chapter 1

Universe

How Do We Know What We Know About the Universe?

Standard 1: Students will understand the scientific evidence that supports theories that explain how the universe and the solar system developed. They will compare Earth to other objects in the solar system.

Standard 1, Objective 1: Describe both the big bang theory of universe formation and the nebular theory of solar system formation and evidence supporting them.

Lesson Objectives

- Investigate and report how science has changed the accepted ideas regarding the nature of the universe throughout history.
- Describe the big bang theory and the evidence that supports this theory (e.g., cosmic background radiation, abundance of elements, distance/redshift relation for galaxies)

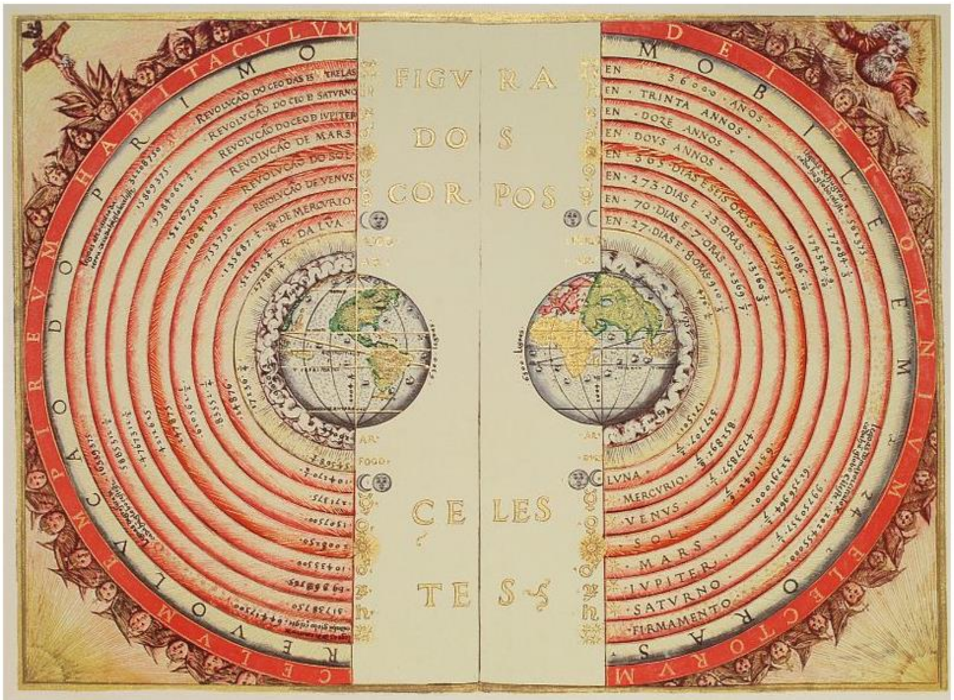
The study of the universe is called cosmology. Cosmologists study the structure and changes in the present universe. The universe contains all of the star systems, galaxies, gas and dust, plus all the matter and energy that exist. The universe also includes all of space and time.

Section 1: Evolution of Human Understanding of the Universe

What did the ancient Greeks recognize as the universe? In their model, the universe contained Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. This idea held for many centuries until new ideas and better observing instruments allowed people to recognize that Earth is not the center of the universe. Galileo's telescope revealed four moons orbiting Jupiter (not Earth) and many more stars than are visible to the naked eye. More importantly, Galileo's experiments established the principal of inertia which countered the physical arguments the Greeks used against a rotating and moving Earth.

Terms to know

- Big Bang Theory
- Doppler Effect
- Redshift
- Universe



Timeline of cosmological theories

4th century BCE – Aristotle, building on the ideas of earlier astronomers, proposes that the Sun, Moon, planets, and stars revolve around a stationary Earth. This is known as the geocentric theory, meaning that the universe revolves around the earth.

2nd century AD – Ptolemy publishes a book that describes a mathematical procedure to calculate future positions of the Sun, Moon, and visible planets in the sky. It reaffirms that all these objects move around a stationary Earth.

1543 – Nicolaus Copernicus publishes his heliocentric (Sun-centered) theory that proposes that Earth is a planet in motion around the Sun.

