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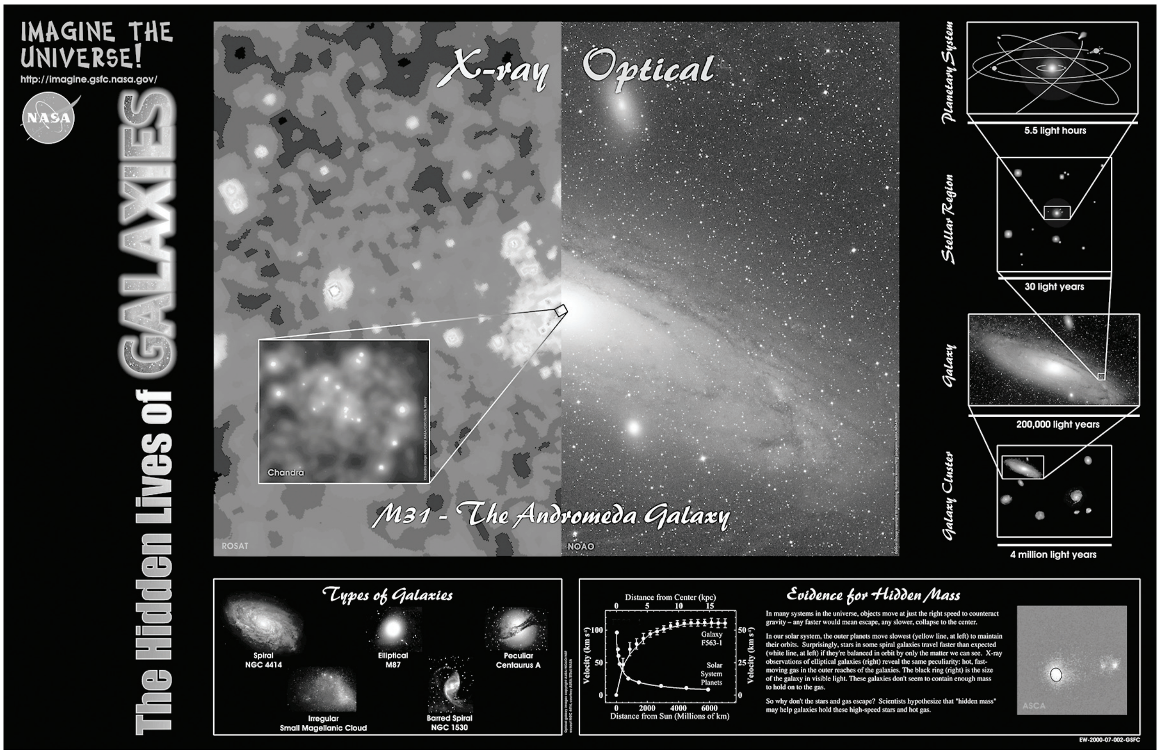
The Hidden Lives of Galaxies



An Information & Activity Booklet

Grades 9-12

2000-2001

(Updated 2005)

IMAGINE THE UNIVERSE!

Probing the Structure & Evolution of the Cosmos

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

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Imagine the Universe!

Presents

The Hidden Lives of GALAXIES

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

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NSES Content Standards are from Chapter 6 of National Science Education Standards, 1996, National Research Council, National Academy Press, Washing DC.

NCTM Math Standards are from Chapter 7 of Principles and Standards for School Mathematics, 2000, National Council of Teachers of Mathematics.

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Evidence for Hidden Mass	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
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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.

This booklet is intended to be used with the poster, "The Hidden Lives of Galaxies" (NASA # EW-2000-07-002-GSFC). To request a copy of the poster, write to us at itu@athena.gsfc.nasa.gov.

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 hard copies 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.

We thank Cheryl Niemela (Puyallup School District, WA) for valuable contributions and input to the revision 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

The constellation Andromeda contains our Galaxy's companion, the Andromeda Galaxy. Under clear skies on a dark night, it can be seen with the naked eye. At a distance of 2.2 million light years, it is the farthest object we can see without a telescope, and yet it is but the first stop in the vastness of the universe outside our Galaxy.

As a tribute to our search for knowledge about these objects in the universe, we recount an early story to explain what we see in the sky.

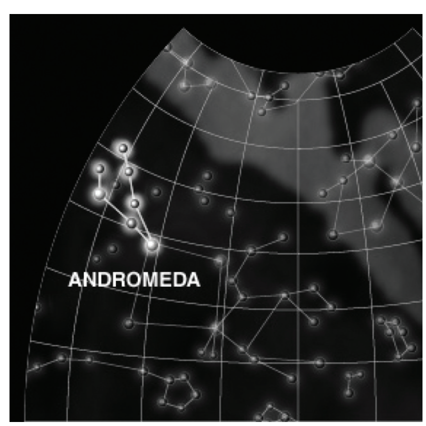
In Greek mythology, Andromeda was the daughter of Queen Cassiopeia and King Cepheus of Ethiopia. Andromeda's mother claimed she was more beautiful than the sea nymphs, the Nereids. The Nereids felt insulted by this and complained to the sea god Poseidon.

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.

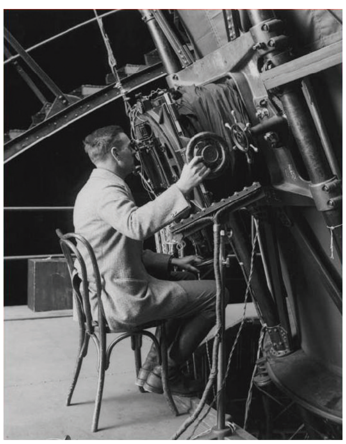


The constellation Andromeda

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. Over very long periods of time, through the action of **gravity**, these clumps acquired more surrounding matter and grew. Galaxies began to form when large clouds of gas and dust condensed. When very large clouds of gas condense through gravity, stars formed.

Introduction



Edwin Hubble

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.

Astronomers debated the nature of these nebulae. The question became whether these objects were within the Milky Way Galaxy, or whether they were stellar communities distinct from our Galaxy. It wasn't until the 1920's 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. Thus, these were found to be individual galaxies. Scientists now estimate that there are about 200 billion galaxies of various types in the universe.

