in optical wavelengths, but are brighter in other parts of the spectrum.

For example, at radio wavelengths astronomers can detect much of the hydrogen that lies between the stars. These hydrogen atoms emit radio waves having a frequency of 1420 MHz (= 1420 x 10^6 Hertz), or as it is more commonly referred to, a wavelength of 21 cm. Astronomers use the detection of this gas to map out the location of hydrogen in our Galaxy. Astronomers can also determine the velocity at which the gas is moving, and whether it is moving toward or away from us. In this manner, the general motion of gas, and presumably the stars formed from the gas, can be determined.

In **X-ray** wavelengths, we see individual stars, **supernova** remnants, binary star systems, and globular clusters. All of these occur in our own Galaxy, and we can see other galaxies which also contain these objects.

Some stars have a hot **corona** composed of gas at a very high temperature. This gas emits X-rays. In external galaxies, the individual stars must be very bright X-ray emitters for us to see them. Thus, most individual stars we see in other galaxies are "O" type stars, which are very massive and very hot. "O" type stars don't live very long and are, in fact, rarely seen in galaxies.

X-rays are also emitted by supernova remnants. These are shrouds of gas and dust left behind after a massive star has exploded at the end of its life. The hot ejecta from the exploded star runs into the gas and dust lying in the region around the star, emitting X-rays. Some massive stars leave behind a dense **neutron star** after the supernova. Neutron stars have a strong magnetic field, which can also feed energy into the remnant.

In addition, observations at X-ray wavelengths show that other galaxies contain binary star systems that emit X-rays. These **X-ray binary systems** consist of a normal star and a "compact object". This compact object may be a **black hole**, neutron star, or white dwarf. These objects areformed from normal stars which have used up their nuclear fuel. In the binary system, material from the companion star is funneled into the compact object. This material is heated as it spirals in and emits X-rays as it is heated.

X-rays may also come from globular clusters. In these dense clusters of stars, the most massive members quickly exhaust their nuclear fuel and become neutron stars (or sometimes black holes). Through motions and gravitational interactions within the cluster, these neutron stars can join with a normal star to become an X-ray binary system. In our Galaxy, some globular clusters are observed to have a number of individual X-ray sources, all of which are believed to be X-ray binaries. Because other galaxies are far away, we see individual globular clusters as a point-like X-ray source.

Finally, it is common for a galaxy to harbor a massive black hole near its center. Observations by the Chandra X-ray Observatory of the central region of the Andromeda Galaxy reveal more than 100 X-ray sources. Many of them are likely X-ray binaries. One of them was at the previously determined position of a super-massive black hole, which has a mass of 30 million times that of our sun. The Chandra observation also showed a diffused glow surrounding the central region of the galaxy. It is not known whether the glow is from many faint individual sources or from a diffuse, hot gas.

B. Hidden Mass

Stars move about in galaxies under the influence of gravity in different ways, depending on the type of galaxy. The stars in elliptical galaxies move in all directions. The stars in the arms of spiral galaxies move in more orderly fashion around the center of the galaxy. Stars in irregular galaxies move more or less in random fashion.

The presence of **dark matter** was first discovered in 1932 by the Dutch astronomer Jan Oort. By examining the **Doppler shifts** in the spectra of stars in the Milky Way Galaxy, Oort measured their velocities. He found that the stars moved faster than expected. Oort expected the stars to move only as fast as the visible mass in the Galaxy (stars, gas, dust) would allow.   In reality, the stars appeared to be moving fast enough to escape the galaxy. Since Oort knew that this couldn't be the case, he hypothesized that there must be additional mass in the galaxy that wasn't visible and would keep the stars bound to the galaxy. A year later, an American astronomer, Fritz Zwicky, came to the same conclusion while measuring the velocities of galaxies in the Coma Cluster. Scientists now know that this "hidden mass", also known as dark matter, can account for nearly 90% of the total mass of a galaxy.

In spiral galaxies, stars located at greater distances from the center of the galaxy are expected to have smaller velocities than stars that are close to the center of the galaxy. What scientists observe is that velocities are constant in the arms, and rise very quickly in the bulge. Scientists can account for this if there is a very massive object at the center of the galaxy, and a large halo of invisible matter surrounding the entire galaxy. X-ray observations confirm that massive black holes lie at the center of many galaxies. In the dark halo, the amount of mass increases linearly with radius. Spiral galaxies have extended dark halos that account for 90% of the total mass of the galaxy. It is not known what the dark matter might be made of. It might be objects too small to become stars and hence too small to give off their own light (e.g., planets and brown dwarfs).   Or it might be an entirely new type of matter made of particles which interact only gravitationally and do not give off light.

Measuring **rotation curves** in an elliptical galaxy is difficult because of the nature of the orbits of stars in this type of galaxy and because the spectral lines are too weakto be used to measure the velocity. However, X-ray observations show that elliptical galaxies have a halo of hot gas extending well outside the optical limits of the galaxy. As an example, in one of the elliptical galaxies in the Virgo Cluster, the total mass of this hot gas can be 10^{10} times the mass of the sun. This is small compared to the total mass of all the stars in the galaxy - 10^{12} times the mass of the sun. However, in order for the gas to be bound to the galaxy, the galaxy must have a mass of $5x10^{12}$ times the mass of the sun. Because this is more than what is seen, astronomers conclude that elliptical galaxies also have halos of hidden mass. As in the case of spiral galaxies, the "dark matter" halos in elliptical galaxies may contain up to 90% of the total mass of the galaxy.