1610 – Johannes Kepler analyzed the accurate astronomical observations of Tycho Brahe, and discovers that the planets move around the Sun in elliptical orbits.

1687 – Sir Isaac Newton publishes the laws of motion and gravity that are used to accurately predict the motion of the Moon and planets.

1915 – Albert Einstein publishes the General Theory of Relativity, proposing that mass and energy cause space and time to curve or warp. This can be used to describe large-scale motion throughout the universe.

1929 – Edwin Hubble discovers a velocity-distance relationship for galaxies that implies that the universe is expanding.

In the early 20th century, an astronomer named Edwin Hubble (1889 - 1953) (see Figure 1 below) discovered that what was then called the Andromeda Nebula was so far away that it had to be a separate galaxy, outside our own Milky Way galaxy. Hubble realized that many of the objects that astronomers called nebulae were enormous collections of stars – what we now call galaxies.

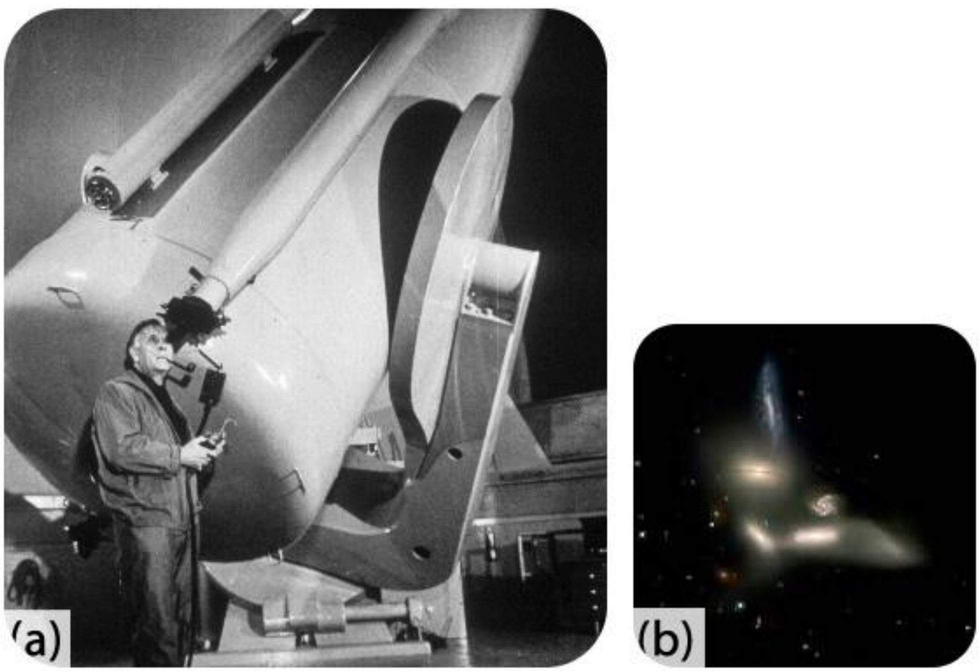


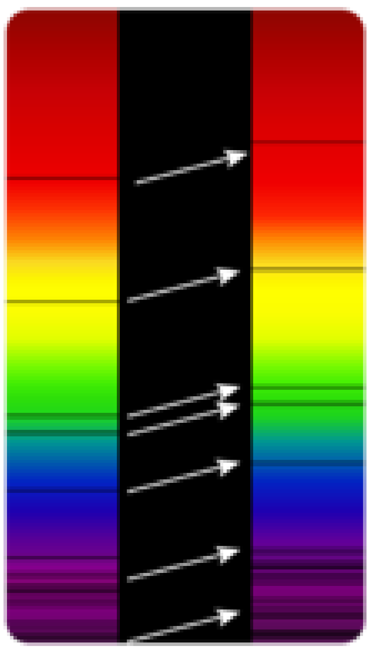
FIGURE 1 (a) Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light were galaxies. (b) Hubble's namesake space telescope spotted this six galaxy group. Edwin Hubble demonstrated the existence of galaxies.