*Recommended Activity: How Big is the Universe***?** *(see p. 14)*

I. The Visible 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.

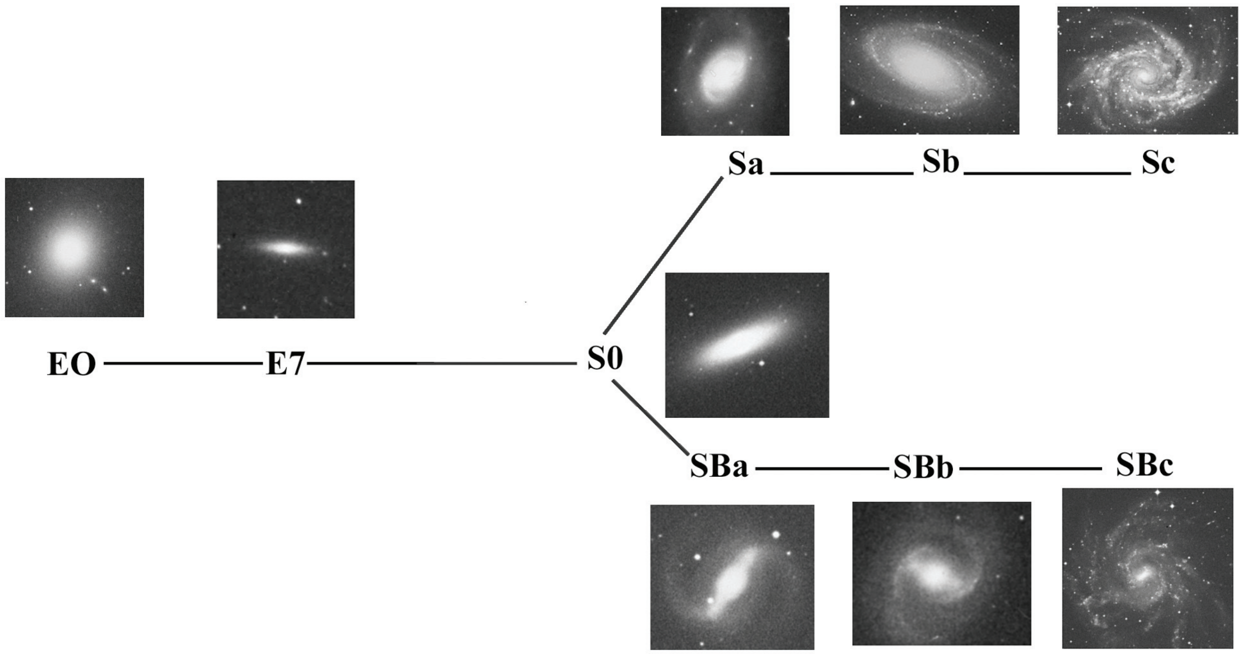
Galaxies come in a variety of shapes. In the 1920's Edwin Hubble was the first to study the **morphology** of galaxies. Using the 100-inch Hooker reflector telescope at Mount Wilson Observatory in California between 1922-1926, Hubble photographed numerous galaxies. He categorized (or "classified") their shapes as spiral, barred spiral, elliptical, irregular, and peculiar. This system was known as the Hubble morphological sequence of galaxy types.

Hubble 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.

Hubble also noted that some spirals had a bright bar of gas through the center, and called these *barred spirals*. Hubble also 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.

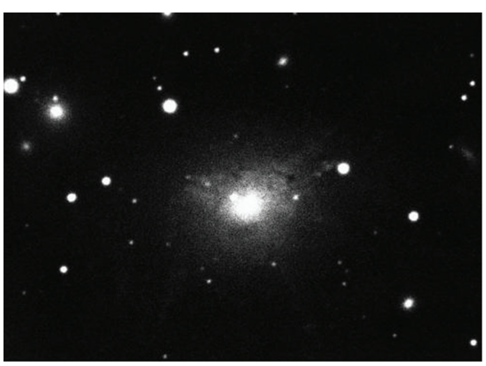
This classification sequence has become so widely used that the basic types, spiral, barred spiral, elliptical, irregular, and peculiar, are still used by astronomers today to classify galaxies according to their visible appearance. Spirals are denoted by "S", and barred spirals by "SB". Letters "a", "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.



Hubble's Fork Diagram of Galaxy Classification

Astronomers now have recognized that the morphology classification consists of two basic 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".



Seyfert Galaxy NGC 1275 in Persus

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.

Recommended Activities: Identifying Galaxies (see p. 14), and Classifying Galaxies Using Hubble's Fork Diagram (see p. 15)

B. How Galaxies Get Their Names

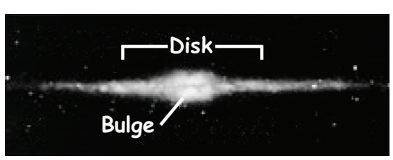
Some galaxies are given descriptive names (e.g. ”Andromeda”, “Whirlpool”) if they are particularly distinctive in location or appearance. But most galaxies are known from their designation in a catalogue. One of the earliest catalogues of objects in the sky was made by Charles Messier. Messier was looking for comets in the 1700’s, but kept finding objects that looked fuzzy, like comets, but didn’t move. Eventually, he created a catalogue of these objects, listing their positions so he wouldn’t be fooled again into thinking they were comets. Later, a number of them were identified as galaxies. Although he categorized many brilliant objects in the night sky, his cataloguing system was completed in a random manner. So M1 (the Crab Nebula in the constellation Taurus) is nowhere near M2 (a globular cluster in Aquarius).

As the capability of telescopes grew, larger catalogues were created. One of the oldest, but still widely used, is the *A New General Catalogue of Nebulae and Star Clusters*, or NGC for short, published by J. L. E. Dreyer in 1888. The NGC numbers objects from west to east across the sky, so that all objects in the same area of the sky have similar NGC numbers. (The Andromeda Galaxy is NGC 224, and the Whirlpool Galaxy is NGC 5194). Other catalogues have been created from specific ground based observatories (e.g. ESO, the European Southern Observatory, and the Uppsala General Catalogue (UGC) from the Palomar Observatory), orbiting observatories (e.g. IR, for the Infrared Astronomical Satellite), or for specific objects with certain properties (e.g. The Markarian catalogue lists galaxies with bright ultraviolet emission). The numbers following the letter designation may indicate either the order in the list or the location of the galaxy in the sky.

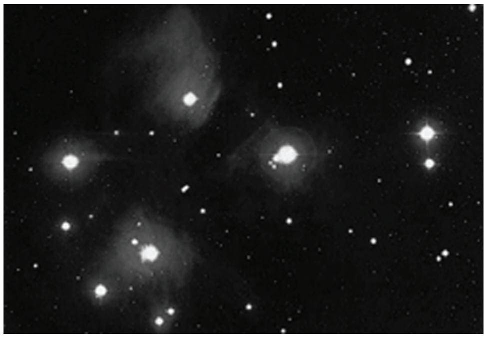
Recommended Activity: Identifying Unusual Galaxies (see p. 14)

C. The Components of a Galaxy

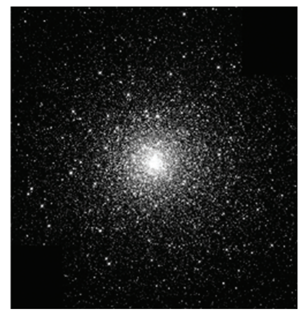
A galaxy may be made up of two visible components. The two components are the **disk** and the **bulge**. Spiral galaxies have most of their stars in a disk. Elliptical galaxies do not have a disk. The stars may be single stars, double, or multiple stars, or may be part of clusters. In the disk, stars 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 an open cluster.



A Near-infrared image of the Milky Way Galaxy


The Pleiades

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 make a full revolution around the center. 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 Globular Cluster M80

Elliptical galaxies consist of just one visible component, the bulge. A good example of this is 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.

Recommended Activity: Open Clusters vs. Globular Clusters (see p. 16)

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.

The Milky Way and our nearest neighbor galaxies form a collection of galaxies called 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. Superclusters are connected by lines (also referred to as filaments) of galaxies or clusters that run outside regions that do not have any galaxies (called voids). The study of these large structures in the Universe provides astronomers with observations that can be used to test their models in understanding how these structures form. Different models of how structure arises give different maps of the Universe.

II. The Hidden Lives of Galaxies

A. Hidden Objects

Observations of galaxies at wavelengths other than optical light reveal 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 (= 1420×10^6 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.

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 are formed 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. 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.

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. Often, this central part of the galaxy is very bright in x-rays gamma rays and radio, because of the large amount of material interacting near the very massive black hole. Such galaxies are said to have an Active Galactic Nucleus, and are often referred to as AGNs. The central black hole can have a mass of millions (or even billions) times the mass of our sun.

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 what would be expected from the gravitation force of the visible mass (stars, gas, dust) in the Galaxy. In reality, the stars appeared to be moving faster than this - 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, a Swiss astronomer, Fritz Zwicky, working in America, 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. Scientists still know little about dark matter. 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. (See section C below for further discussion on the possible sources of dark matter.)