Activity #6a - Evidence for Hidden Mass

Objectives:

1. Student will be able to interpret and analyze the information in the data presented on the "Evidence for Hidden Mass" graph.
2. Student will be able to determine why the data looks the way it does on the graph.
3. Student will be able to observe trends to determine if there is a pattern to the way the data is shown.

Directions:

1. Finish writing the paragraph by interpreting the data about Solar System planets on the "Evidence for Hidden Mass" graph on the "Hidden Lives of Galaxies". (See Transparency #6: Evidence for Hidden Mass, http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/transparencies/)

There are ________ solar system planets presented on the graph. The planets, from the closest to the sun to the furthest from the sun, are _______ ____ ____. Using the graph, the velocities of the solar system planets, from the lowest value to the highest value, are ____ ____. Using the graph, the distances of the planets from the Sun are, from least to greatest, ____ ____. In general, the further the planet is away from the sun the _________________its velocity. The closer the planet is to the sun the ___________________its velocity.

2. Write a paragraph interpreting the data for Galaxy F563-1. Include information about distance from the center, velocity, and trends.

____
____
____
____
____
____
____
____
____

Activity #6b - Extension: Weighing a Galaxy

Objectives:

- Students will be able to use Newton's Laws of Motion to determine the mass of the sun from the motions of the planets.
- Students will be able to estimate the mass of a galaxy by applying Newton's Laws to the motion of stars in the galaxy.
- Students will be able to convert among different units used in astronomy.

Directions:

Using Newton's Law for gravity, we can determine the mass of an object by measuring the motion of other bodies around it. We can show this by applying Newton's Law of motion to bodies orbiting around another body.
We start with Newton's Second Law

$$F = ma,$$

where *F* is the force exerted on the orbiting body, *m* is its mass, and *a* is its acceleration. The force is the gravitational force exerted by the central object, and the acceleration is due to circular motion. So we now have

$$GMm/r^2 = mv^2/r,$$

where *G* is the gravitational constant, *M* is the mass of the central object, *r* is the distance of mass *m* from *M*, and *v* is the velocity of *m*. Simplifying gives

$$GM/r = v^2.$$

Solving for *M* gives

$$M = v^2r/G.$$

Note that $G = 6.67 \times 10^{-11}\ m^3/kg\text{-}s^2$.

1. Apply this equation to three of the planets in our solar system, given in the table below.

Planet	Distance from Sun (km)	Velocity (km/s)	Mass (kg)
Earth	1.5×10^8	29.8	
Jupiter	7.8×10^8	13.1	
Neptune	4.5×10^9	5.4	

What do you notice about the values of the Mass ? ____________________
What would you conclude the mass of the sun to be ? __________________

2. Now apply this equation to the galaxy F563-1. Determine the mass M using the equation and the velocity at various distances from the center of the galaxy given in the table below. Each of these resulting mass values gives mass enclosed within that distance. [Note that 1 kiloparsec (kpc) = 3.1×10^{19} meters]

Distance (kpc)	Velocity (km/s)	Mass (kg)
5.0	95.0	
10.0	110.0	
15.0	110.0	

What do you notice about the values of the mass as the distance increases?
____.
What would you conclude the mass of the galaxy to be ? ______________________.
How much more massive is this galaxy than our sun ? ________________________.

C. Possibilities for Dark Matter

The three main categories of objects that scientists consider as possibilities for dark matter include MACHOs, WIMPs, and gas. The first two are acronyms which help us to remember what they represent. Listed below are the pros and cons for the likelihood that they might be a component of dark matter.

MACHOs (Massive Compact Halo Objects): MACHOs are the big, strong, dark matter objects ranging in size from small stars to super massive black holes. MACHOS are made of ordinary matter, which is called baryonic matter. Astronomers search for MACHOs. Examples: black holes, neutron stars, white dwarfs, brown dwarfs.

Neutron Stars and Black Holes are the final result of a supernova. They are both very massive stars. Neutron stars are 1.4 to 3 times the mass of the sun. Black holes are greater than 3 times the mass of the sun.

Pros: They both can be dark. However, black holes emit no light; they are truly black.

Cons: These objects occur less frequently than white dwarfs. As a result of a supernova, a release of a massive amount of energy and heavy elements should occur. However, there is no such evidence that they occur in sufficient numbers in the halo of galaxies.

White Dwarfs are what remain of a small to medium sized star after it has passed through the red giant phase.

Pros: There is an abundance of white dwarfs in the universe. If young galaxies produced white dwarfs that cool more rapidly and become undetectable, maybe they could be abundant enough to explain dark matter.

Cons: With the production of huge numbers of white dwarfs, in theory, one would expect to see the production of massive amounts of helium. However, this is not observed.

Brown Dwarfs have a mass that is less than eight percent of the mass of the sun, resulting in a mass too small to produce the nuclear reactions that make stars shine. The signature of these objects is an occasional brightening.

Pros: Astronomers have observed distant objects that are either brown dwarf stars or large planets around other stars. Astronomers believe that the brightening and dimming of brown dwarfs are due to the gravitational lens effect of a foreground star. They also believe the brightening and dimming may provide further evidence for a large population of brown dwarfs in our Galaxy.

Cons: While they have been observed, astronomers have found no evidence of a large population of brown dwarfs that would account for the dark matter in our Galaxy.

WIMPs (Weakly Interacting Massive Particles): WIMPs are the little, weak, subatomic dark matter candidates, which are thought to be made of stuff other than ordinary matter, called non-baryonic matter. Particle physicists search for WIMPs. Examples: Exotic subatomic particles such as axions, heavy neutrinos, and photinos.