Hubble showed that the universe was much larger than our own galaxy. Today, we estimate that the universe contains several hundred billion galaxies—about the same number of galaxies as there are stars in the Milky Way Galaxy.

Section 2: Is the Universe Getting Bigger or Smaller?

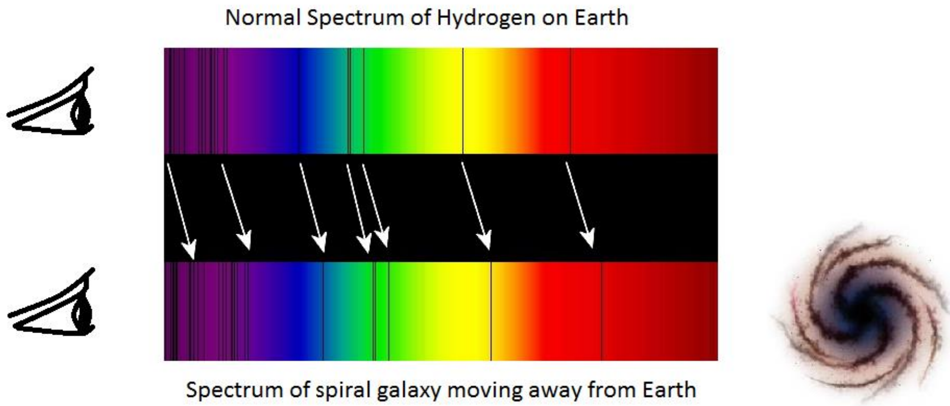
After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed.

Redshift. If you look at a star through a prism, you will see a spectrum, or a range of colors through the rainbow. The spectrum will have specific dark bands where elements in the star absorb light of certain wavelengths. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun—not on Earth—by analyzing the absorption lines in the spectrum of the Sun.



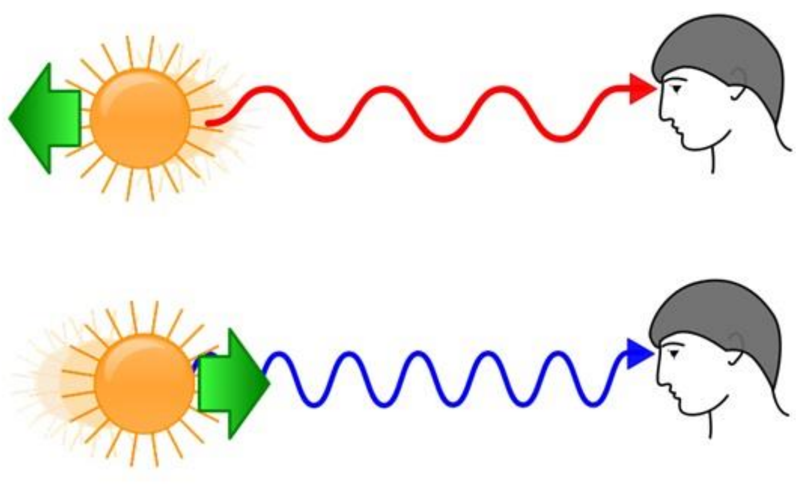
While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in the Figure below. This shift of absorption bands toward the red end of the spectrum is known as redshift (-the shift of spectral lines toward longer wavelengths (the red end of the spectrum) in radiation from distant galaxies and celestial objects).

This figure shows the absorption lines in the visible spectrum of a distant galaxy (right), as compared to absorption lines in the visible spectrum of the Sun (left). Arrows indicate redshift. Wavelength increases up towards the red, showing the galaxy moving away from the Earth.



Redshift occurs when the light source is moving away from the observer or when the space between the observer and the source is stretched. What does it mean that stars and galaxies are redshifted? When astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth. On the other hand, a blueshifted galaxy is a galaxy moving towards the earth.

If galaxies were moving randomly, would some be redshifted and others be blueshifted? Of course, since almost every galaxy in the universe has a redshift, almost every galaxy is moving away from Earth.



If a source of light is moving away from an observer then the electromagnetic spectrum will be redshifted, If the source is moving toward the observer it is blueshifted.