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 weak to 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.

Recommended Activities: Modeling Mass in the Solar System and a Galaxy (see p. 17), Evidence for Hidden Mass (see p. 18), Getting a Feel for Rotation Curves (see p. 19), and Weighing a Galaxy (see p. 19)

C. Possibilities for Dark Matter

The search for the nature of dark matter is a very active field in astronomy and physics. Scientists do not know what it is made of, but they are investigating a number of possibilities.

The chief property of dark matter is that it is "dark", i.e. that it emits no light. Not visible, not x-ray, not infrared. So it is not large clouds of hydrogen gas, since we can usually detect such clouds in the infrared or radio. In addition, dark matter must interact with visible matter gravitationally. So the dark matter must be massive enough to cause the gravitational effects that we see in galaxies and clusters of galaxies. Large clouds of hydrogen gas don't have enough mass to do what the dark matter does.

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

MACHOs (MAssive Compact Halo Objects): MACHOs are objects ranging in size from small stars to super massive black holes. MACHOS are made of ordinary matter (like protons, neutrons and electrons). They may be black holes, neutron stars, or brown dwarfs.

Neutron Stars and Black Holes are the final result of a supernova of a massive star. They are both compact objects resulting from the supernovae of 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. Because a supernova usually leaves behind a remnant cloud of gas, these objects must travel far from the remnant to be "hidden."

Pros: Neutron stars are very massive, and if they are isolated, they both can be dark.

Cons: Because they result from supernovae, they are not necessarily common objects. 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.

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.

Astronomers have been detecting MACHOs using their gravitational effects on the light from distant objects. In formulating his theory of gravity, Einstein discovered that the gravitational attraction of a massive object can bend the path of a light ray, much like a lens does. So when a massive object passes in front of a distant object (e.g. a star or another galaxy), the light from the distant object is "focused" and the object appears brighter for a short time. Astronomers search for MACHOs (usually brown dwarfs) in the halo of our galaxy by monitoring the brightness of stars near the center of our galaxy and of stars in the Large Magellanic Cloud.

The MACHO Project, one of the groups using this "gravitational lens" technique, observed about 15 lensing events toward the LMC over a span of 6 years of observations. They set a limit of 20% as the contribution to the dark matter in our Galaxy due to objects with mass less than 0.5 that of the sun.

Pros: Astronomers have observed objects that are either brown dwarfs or large planets around other stars using the properties of gravitational lenses.

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

WIMPs (Weakly Interacting Massive Particles): WIMPs are the subatomic particles which are not made up of ordinary matter. They are “weakly interacting” because they can pass through ordinary matter without any effects. They are “massive” in the sense of having mass (whether they are light or heavy depends on the particle). The prime candidates include neutrinos, axions, and neutralinos.

Neutrinos were first “invented” by physicists in the early 20th century to help make particle physics interactions work properly. They were later discovered, and physicists and astronomers had a good idea how many neutrinos there are in the universe. But they were thought to be without mass. However, in 1998 one type of neutrino was discovered to have a mass, albeit very small. This mass is too small for the neutrino to contribute significantly to the dark matter.

Axions are particles which have been proposed to explain the absence of an electrical dipole moment for the neutron. They thus serve a purpose for both particle physics and for astronomy. Although axions may not have much mass, they would have been produced abundantly in the Big Bang. Current searches for axions include laboratory experiments, and searches in the halo of our Galaxy and in the Sun.

Neutralinos are members of another set of particles which has been proposed as part of a physics theory known as supersymmetry. This theory is one that attempts to unify all the known forces in physics. Neutralinos are massive particles (they may be 30x to 5000x the mass of the proton), but they are the lightest of the electrically neutral supersymmetric particles. Astronomers and physicists are developing ways of detecting the neutralino either underground or searching the universe for signs of their interactions.

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. These particles are also important to physicist who seek to understand the nature of sub-atomic physics.

Cons: The neutrino does not have enough mass to be a major component of Dark Matter. Observations have so far not detected axions or neutralinos.

There are other factors which help scientists determine the mix between MACHOs and WIMPs as components of the dark matter. Recent results by the WMAP satellite show that our universe is made up of only 4% ordinary matter. This seems to exclude a large component of MACHOs. About 23% of our universe is dark matter. This favors the dark matter being made up mostly of some type of WIMP. However, the evolution of structure in the universe indicates that the dark matter must not be fast moving, since fast moving particles prevent the clumping of matter in the universe. So while neutrinos may make up part of the dark matter, they are not a major component. Particles such as the axion and neutralino appear to have the appropriate properties to be dark matter. However, they have yet to be detected.

Recommended Activity: Dark Matter Possibilities (see p. 20).

D. Formation of Galaxies

How galaxies formed after the Big Bang is a question still being studied by astronomers. Astronomers hypothesize that within the first few hundred thousand 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. These first galaxies appeared 12.5 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.

Recommended Summary Activities: The Universe as Scientists Know It (see p. 21), and Seeing as Far as You Can See (see p. 22).

III. Classroom Activities

Most of the classroom activities have a Student Worksheet which accompanies them. These worksheets appear on pages 24-46 and are formatted for easy copying. Some activities also use transparencies that are available at **http://imagine.gsfc.nasa.gov/docs/teachers/transparencies/**.

Activity #1 – How Big is the Universe?

In this activity, students estimate the size of the visible universe in relation to the size of the Milky Way Galaxy. To do so, students will get a sense of scale and will convert from centimeters to kilometers.

See Student Worksheet, page 24

Worksheet Answers

1. What is the total size of the Milky Way Galaxy? 100,000 light years
2. If the Milkyway Galaxy is represented by an 8 cm wide coffee mug, the visible universe would approximately 12 km in radius.

Activity #2 – Identifying Galaxies

In this activity, students describe the characteristics of the different types of galaxies (spiral, elliptical, barred spiral, peculiar, or irregular) in their own words. They also classify galaxies seen in the Hubble Deep Field. Note that this activity uses the transparencies that accompany this booklet. The transparencies are also available at **http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/transparencies/**

See Student Worksheet, page 25.

Worksheet Answers/Assessment Guide

1. Show the students either "The Hidden Lives of Galaxies" poster or Transparency #1: Types of Galaxies. Students write a brief description of each galaxy type.
   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. Show Transparency #2: Deep Survey Image. Students 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

In this activity, students explore the idea of classifying objects. They start by giving examples of objects that can be classified in everyday life and in science. They then characterize and classify a set of galaxies using their own scheme, and using Hubble’s classification scheme.

See Student Worksheet, page 26.

Note that the Galaxy Classification Chart is on the “Hidden Lives of Galaxy” poster and is available as Transparency #4 – Galaxy Classification Images. Transparencies are available at **http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/transparencies/**.

Worksheet Answers/Assessment Guide

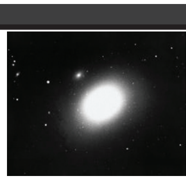
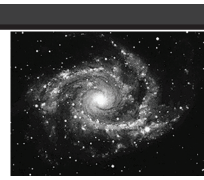
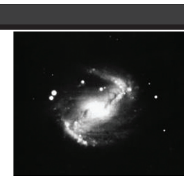
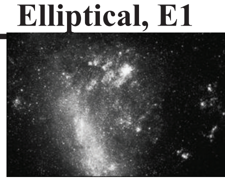
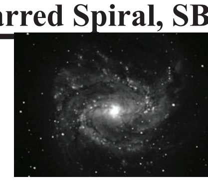
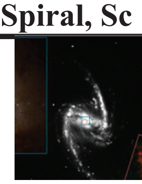
Part 1

1. We put objects into categories to help us organize the items, and to identify similarities. By putting items in different categories, we can identify their differences.
2. Examples of items we categorize in everyday life may include a CD collection, clothes, magazines, books. 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. Classifying objects into categories helps us identify similarities in their properties and/or their functions. Examining a group of similar objects together helps scientists determine the reasons or causes behind their properties or behavior.
3. Scientists classify the different elements (through the periodic table), different forms of life (through kingdoms, species, etc.), different types of stars, as just a few examples.