Pros: Theoretically, there is the possibility that very massive subatomic particles, created in the right amounts, and with the right properties in the first moments of time after the Big Bang, are the dark matter of the universe.

Cons: Observations have been fruitless. No one has observed even one of these particles.

Hydrogen Gas

Pros: Hydrogen gas, one of the most basic elements, is 70-75% of the visible matter in the universe. Most of the dark matter may exist as small clouds of hydrogen gas.

Cons: Hydrogen is easily detected by radio, infrared, optical, ultraviolet, and X-ray telescopes. The necessary amount of hydrogen hasn't been seen.

Activity #7 – Dark Matter Possibilities

Objectives:

1. The student will be able to complete the graphic organizer using the knowledge gained from reading section "C- Possibilities for Dark Matter".
2. The student will gain a greater understanding of the three possibilities for the hidden mass in galaxies.

Directions:

1. Reread the Possibilities for Dark Matter. Complete the graphic organizer, "Decision-Making", stating the pros and cons of the possibilities.
2. To complete the assessment, read the definition of Einstein's Theory of Gravity given after the Assessment.

Decision Making

Problem	Goals
What can the dark matter be? 	3. Provide a conceptual framework for integrating new information. 4. Process and reorganize information. 5. Select important ideas and details.

Possibilities	**Pros and Cons**
MACHOs (Massive Compact Halo Objects) • Neutron Stars & Black Holes • White Dwarfs • Brown Dwarfs	
WIMPs (Weakly Interacting Massive Particles) 1. Exotic subatomic particles, such as axions, massive neutrinos, photinos	
Hydrogen Gas	

Assessment: Could Einstein's Theory of Gravity, which has proved to be correct in all cases so far, be somehow wrong? Justify your answer.
Einstein's Theory in a Nutshell: Space-time tells matter how to move. Matter tells space-time how to bend.

Decision(s)	Reason(s)

D. Formation of Galaxies

How galaxies formed after the Big Bang is a question still being studied by astronomers. Astronomers hypothesize that approximately a billion years after the Big Bang, there were clumps of matter scattered throughout the universe. Some of these clumps were dispersed by their internal motions, while others grew by attracting other nearby matter. These surviving clumps became the beginnings of the galaxies we see today. They first appeared about 14 billion years ago.

When a clump becomes massive enough, it starts to collapse under its own gravity. At this point, the clump becomes a protogalaxy. Astronomers hypothesize that protogalaxies consist of both dark matter and normal hydrogen gas. Due to collisions within the gas, the hydrogen loses energy and falls to the central region of the protogalaxy. Because of the collisions of the gas, protogalaxies should emit infrared light. The dark matter remains as a halo surrounding the protogalaxy.

Astronomers think that the difference in appearance between elliptical and spiral galaxies is related to how quickly stars were made. Stars form when gas clouds in the protogalaxy collide. If the stars are formed over a long period of time, while some stars are forming, the remaining gas between the stars continues to collapse. Due to the overall motion of matter in the protogalaxy, this gas settles into a disk. Further variations in the density of the gas result in the establishment of "arms" in the disk. The result is a spiral galaxy. If, on the other hand, stars are made all at once, then the stars remain in the initial spherical distribution that the gas had in the protogalaxy. These form an elliptical galaxy.