Part 2

3. Below are the names given to these galaxies by astronomers (hopefully your students came up with better names!), the galaxy type, and galaxy classification using the Hubble Fork Diagram.

Galaxy Classification Chart

 **M84** **Elliptical, E1**	 **NGC 2997** **Spiral, Sb**	 **NGC 5383** **Barred Spiral, SBb**
 **Large Magellanic Cloud** **Irregular, Ir**	 **NGC 4622** **Spiral, Sb**	 **M83** **Spiral, Sc**
 **Centaurus A** **Peculiar, P**	 **M59** **Elliptical, E5**	 **NGC 1365** **Barred Spiral, SBc**

Activity #4 – Identifying Unusual Galaxies

In this activity, students will identify galaxies by their distinctive appearance.

See Student Worksheet, page 29.

Worksheet Answers

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

In this activity, students will describe similarities and differences between galactic star clusters and globular clusters.

Show students Transparency #5: M37/M80, compare the open cluster M37 to the globular cluster M80 (See **http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/transparencies/** for transparency.) Also review the material in section C on the components of a galaxy.

See Student Worksheet, page 30.

Worksheet Answers/Assessment Guide

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 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.

The analogy between a globular cluster and bees swarming about a beehive can be appropriate in the depiction of many stars moving about a common center. The analogy can be inappropriate in that the stars move slowly, and in paths determined by the gravitational forces of the stars in the cluster. The bees, on the other hand, are “self-propelled” and move more randomly.

Activity #6

This is a series of activities which illustrate the principles behind hidden mass, rotation curves and the evidence for hidden mass,

Activity #6a: Modeling Mass in the Solar System and a Galaxy

In this activity, students will discover how mass is distributed in the solar system and a galaxy.

Materials:
1 10-lb (4.54 kg) bag of kitty litter
Material such as sand or small pebbles
large paper
A balance capable of measuring a few grams
A balance capable of measuring a few kilograms.

The Student Worksheet (page 31) gives the instructions for the activity.

Worksheet Answers

Part A

1. To get the "kitty litter" equivalent masses of the planets, use ratios. For example, for Jupiter, use $x/4536 = (1.90 \times 10^{27})/(2 \times 10^{30})$. Here are the masses of the planets, and those masses as fractions of the sun's mass

Object	Mass (kg)	Kitty Litter Equiv. (g)	Distance (km)	Mass Inside Orbit (g)
Sun	2.00×10^{30}	4536	0	4536
Mercury	3.30×10^{23}	7.5×10^{-4}	57.9×10^{6}	4536
Venus	4.87×10^{24}	1.1×10^{-2}	108.2×10^{6}	4536.01
Earth	5.97×10^{24}	1.4×10^{-2}	149.6×10^{6}	4550.02
Mars	7.35×10^{22}	1.7×10^{-4}	227.9×10^{6}	4550.02
Jupiter	1.90×10^{27}	4.31	778.4×10^{6}	4540.34
Saturn	5.69×10^{26}	1.29	1427×10^{6}	4541.63
Uranus	8.68×10^{25}	0.20	2871×10^{6}	4541.83
Neptune	1.02×10^{26}	0.23	4498×10^{6}	4542.06
Pluto	1.3×10^{22}	2.9×10^{-5}	5906×10^{6}	4542.06

So if the sun is represented by 4.55 kg of kitty litter, then Jupiter is 4.3 gms, Saturn is 1.3 gms, Uranus and Neptune are each about 0.2 gms, and all the terrestrial planets combined are about 0.025 gms. The "kitty litter" equivalents of the terrestrial planets individually are impossible to measure out; even their combined amount is most likely difficult. Computing these "kitty litter" equivalents provides the students a sense of how much more massive the sun is.

4. Note that in this exercise, the students are asked to imagine passing the *orbits* of the planets. The masses they are adding up is the mass within that distance to the sun. So it doesn't matter if the planet is actually on the opposite side of the sun, just as long as its closer to the sun than the distance being considered. Alternatively, you may ask students to imagine that the planets are lined up.

   The mass within the distance between you and the sun is the sun's mass plus whatever planet orbits haven't been passed. For the most part, it's 4.536 kg. Details are in the chart above. Students should not record values less than one hundredth of a gram.

Part B

1. You expect the matter in the galaxy to be where the light is. So a good deal of the mass should be in the central bulge, but a fair amount should be spread around in the spiral arms.
2. Using the fact that the area of a pie segment is $0.5\ R^2\ \theta$ (where θ is in radians), advanced students might derive the appropriate radii for the portions.
4. Now the students should note that the mass within their distance to the center will significantly decrease as they move toward the center.
5. Distribute the new material uniformly throughout the model galaxy.
6. Each third of the slice will be more massive. What the students should note is that the fraction by which the mass increases is larger for the outer thirds of the pie segment. This is because we distributed the "dark matter" uniformly, but the original visible matter is not. So the mass in the outer portion has more of an effect.
7. Now the students will note that the mass does not change as much. If they could "see" the dark matter, the distribution of mass in the galaxy would look more uniform.

Activity #6b - Evidence for Hidden Mass

In this activity, students will interpret and analyze the information presented on the "Evidence for Hidden Mass" graph. They will observe trends in the graphs, and use it to determine if there is evidence for hidden mass.

The "Evidence for Hidden Mass" graph is on the "Hidden Lives of Galaxies" poster. It is also available as Transparency #6 , as part of the transparency set. The transparencies are available at **http://imagine.gsfc.nasa.gov/docs/teachers/galaxies/**.

See Student Worksheet, page 33.

Worksheet Answers

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 the distance ranges from 0 to about 19 kpc, and the velocity ranges from 0 to 100 km/s. The velocities first increase with increasing distance. But at distances larger than 10 kpc, the velocity becomes constant with increasing distance.

Activity #6c – Getting a Feel for Rotation Curves

This activity is a kinesthetic exercise for students to experience rotation curves for themselves. ***Note that there is no student worksheet for this activity.***

Divide the students into two groups. One group will participate in the activity while the other observes. The groups should switch for different parts of the activity.

1. Have students stand in a line, linking arms. Have the person at one end start to turn slowly. Ask the Observers, "How would you describe the motion of the other students? Can you plot their positions as they change with time? What would its rotation curve look like?"
   - The students represent objects that are tightly bound together, e.g like a rod, or a CD or a vinyl record. So the students will likely move mostly in unison, but the inner students cover shorter distances than the outer students do in the same amount of time. The rotation curve would show a linear increase in student velocity as distance from the center increases. This mimics stars in the bulge of a galaxy.

2. Now have the students hold hands. Again have the person at one end turn slowly in place. Ask the Observers, "Now how would you describe the motion of the other students? What does the rotation curve look like now?"
   - Now the students are not so tightly bound together, but they still move in a circle around the central point. The students will not move so much in unison. The rotation curve will initially rise but then level off as distance increases. This mimics stars in the spiral arms of a galaxy.