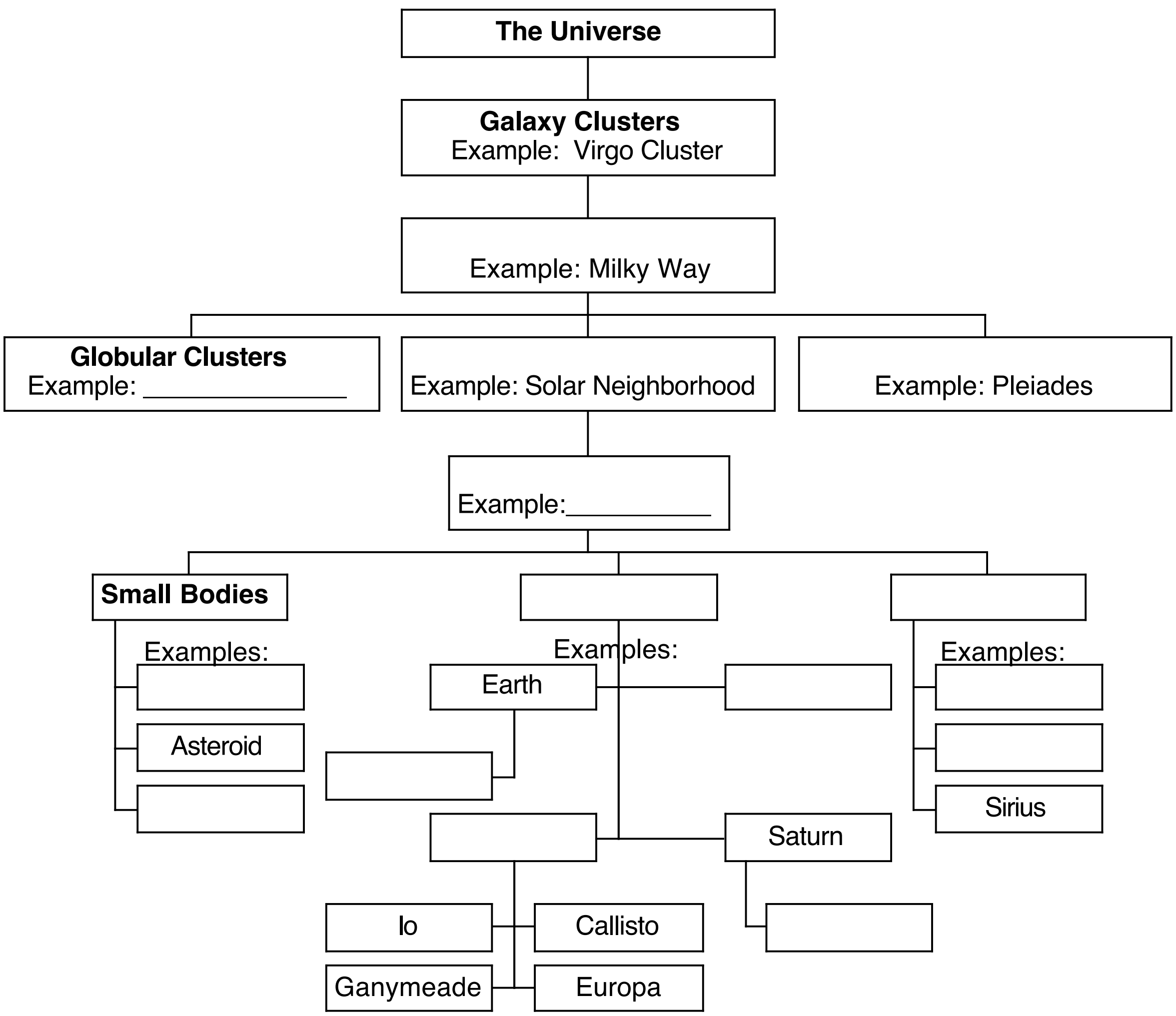
Astronomers also think that collisions between galaxies play a role in establishing the different types of galaxies. When two galaxies come close to each other, they may merge, throw out matter and stars from one galaxy, and/or induce new star formation. Astronomers now think that many ellipticals result from the collision of galaxies. We now know that giant ellipticals found in the center of galaxy clusters are due to multiple galaxy collisions.

Activity # 8 – The Universe as Scientists Know It

Objective:
Student will be able to assess his/her degree of understanding of what makes up the universe as scientists know it.

Directions:
Using knowledge gained, fill in the concept map with the following terms: Planetary Systems, Galaxies, Planets, Sun, Venus, Moon, Stars, Sirius, Solar System, Comet, Meteor, Open Clusters, Stellar Regions, Jupiter, Titan, Solar Neighborhood, M80.

The Universe as Scientists Know it



Activity # 9 – Scavenger Hunt in the Night Sky

Objectives:

- Student will become familiar with how objects appear using the naked eye, binoculars, **finderscope**, and telescope.
- Student will be able to identify the major uses of a telescope and identify the two main types of telescopes.
- Student will be able to identify the galaxy in which our Solar System islocated and distinguish the morphology of the five basic kinds of galaxies.
- Student will be able to identify five common constellations.

Materials Needed

Flashlight
Piece of red cellophane
Rubberband
Pencil
Planisphere
Observation Log (included)
Seasonal Guide Posts (included)
Scavenger Hunt in the Night Sky Tip Sheet (included)
Blanket/Lawn Chair
Telescope
Binoculars

Suggestions for locating telescopes in your community

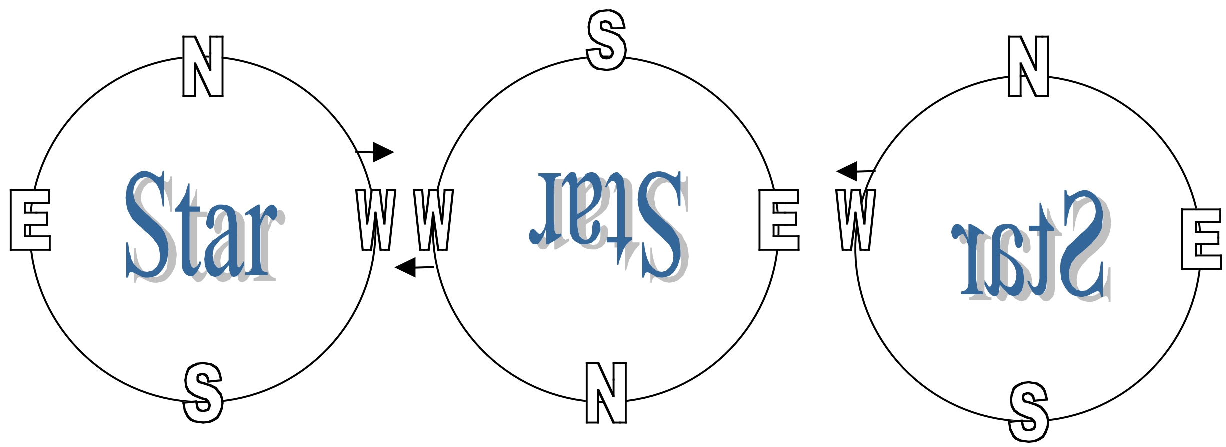
- School
- Parent in the school
- Other local schools
- Local astronomy clubs
- Local science museum/planetarium
- Local universities

Directions:

1. Orient yourself to the objects in the night sky by looking at Directional Chart.
2. Read Seasonal Guide Posts and "Scavenger Hunt in the Night Sky" Tip Sheet.
3. Fill out Observation Log (p. 29). Make additional copies for additional objects
4. Complete assessment.

Directional Chart

Below are three orientations of a star field: as it appears to the naked eye; as it appears in the finderscope (upside down and backwards); and as it appears in most telescopes with a star diagonal (mirror image). Newtonian Reflectors will not have the mirror image effect. The arrows show the directions that stars appear to drift, moving east to west, across the field of view.



Naked Eye	Finderscope	Most Telescopes with star diagonal
Binoculars	Most Telescopes without star diagonal	

Autumn Seasonal Guide Posts: For Naked Eye/Binoculars (~ 9 p.m.)

Object	**Constellation**	**Type**
Polaris	Ursa Minor	Star
Big Dipper	Ursa Major	Asterism
Altair	Aquila	Star
Vega	Lyra	Star
Deneb	Cygnus	Star
Great Square	Pegasus	Asterism
Cassiopeia	Cassiopeia	Constellation
Pleiades	Taurus	Open cluster
Capella	Auriga	Star
Andromeda (M31)	Andromeda	Spiral Galaxy

Looking due north, about half-way up from the horizon will be a bright star, **Polaris**, the North Star. The **Big Dipper** can be hard to find in Autumn because it lies along the northern horizon. Now look to the south and west of Polaris. There you will see the 3 bright stars of the summer triangle slowly setting. **Altair** is to the south; the brilliant star nearest to the horizon is **Vega**; and a bit higher overhead is **Deneb**. Deneb is at the top of a collection of stars in the form of a cross. The cross is between Vega and Altair, standing almost upright this time of year. High overhead are the 4 stars of the **Great Square**. Although they're not particularly brilliant, they stand out because they are brighter than any other stars near them. After you have found the Great Square, look north. You'll see the 5 main stars of **Cassiopeia** making a bright "W" shape or an "M" depending on the way that you're turned around. To the east you'll see a small cluster of stars called the **Pleiades**. North of the Pleiades, the brilliant **Cappella** rises. --- Now to find the **Andromeda Galaxy**, locate the Great Square overhead. Between Cassiopeia and the Great Square is the constellation Andromeda. From the northeast corner, find 3 bright stars in a long line, arcing across the sky west to east, just south of Cassiopeia. From the middle of these 3 stars go north towards Cassiopeia past 1 star to a second star, in a slightly curving line. The galaxy is just barely visible to the naked eye.

Seasonal Guide Posts for Galaxies: For the Telescope

Season	Object	Name	Constellation	Morphology	Rating
Autumn	M31	Andromeda Galaxy	Andromeda	Spiral	4
	M32	Companion to M31	Andromeda	Elliptical	2
Winter	M33	Triangulum Galaxy	Triangulum	Spiral	3
Spring	M81		Ursa Major	Spiral	3
	M82		Ursa Major	Peculiar	2

Now to find the **Andromeda Galaxy,** locate the Great Square overhead. From the northeast corner, find 3 bright stars in a long line, arcing across the sky west to east, just south of Cassiopeia. From the middle of these 3 stars go north towards Cassiopeia past 1 star to a second star, in a slightly curving line. Through a telescope, the galaxy looks like a bright oval embedded in the center of a long swath of light, which extends across the field of view. Off to the south, and a bit east, is what looks like an oversized star making a right triangle with 2 faint stars. This is the companion galaxy, **M32.** Increasing magnification, you can see it is an egg-shaped cloud of light. Next, to locate the **Triangulum Galaxy**, find the Great Square high in the east. From the northeast corner, find 3 bright stars in a long line arcing across the sky west to east just below Cassiopeia. Down and to the left of the second and third stars you'll find 3 stars forming a narrow triangle pointing towards the southwest. This is the constellation Triangulum. Use the distance from the northernmost star of this triangle to the point of the triangle as a yardstick. Half this distance up and to the right from the point is a very faint star. Past this star half as far is **M33**. Four stars in the shape of a "kite" should be visible in the telescope. The galaxy will look like a large, but very faint patch of light in this kite. Be sure to use your lowest power. Finally, to locate **M81** and **M82**, look for the Big Dipper, and locate the 4 stars which make up the bowl of the Dipper. Start from the lower handle end of the bowl, and imagine a line running diagonally upward across the bowl to the opposite side of the bowl. Continue on this path until you reach M81 and M82. The 2 galaxies look like 2 fuzzy spots of light. The one to the south, away from Polaris, is M81. It has an obvious oval shape. M82 is thin and pencil-shaped, looking like a string of pearls.

Scavenger Hunt in the Night Sky Tip Sheet

It's sometimes difficult to identify objects in the night sky. Here are some hints to help you determine what you're looking at.

<u>Jets, Planes, Earth-orbiting Satellites</u>
These objects move extremely fast. Blinking lights and loud noises reveal a jet plane. Satellites travel in a straight line across the sky.

<u>Planets</u>
Some planets have a distinct appearance, others do not. To the naked eye, the planets do not twinkle as the stars do. The disk of the brighter planets can be seen with a telescope.

<u>Meteors</u>
Meteors are small pieces of rock that blaze across the sky appearing to leave a trail. They are often called "shooting stars".

<u>Comets</u>
These objects come into sight over a course of several weeks. They usually appear with a long tail and a somewhat fuzzy head.

<u>Stars</u>
The majority of the objects that we see in the night sky are stars. They appear to be moving slowly because the Earth is turning underneath them.

<u>Galaxies and Nebulae</u>
Most galaxies and nebulae are too faint to see with the naked eye. Therefore, you will need to use binoculars or a telescope. The two exceptions are the Andromeda Galaxy and the Orion Nebulae.