3. Now let the first half of the line links arms, and the rest of the students hold hands. Ask the Observers to describe the motion.
   - The students linking arms will move mostly in unison, while velocity of the outer students will approach a constant value. Together, this mimics motions of stars in the bulge and spiral arms.

4. Finally, let the students walk freely in circles (i.e. as in orbits) around the student in the center.
    - Here the rotation curve will vary depending on the creativity of the students. See if they can imitate the rotation curve of the solar system by having the inner students move more quickly than the outer students.

Activity #6d - Weighing a Galaxy

Students will use Newton's Laws of Motion to determine the mass of the sun from the motions of the planets. They will then use the same techniques to determine the mass of a galaxy. In doing so, students will convert among different measurement units used in astronomy.

See Student Worksheet, page 35.

Worksheet Answers

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

In this activity, students investigate one specific topic related to dark matter using available resources. Students will organize their findings and present this information in a creative and engaging fashion.

See student worksheet, page 37.

Directions:

1. Organize students into groups of about four students each. Assign each group one of the following topics related to dark matter (you may need to assign several groups to the same topic).

    - Massive Compact Halo Objects (MACHOs)
    - Weakly Interacting Massive Particles (WIMPs)
    - Hydrogen Gas

2. The Student Instruction Sheet (see page 37) gives students a series of questions to guide the investigation of their topic. It also lists suggested resources to use. Ask students to gather their information, citing their sources in a bibliography. Allow one to two days for the students to carry out their research.

3. Ask students to prepare a presentation to the class. Some possible presentation formats are on the Student Instruction Sheet. Feel free, of course to suggest and/or encourage others.

A suggested rubric for assessment:

Criteria	1 point	2 points	3 points	4 points
Answering Questions	Half of the questions are answered with little attempt for complete sentences and spelling	Most questions are answered; most in complete sentences with correct spelling	All questions are answered; most in complete sentences with correct spelling	All questions are answered completely, in complete sentences with correct spelling
Citing Resources	At least one source is listed, using correct bibliography formatting	At least two sources are listed, using correct bibliography formatting	At least three sources are listed, using correct bibliography formatting	At least four sources are listed, using correct bibliography formatting
Working in Groups	Group members are able to complete their research and complete the project	Group members attempt working together with little teacher intervention	Group members work effectively together with only one warning	Group members work effectively together with no warnings
Presentation	One to two minutes long; half of the research information	One to two minutes long; includes most of the research information	2 to 3 minutes long; includes all of the research information	3 to 5 minutes long; includes all of the research information
Creativity	No attempt to engage audience is made	Audience is engaged; no props are used	Audience is engaged; one or two props are created/used	Audience is engaged; several props are created/used

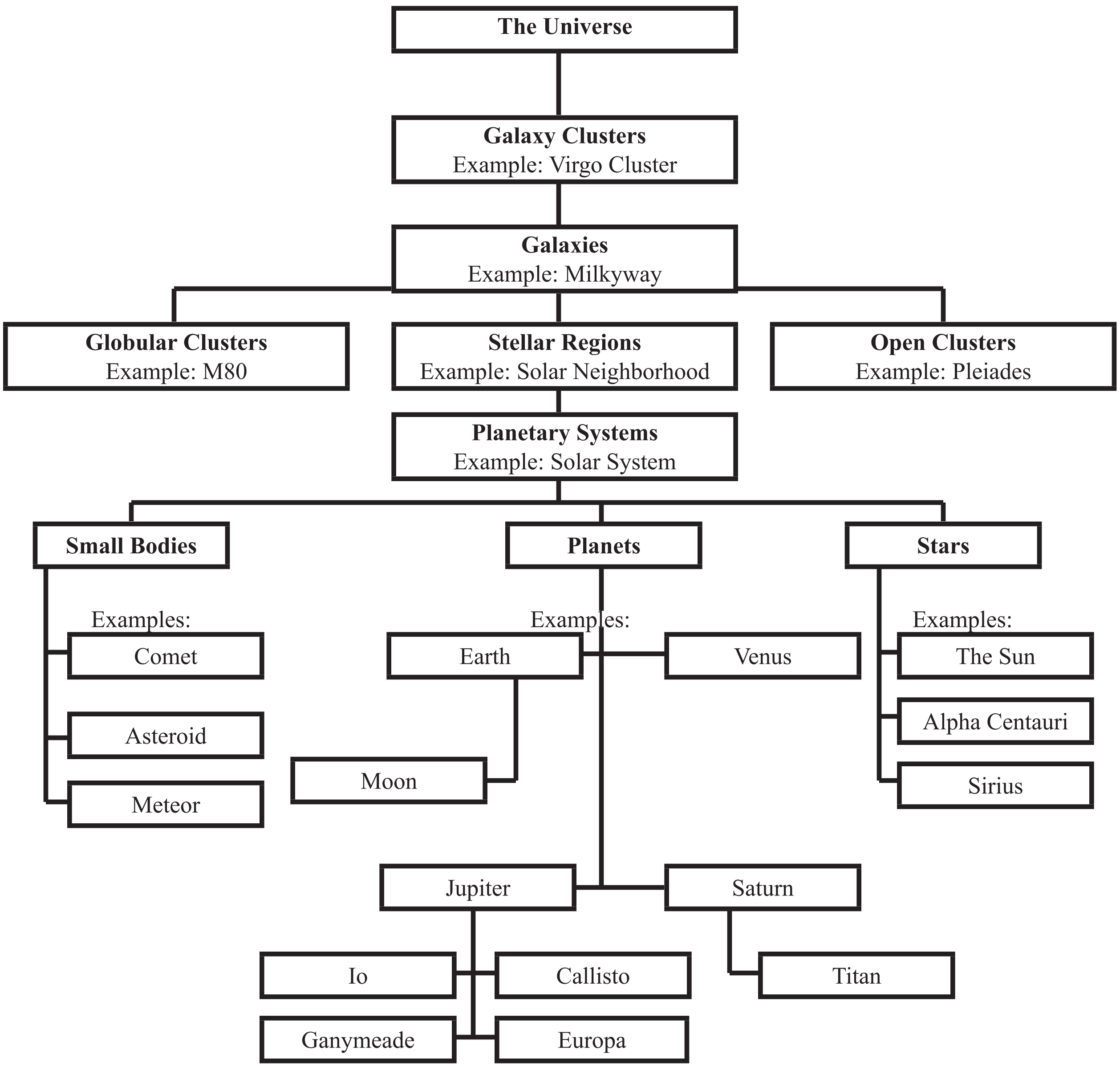
Activity #8 - The Universe as Scientists Know It

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

See Student Worksheet, page 39.

Worksheet answer

The Universe As Scientists Know It



Activity #9 – Seeing as Far as You Can See

In this activity, students become familiar with using binoculars and/or a telescope. They locate and identify constellations, and the Andromeda Galaxy.

This is a night-time activity that may be best done with the help of parents, a local astronomy club, museum, planetarium, or university. It offers the opportunity for students to experience the night sky and to see a galaxy. This activity is designed to be done in the fall, when the Andromeda Galaxy is most easily visible in the early evening.

See Student Worksheet, pp 40-46.

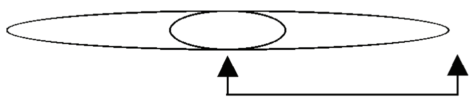
Assessment:

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. Answers may vary, but The Big Dipper (part of Ursa Major), Pegasus, Cassiopeia, Cygnus, Andromeda are among the possibilities
3. The Solar System is located in the Milkyway galaxy. The morphology of the Andromeda Galaxies is spiral; the Triangulum Galaxy is also spiral; M33, the companion to Andromeda is elliptical.