Observation Tips

- Choose a safe location on a clear night. Be patient and let your eyes adjust to the darkness for 30-45 minutes.
- Allow telescopes and binoculars to adjust to the air temperature. Let condensation on lenses or mirrors evaporate on its own.
- Attach red cellophane to the flashlight using the rubberband. Red light interferes the least with night vision.
- Take along a pencil, observation log, and your planisphere.

Scavenger Hunt: Observation Log **Observation Date:_________**

Observer's Name:____

Location (City, Country):____

Temperature:______________**Cloud Cover (% estimated)**:___________

Object Name:____

Description:____
____
____
____
____
Observing Start Time:___________**Observing End Time**:_____________

Explanation of Rating Scale based on a small telescope

Rating:______

Sketch:

Rating	**Description**
5	Breathtaking, easily seen even on a hazy night, the best example of its type, not to be missed.
4	Impressive, easily seen even on a hazy night, a good example of its type.
3	Also impressive, but not the best of its class.
2	May or may not be easy to find, but not exciting to observe, lacks color
1	Not spectacular at first sight. Difficult to see. Pushes the small telescope to its limits.

Assessment:

- Name the major uses of a telescope and identify the two main types of telescopes.

  ____
  ____
  ____.

- Identify the galaxy in which our solar system is located and list the morphology of the galaxies you observed in the night sky.

  ____
  ____
  ____.

- Identify five common constellations you observed in the night sky.

  ____
  ____
  ____.

Answer Key for Activities

Activity #1 - How Big is the Universe

1. What is the total size of the Milky Way Galaxy? <u>100,000 light years</u>
2. The visible universe will be a sphere approximately <u>12</u> km in radius.

Activity #2 – Identifying Galaxies

1.Titles will vary, but may be, e.g. "The Galaxy Types", or "Five Types of Galaxies"

A. Spiral – galaxy with tightly wound spiral arms
B. Elliptical – slightly elliptical to nearly circular
C. Barred Spiral – spiral with a bright bar of gas through the center
D. Peculiar – fits none of the descriptions
E. Irregular – small, patchy, irregularly shaped galaxy

2. Identify the types of the ten galaxies labeled on the Deep Survey Image.

A. Irregular
B. Spiral
C. Spiral
D. Elliptical
E. Barred spiral
F. Barred spiral
G. Elliptical
H. Spiral
I. Irregular (or Peculiar)
J. Elliptical

Assessment

Inferences that can be made from observing the Hubble Deep Survey Image should include that the objects are galaxies and not stars. These galaxies are of different sizes, shapes, brightnesses, distances, and color.

Activity #3 – Classifying Galaxies Using Hubble's Fork Diagram

Galaxy Classification Chart

Galaxy	Scheme	Classification
Andromeda	**Spiral**	**Sb**
M84, NGC4374	Elliptical	E1
NGC 2997	Spiral	Sb
NGC5383	Barred Spiral	SBb
Large Magellanic	Irregular	Ir
NGC4622	Spiral	Sb
M83	Spiral	Sc
Centaurus A	Peculiar	P
M59, NGC4621	Elliptical	E5
NGC1365	Barred Spiral	SBc

Assessment

1. Examples of how to classify objects in everyday life may include organizing a CD collection, sorting clothes, organizing magazines.
2. An example of how classifying helps organize one's life may be that an organized CD collection makes it easier to locate music by artist name or music type.

Activity #4 – Identifying Unusual Galaxies

1. c. {Sombrero Galaxy} With a bright halo of stars and a large central bulge of stars, it looks like a hat.
2. d. {Whirlpool Galaxy} It looks like a whirlpool in the ocean or water going down a drain.
3. a. {Polar Ring Galaxy} It contains an inner central disk of old stars and an outer ring of younger stars giving it the appearance of a ring on a ringer.
4. b. {Siamese Twins Galaxy} It shows how gravitational pull sometimes causes two galaxies to collide or brush against each other, giving the appearance of two joined bodies.

Activity #5 - Open Clusters versus Globular Clusters

Answers should include the following similarities: **both** contain numerous red stars, and colored stars. **Globular clusters** contain older stars. Stars near the center tend to be brighter. The stars appear to be gravitating towards the center of the cluster, like bees swarming around the hive. The cluster contains hundreds to thousands of stars. The stars appear closer together. **Open cluster** stars appear scattered. The blue stars are more visible. Open clusters contain hundreds of stars, many which are bright, young, and blue.

Activity #6a - Evidence for Hidden Mass

1. There are **9** Solar System planets presented on the graph. The planets from the closest to sun to the furthest from the sun, are **Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.**
   Using the graph, the velocities of the solar system planets, from the lowest value to the highest value, are **approximately 48, 35, 30, 24, 13, 10, 7, 5, 4 km s^{-1}**.
   Using the graph, the distances of the planets from the Sun are, from least to greatest, **0, 110, 150, 250, 800, 1500, 2800, 4500, 6000 million km.**
   In general, the further the planet is away from the sun the **slower** the **velocity**. The closer the planet is to the sun the **faster** the **velocity**.
2. Answers should include fact that velocities first increase with increasing distance. At distances larger than 10 kpc, the velocity becomes constant with increasing distance.

Activty #6b - Extension: Weighing a Galaxy

1. The calculation for each of the planets should result in a value for *M* of 2.0×10^{30} kg, which is the mass of the Sun. It is the same for each because the central mass for the solar system is concentrated in the Sun.
2.