Activity #1
How Big is the Universe?

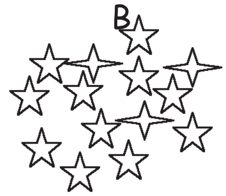
The Milky Way has a radius of approximately 50,000 **light years**. The visible universe has a size of approximately 15 billion light years. If the Milky Way is represented by an 8 centimeter wide coffee cup, how big would the rest of the universe be in kilometers?

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 of approximately 15 billion light years.

So if an 8 cm wide coffee cup represents the Milky the visible universe would be approx. ________ km in radius.

Show your calculations

What other objects can you use to compare the size of the universe with the size of the Milky Way galaxy?

Activity #2
Identifying Galaxies

1. Your teacher will show you an image of different types of galaxies. List the five types of galaxies and write a brief description of each.

Title______________________________

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

2. The "Hubble Deep Field" image was taken by the Hubble Space Telescope December 18 – 28, 1995. It was taken of a region near the handle of the Big Dipper, and covers a patch of sky about only 0.05 degrees across (equivalent to the width of a dime viewed 75 feet away). This region was chosen because there are very few stars there. So nearly every object in the image is a galaxy.

   Your teacher will show you a portion of the Hubble Deep Field image. Identify the types of the ten galaxies labeled on the Deep Survey Image.

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

Assessment:
List at least five specific observations from Deep Survey Image.

Activity #3

Classifying Galaxies with Hubble's Fork Diagram

Part I

Brainstorm answers to the following questions in your group.

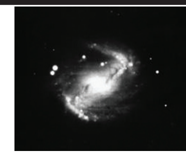
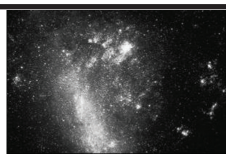
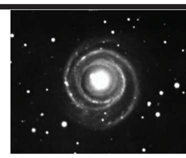
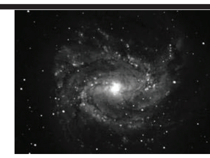
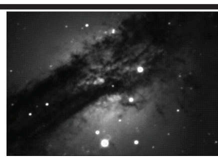
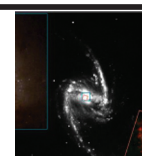
1. Why do people put things into classifications or categories? How does this help us? ____
____
____
2. What are some things we categorize in our daily lives? Why? ______________
____
____
____
3. What types of objects do scientists classify? Name five different areas of science that classify objects and identify them. Tell what they classify.
   - ❑ ____
   - ❑ ____
   - ❑ ____
   - ❑ ____
   - ❑ ____

Part II

In your groups, look at the images of actual galaxies on the page 2 and suggest answers to the following questions.

1. Pretend that a NASA astronomer comes to your school and asks you to name the galaxies pictured in the chart based upon their resemblance to common objects. What would you name them? Write your suggestions underneath each picture.

Galaxy Classification Chart

 --------------------- ---------------------	 --------------------- ---------------------	 --------------------- ---------------------
 --------------------- ---------------------	 --------------------- ---------------------	 --------------------- ---------------------
 --------------------- ---------------------	 --------------------- ---------------------	 --------------------- ---------------------

2. Without using any prior information, how many different types of galaxies are represented in these pictures? Decide on how many groups or classifications you would have and give each group a name. Then, underneath, include the criteria you would use to include a galaxy in this group.

- ❑ Group Name : ____
  Criteria : ____
  ____
- ❑ Group Name : ____
  Criteria : ____
  ____
- ❑ Group Name : ____
  Criteria : ____
  ____
- ❑ Group Name : ____
  Criteria : ____
  ____
- ❑ Group Name : ____
  Criteria : ____
  ____

3. Now imagine that the NASA astronomer needs your help to classify these newly discovered galaxies based upon your knowledge of the Hubble Fork Diagram. Classify each galaxy according to that scheme. Write the galaxy type and classification below your name of each image. (For example, the Andromeda Galaxy is Spiral, Sb.)

Part III – Optional

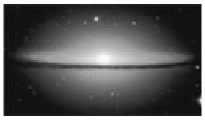
In your groups, research one of the different types of galaxies in the Hubble Fork Diagram. Using the resources provided by your teacher, identify the following information about your galaxy type and present this information to the class.

- Type and classification
- Shape
- Examples of this galaxy type
- How this galaxy forms
- How stars move in this galaxy type

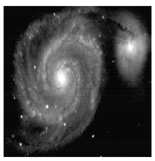
You must use at least one of the following methods to present this information: create one large 3-D poster, write and perform a skit, write and perform a song or rap, or create a 3-D model.

Activity #4
Identifying Unusual Galaxies

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

1.______  a. Polar Ring Galaxy

Reason_________________________________
____

2. ______  b. Siamese Twins Galaxy

Reason_________________________________
____

3. ______  c. Sombrero Galaxy

Reason_________________________________
____

4. ______  d. Whirlpool Galaxy

Reason________________________________
____

Activity #5
Open Clusters vs. Globular Clusters

Using the image provided by your teacher, compare the open cluster M37 to the globular cluster M80. Complete the Venn diagram below to compare and contrast the properties of open clusters with globular clusters.

Assessment:
A globular cluster is sometimes compared to bees swarming around a beehive. How might this analogy be appropriate? How might this analogy be inappropriate?

Activity #6a
Modeling Mass in the Solar System and a Galaxy

Part A: Create a mass model of the solar system

1. Using the chart below, answer the following questions
   a. If the mass of the sun is represented by 4.55 kg of kitty liter, how much kitty litter would represent the mass of Jupiter?
   b. Of Saturn?
   c. Of Uranus or Neptune?
   d. All the other planets (Mercury, Venus, Earth, Mars, Pluto) combined?

Object	Mass (kg)	Kitty Litter Equivalent (g)	Avg. Distance from Sun (km)	Mass Inside Orbit (g)
Sun	2.00×10^{30}	4550	0	
Mercury	3.30×10^{23}		57.9×10^{6}	
Venus	4.87×10^{24}		108.2×10^{6}	
Earth	5.97×10^{24}		149.6×10^{6}	
Mars	7.35×10^{22}		227.9×10^{6}	
Jupiter	1.90×10^{27}		778.4×10^{6}	
Saturn	5.69×10^{26}		1427×10^{6}	
Uranus	8.68×10^{25}		2871×10^{6}	
Neptune	1.02×10^{26}		4498×10^{6}	
Pluto	1.3×10^{22}		5906×10^{6}	

2. Measure out these masses from the kitty litter for each of the gas planets and for the combination of the terrestrial planets.
3. Optional – Pour out the rest of the kitty litter to represent the mass of the sun.
4. If you were a space alien entering the solar system, as you approach the sun you would pass the orbits of the planets. As you passed by the orbits of each of the planets, how much mass (using the "kitty litter equivalents") is left within the distance between you and the sun? Fill in this information in the fourth column of the chart. Make a graph of this mass vs. distance.

Part B: Create a mass model of a galaxy.

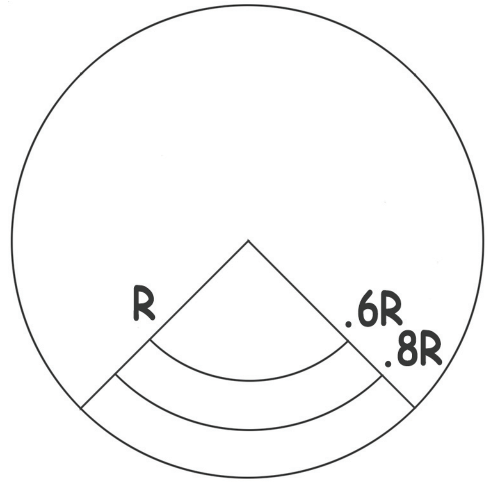
1. Examine a picture of the Andromeda galaxy. Where do you expect the matter to be in the galaxy?