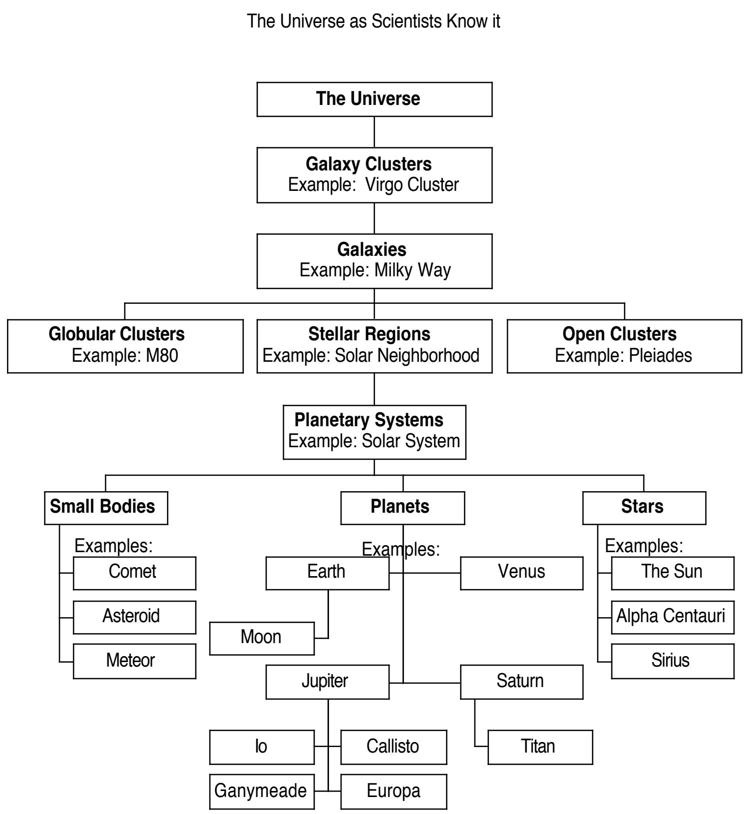
Distance (kpc)	Velocity (km/s)	Mass (kg)
5.0	95.0	2.1×10^{40}
10.0	110.0	5.6×10^{40}
15.0	110.0	8.4×10^{40}

The mass increases as the distance from the center of the galaxy increases. This is because stars move under the gravitational influence of all the matter within their orbit.
So stars at greater distances move under the influence of more mass than stars closer to the center.

The best estimate for the mass of the galaxy is the one which includes the most amount of mass. From this calculation, the largest value is 8.4×10^{40} kg. The actual mass of the galaxy is likely to be more than this. From Part 1, we know the mass of the sun is 2.0×10^{30} kg. So this galaxy is at least 4.2×10^{10} times more massive than the sun.

Activity #7 – Dark Matter Possibilities
Students should restate the material presented in "Possibilities for Dark Matter".
Assessment – Student's decisions may vary, but they should give reasons for their decision.

Activity #8 - The Universe as Scientists Know It



Activity #9 – Scavanter Hunt in the Night Sky
Assessment:
1. Telescopes are used to make small objects appear larger and dim objects appear brighter. The two main types of telescopes are refractors and reflectors.
2. The Solar System is located in the Milkyway galaxy. Morphology of galaxies will usually be spiral and elliptical.
3. Answers will vary depending on the season.

Glossary

ACTIVE GALAXY – A galaxy whose center emits large amounts of excess energy, often in the form of radio emissions. Active galaxies are suspected of having massive black holes in their centers into which matter is flowing.

BIG BANG THEORY – A theory in which the expansion of the universe is presumed to have begun with an explosion (referred to as the "Big Bang").

BLACK HOLE – An object whose gravity is so strong that not even light can escape from it.

BULGE – The round or elliptical central region of a galaxy. It is often uniform in brightness.

CORONA – The hot, tenuous, outermost region of the sun and other stars. The sun's corona is visible during a total solar eclipse.

CONSTELLATION – A grouping of stars into one of the 88 areas of the sky.

DARK MATTER – A form of matter which does not emit light. Its nature is still being investigated.

DISK – The flat, circular region of a spiral galaxy extending out from the central bulge. The disk of a spiral galaxy often has distinct arms of stars and bright gas.

DOPPLER SHIFT – The apparent change in wavelength of sound or light caused by the motion of the source, observer or both. Waves emitted by a moving object as received by an observer will be blueshifted (compressed) if approaching, redshifted (elongated) if receding.

FINDERSCOPE – A small, low-power telescope with a wide field of view, attached to the main telescope.

GALAXY CLUSTER – A group of galaxies bound together by gravity.

GRAVITY – A mutual physical force attracting two bodies.

LIGHT YEAR – The distance light travels in one year, which is approximately 9.46×10^{15} meters.

MORPHOLOGY – The study of the shape and structure of galaxies.

NEBULA – A diffuse mass of interstellar dust and gas.

NEUTRON STAR – The imploded have a mass 1.4 times the mass of the Sun, and a radius of about 5 miles. Neutron stars can be observed core of a massive star sometimes produced by a supernova explosion. Neutron stars are typically as pulsars.

PARSEC – A distance equal to 3.26 light years, or 3.1 x 10^{18} cm. A **kiloparsec** (kpc) is equal to 1000 parsecs. A **megaparsec** (Mpc) is equal to a million (10^6) parsecs.

PLANETARY SYSTEM – A star with one or more planets. This system may include moon(s), comet(s), meteoroids, and asteroid belts in addition to planets.

PLANISPHERE – A handheld device which shows the appearance of the night sky at any specified time of day and day of the year.

ROTATION CURVE – A graph of stellar velocity versus stellar distance from the center of a galaxy.

SEYFERT GALAXY – A spiral galaxy whose nucleus shows bright spectral emission lines in all wavelengths; a class of galaxies first described by C. Seyfert.

SPECTRA – A plot of the intensity of light at different frequencies.

STELLAR REGION – A region in space consisting of hundreds to thousands of stars.

SUPERCLUSTER – A collection of clusters of galaxies**.**

SUPERNOVA – The death explosion of a massive star, resulting in a sharp increase in brightness followed by a gradual fading. At peak light output, supernova explosions can outshine a galaxy. The outer layers of the exploding star are blasted out in a radioactive cloud. This expanding cloud, visible long after the initial explosion fades from view forms a supernova remnant (SNR).

TELESCOPE – A tool used to make dim objects look brighter and smaller objects look larger.

X-RAY – A form of with a wavelength between that of ultraviolet radiation and gamma rays.

X-RAY BINARY SYSTEM – A binary star system contain contains a normal star and a collapsed star. The collapsed star may be a white dwarf, neutron star, or black hole. X-rays are emitted from the region around the collapsed star.

About the Poster

"The Hidden Lives of Galaxies" poster illustrates various facets of galaxies, both what is visible at optical wavelengths and what can be seen and revealed only at X-ray wavelengths. The central image is a composite X-ray (left-hand side) and optical (right-hand side) image of the Andromeda Galaxy. The optical image shows the familiar dust lanes and spiral arms. The X-ray image, taken from ROSAT data at 0.5-2.0 keV, shows individual sources and emission from gas in the galaxy. The inset shows a portion of the observations taken by the Chandra X-ray Observatory. The increased spatial resolution of the Chandra data now reveals many individual X-ray sources in the central region of the galaxy, as well as diffuse X-ray emission from hot gas.

On the right hand side of the poster is an illustration of the changing size and distance scale within the universe as we compare a planetary system to a neighborhood of stars in a stellar region, to a galaxy, and finally to a cluster of galaxies.

The lower left box shows the different types of galaxies – spiral, barred spiral, elliptical, irregular, and peculiar.

The lower right box illustrates and discusses the evidence for missing mass in galaxies as revealed by optical and X-ray observations. The left-hand plot compares the rotation curve of a galaxy to the velocities of planets in the solar system. The constant value for the velocities of stars in the outer reaches of the galaxy shows that there must be more mass in the galaxy than just the visible mass in order for the stars to remain bound to the galaxy. Likewise, the right-hand plot shows hot X-ray gas extending far beyond the visible image of the elliptical galaxy. Because this gas must be part of the galaxy, this too shows evidence for more matter than what is visible.

Poster Credits

"The Hidden Lives of Galaxies" poster was designed and assembled by Karen Smale, with additional artwork by Maggie Masetti. Also contributing were Gail Rohrbach, Brian Hewitt, and Steve Fantasia. Chief scientific consultant was Dr. Greg Madjeski, with additional assistance from Dr. Michael Lowenstein. Thanks also to Drs. Kimberly Weaver and William Pence for additional comments. The project was supervised by Dr. James Lochner.

The Chandra image of the nucleus of M31 is courtesy of Dr. Steve Murray, NASA/CXC/SAO. The rotation curve of the galaxy F563-1was provided by Dr. Stacy Mcgaugh, Univ. of Maryland. The optical image of NGC 4414 is from the Hubble Space Telescope, courtesy AURA/STScI/NASA, whereas the optical images M87, Centaurus A, Small Magellanic Cloud and NGC 1530 are copyright AURA/NOAO/NSF, used by permission. The image of M31 is copyright Bill Schoening, Vanessa Harvey, REU program/AURA/NOAO/NSF, used by permission for educational purposes.

References and Other Resources:

For additional activities using the Hubble Deep Field, see “Galaxies Galore” on Amazing Space, http://amazing-space.stsci.edu/

For additional information on active galaxies, see the Active Galaxy articles on Imagine the Universe!, http://imagine.gsfc.nasa.gov/docs/science/know_l1/active_galaxies.html

Planishperes may be purchased at any planetarium and many science museum shops. To make your own planisphere, see http://www.otterbein.edu/dept/PHYS/is410/plan.html.

For an excellent summary of the formation of galaxies, see

- http://blueox.uoregon.edu/~karen/astro123/lectures/lec25.html

You can construct your own galaxy rotation curves at

- http://www.astro.queensu.ca/~dursi/dm-tutorial/rot-vel.html

A detailed description of how a galaxy rotation curve is made from an observation is at http://www.astro.ruhr-uni-bochum.de/geiers/GAL/gal_rot.htm.

For other discussions of rotation curves and the evidence for dark matter, see

- http://cfa-www.harvard.edu/~mwhite/darkmatter/rotcurve.html
- http://www.owlnet.rice.edu/~spac250/elio/spac.html

For additional discussion of dark matter, see

- http://www.physics.fsu.edu/courses/spring99/ast3033/darkmatter.htm

An excellent guide to observing the night sky with a small telescope is “Turn Left at Orion: A Hundred Night Sky Objects to See in a Small Telescope - And How to Find Them,” by Dan M. Davis, Guy J. Consolmagno, Daniel M. Davis, Cambridge Univ Pr (Trd); ISBN: 0521482119.