   ____

   ____

   Distribute the kitty litter according to where you expect the matter to be.

2. Select a pie section of your model galaxy. Divide that pie section radially into thirds (so there's an inner portion, a middle portion, and an outer portion). Each third should have the same area (If R is the radius of the pie section, the first third should extend 0.6R from the center, and the second portion between 0.6R and 0.8R from the center). If you divide a slice of a galaxy into equal thirds in this manner, would you expect to have the same amount of mass in each? Why or why not?



____
____
____
____
____

3. Determine and record the mass of each third of the slice:
   Outer Third ______ Middle Third ________ Inner Third _______
4. Now imagine you are a traveling to the Andromeda galaxy. As you travel through the galaxy, how much mass remains between you and the center. Create a graph of mass vs distance for this.

____
____

5. Now your teacher will distribute a new material in your galaxy.
6. Determine the mass of each of your portions in the pie section again.
   Outer Third ______ Middle Third ________ Inner Third _______
   Compare with your previous measurements. What do you notice?

____
____

7. Repeat your imaginary trip through the galaxy. Now what does the graph of mass vs distance look like? If you could see the hidden mass, what do you think the galaxy would look like? Draw a picture of what you think the galaxy would look like if you could see the whole galaxy?

____
____
____

Activity #6b
Evidence for Hidden Mass

Examine the "Evidence for Hidden Mass" graph. Note that the graph has a curve labeled "Solar System Planets" (in yellow) and a curve labeled "Galaxy F563-1" (in white). The curve for the Solar System shows the relationship between distance from the sun and orbital velocity for each of the planets. The curve for the galaxy shows the relationship between distance from the galaxy center and velocity around that center for stars in the galaxy.

1. Finish writing the paragraph below by interpreting the data about Solar System planets on the "Evidence for Hidden Mass" graph.

   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.

Activity #6b
Evidence for Hidden Mass (cont.)

2. Now use your own words to describe the graph for Galaxy F563-1. Describe the range of distances and velocities. Also describe the behavior of velocity as distance increases. ____
____
____
____
____
____
____
____
____
____
____________________________________.

Activity #6d
Weighing a Galaxy

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 ? __________________

1. 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? ___________________________
_________________________________.

Activity #7
Dark Matter Possibilities

In this activity, you will research one of the topics related to the possible sources of dark matter.

As you research your topic, answer the following questions:

1. What are the objects that could be included into this category?
2. What are the characteristics of these object(s)? Specifically:
    a. Where are these objects found in space?
    b. What is their approximate size per particle or object?
    c. How are these objects formed? Do they appear together or separately in space?
    d. Are these objects found in conjunction with other astronomical objects (e.g. stars, galaxies or nebulae)?
3. How could these objects be thought to contribute to dark matter?
4. What tools are required to detect these objects by astronomers or physicists?

Here are some suggested resources for investigating your topic:

- Imagine the Universe! web site:
  http://imagine.gsfc.nasa.gov/docs/science/know_l1/dark_matter.html
- Imagine the Universe! CD-ROM
- BBC Science & Nature:
  http://bbc.co.uk/science/space/deepspace/darkmatter/
- WMAP web site:
  http://map.gsfc.nasa.gov/m_uni/uni_101matter.html

Activity #7
Dark Matter Possibilities (continued)

Now you will present your findings to the class. Here are some suggested ways to present your results:

- Imagine that your group is to give a press conference about your newly discovered object(s), explaining what this is and how it may be a source for dark matter. Prepare your 5-minute presentation for the press, covering the information you discovered in answering the questions. Select one person to be the news anchor, one person to be the science reporter asking the questions, and one or two people to be the astronomers answering the questions. Dress your part! Act your part! (There may be a Nobel Prize in this for you!) Help the public understand your new findings. Create props, as needed.

- Imagine that you are a pop musician asked to produce a new CD for high school students that teaches about the subject of dark matter. This is a little different from your regular music, but you are willing to give it a try because you want to help students become excited about exploring space. In your group, write and perform a song or rap to teach about dark matter and the different possibilities for it. Give details about the topic that your group explored in your research. Perform this for the class, using props, backup music and costumes, as needed. Remember, you want your audience informed and excited about dark matter!

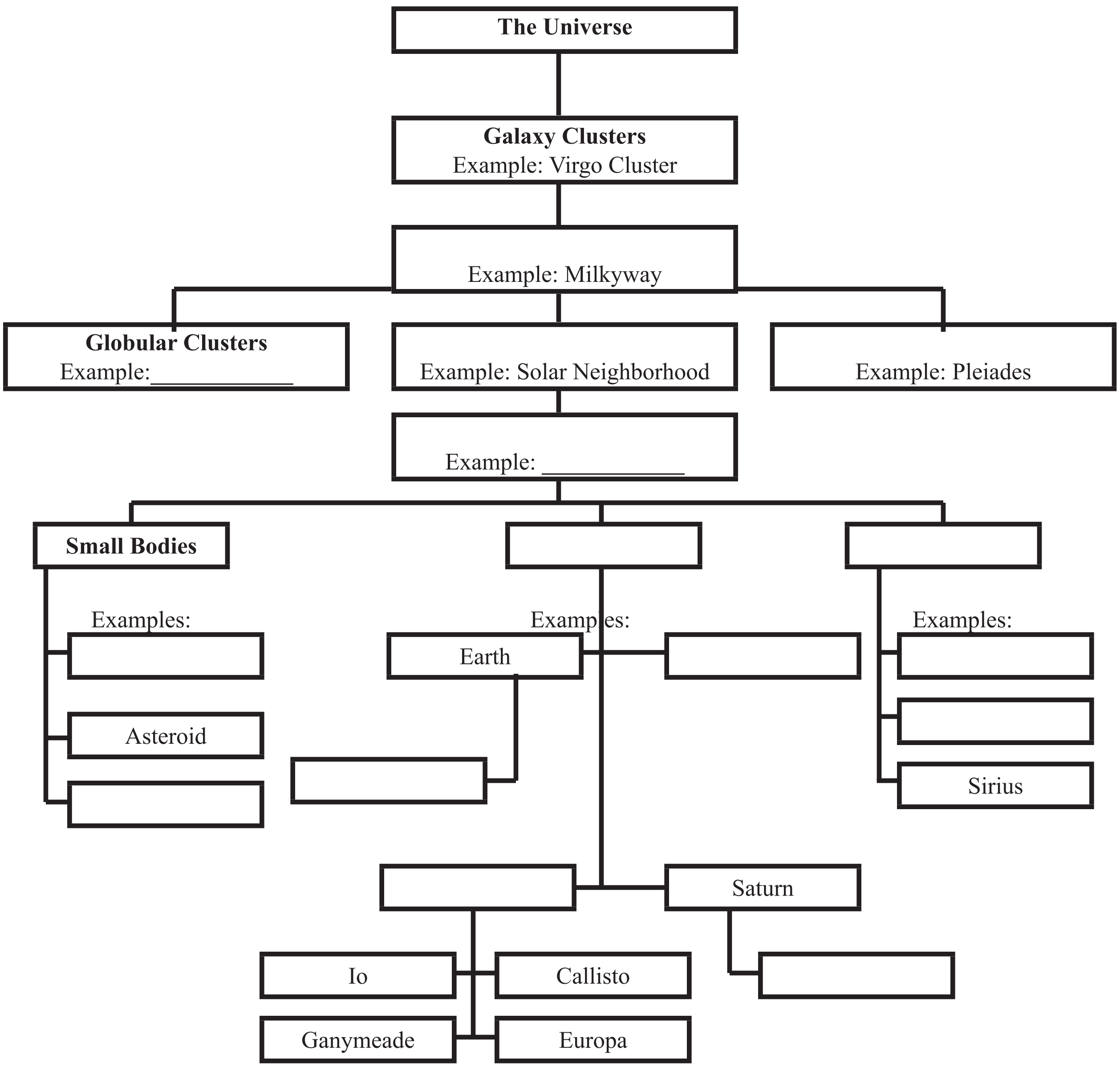
- Imagine that your group has been asked to create a game for high school students that will teach them about dark matter and, specifically, about the topic you researched. You and this game are to be featured in the local newspaper, as everyone in the community has heard how creative you are. You may create a card game, board game or physical game (e.g. tag, relay race) that will teach your material to the participants. When you are done, name your game, and teach it to the class.

- Imagine that your group has been contacted by a local theater company, specializing in interpretive drama. They have run out of fresh material and have just learned that you have discovered new information about something exotic called "dark matter." Naturally they think that this would make an excellent subject for a new play and they want you to help them write and perform it. Your job is to write a short play that explains your information in a creative way. Create costumes and find props that can help your play become more dramatic. Remember, if your audience isn't entertained, they won't learn as much! (There may be an Academy Award in this for you!)

Activity #8
The Universe as Scientists Know It

Directions:
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, Upsilon Andromeda.

The Universe As Scientists Know It



Activity # 9
Seeing as Far as You Can See

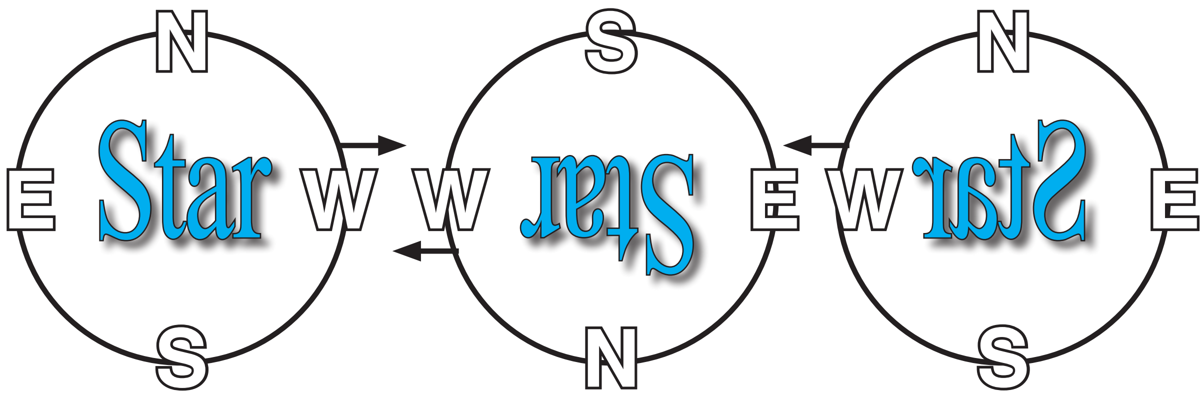
Directions:
In this night-time activity, you will become familiar with some of the stars and constellations in the autumn sky. You will also locate and see the Andromeda Galaxy.

1. Orient yourself to how objects in the night sky appear in binoculars and telescopes by looking at Directional Chart.
2. Read "Tip Sheet" for types of objects you might see in the night sky, and for observing tips.
3. Read "Autumn Seasonal Guide Posts" and "Galaxies Visible in the Autumn Sky" to identify constellations in the Autumn sky and directions for locating the Andromeda Galaxy.
4. Fill out "Observation Log" for each object you observe. Make additional copies for additional objects.
5. Complete the assessment.

Materials Needed
Flashlight
Piece of red cellophane
Rubberband
Pencil
Planisphere
Observation Log (included)
Seasonal Guide Posts (included)
Tip Sheet (included)
Blanket/Lawn Chair
Telescope
Binoculars

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 as it appears in most telescopes with a star diagonal (mirror image). Reflecting telescopes 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	

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.

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

Planets
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.

Meteors
Meteors are small pieces of rock that blaze across the sky appearing to leave a trail. They are often called “shooting stars”.

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

Stars
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.

Galaxies and Nebulae
Most galaxies and nebulae are too faint to see with the naked eye. Therefore, you will need to use binoculars or a telescope. Two exceptions are the Andromeda Galaxy and the Orion Nebula.

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.

Autumn Seasonal Guide Posts

The following will help you become familiar with the stars and constellations of the Autumn sky.

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	Andromeda	Constellation

Looking due north, about half-way up from the horizon will be a modestly 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. Between Cassiopeia and the Great Square is the constellation **Andromeda**. To the east you'll see a small cluster of stars called the **Pleiades**. North of the Pleiades, the brilliant **Cappella** rises.

Now we locate a few galaxies in the Autumn sky. You'll need binoculars to see the Andromeda Galaxy, and a small telescope to see the other. It should also be a night in which the moon is not up, and you are at a dark site.

Galaxies Visible in the Autumn Sky

Galaxies Visible in the Autumn Sky				
Object	**Name**	**Constellation**	**Morphology**	**Rating**
M31	Andromeda Galaxy	Andromeda	Spiral	4
M32	Companion to M31	Andromeda	Elliptical	2
M33	Triangulum Galaxy	Triangulum	Spiral	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. (These 3 stars are part of the constellation Andromeda). From the middle of these 3 stars go north towards Cassiopeia past one star to a second star, in a slightly curving line. The Andromeda Galaxy is near the second star. On a moonless night in a dark sky you may be able to see it without binoculars. If so, Congratulations! You're seeing an object 2.2 million light years away! Through binoculars, the galaxy looks like a bright oval embedded in the center of a long swath of light. In a small telescope at low power, the galaxy extends across the field of view. In the telescope, 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, locate the **Triangulum Galaxy (M33)**, which is not far from the Andromeda Galaxy. Locate again the Great Square, and follow the curving line of 3 stars toward Cassiopeia. We used the middle of these to find the Andromeda galaxy. Starting at the middle star again, the Triangulum galaxy is in the opposite direction from Andromeda. 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**. On a dark night you may be able to see it in binoculars. In a telescope, the galaxy is toward one end of 4 stars arranged as a "kite". The galaxy will look appear large, but very faint. Be sure to use your lowest power.

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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.

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- 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	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.

Rating:______
Sketch:

Assessment:

1. Identify five constellations you observed in the night sky.

____
____
____
______________________________.

2. Identify any planets that you located.

____
____
____
______________________________.

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

____
____
____
______________________________.

V. Glossary

ARM – In galaxies, a structure composed of gas, dust, and stars which winds out from near the galaxy's center in a spiral pattern.

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. It's 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 core of a massive star sometimes produced by a supernova explosion. Neutron stars are typically have a mass 1.4 times the mass of the Sun, and a radius of about 5 miles. Neutron stars can be observed 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 light 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

VI. 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 F563-1 was 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.

VII. 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.washjeff.edu/physics/plan.html**.

The galaxy images used in this booklet are from the Digital Sky Survey, as catalogued on the Interactive NGC Catalog Online

- **http://www.seds.org/~spider/ngc/ngc.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**

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

- **http://astron.berkeley.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.

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