Redshift can occur with other types of waves too. This phenomenon is called the **Doppler Effect** (an increase or decrease in the frequency of sound, light, or other waves as the source and observer move toward (or away from) each other. The effect causes the sudden change in pitch noticeable in a passing siren, as well as the redshift seen by astronomers). An analogy to redshift is the noise a siren makes as it passes you. You may have noticed that an ambulance seems to lower the pitch of its siren after it passes you. The sound waves shift towards a lower pitch when the ambulance speeds away from you. Though redshift involves light instead of sound, a similar principle operates in both situations.

An animation of **Doppler Effect**:
http://bit.ly/LxSbyM

Youtube video:

http://bit.ly/LiLRKL

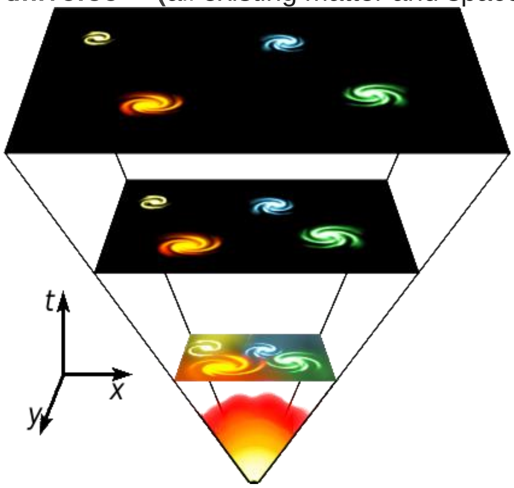
Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: the farther away a galaxy is, the faster it is moving away from us. What could this mean about the universe? It means that the universe is expanding.

The Figure below shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. Also the dots farther away from you on the balloon would move away faster than dots nearby.

Section 3: Expansion of the Universe Diagram

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies like the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the

universe - (all existing matter and space considered as a whole; the cosmos).



In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

An animation of an expanding universe is shown here:

http://www.astro.ubc.ca/~scharein/a311/Sim/bang/BigBang.html

One other difference between the universe and a balloon involves the actual size of the galaxies. On the balloon, the dots will become larger in size as you inflate it. In the universe, the galaxies stay the same size due to gravitational forces within the galaxy, just as the space between the galaxies expands.

Section 4: Formation of the Universe

Before Hubble, most astronomers thought that the universe didn't change. But if the universe is expanding, what does that say about where it was in the past? If the universe is expanding, the next logical thought is that in the past it had to have been smaller.

How Did the Universe Form?

The **Big Bang theory** - (the theory that the universe originated sometime between 10 billion and 20 billion years ago from the cataclysmic explosion of a small volume of matter at extremely high density and temperature) is the most widely accepted cosmological explanation of how the universe formed. If we start at the present and go back into the past, the universe is contracting -- getting smaller and smaller. What is the end result of a contracting universe?

According to the Big Bang theory, the universe began about 13 to 14 billion years ago. Everything that is now in the universe was squeezed into a very small volume. Imagine the entire known universe compressed into a single, hot, chaotic mass. An explosive expansion caused the universe to start growing rapidly. All the matter and energy in the universe, and even space itself, resulted from this expansion.

What came before the Big Bang? There is no way for scientists to know since there is no remaining evidence.

After the Big Bang

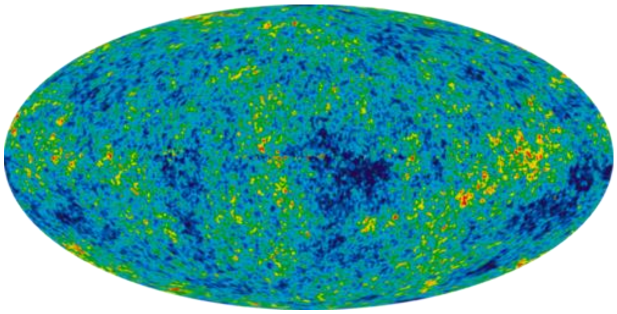
In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a millionth of a second, protons (hydrogen nuclei) and neutrons could form. After a few minutes some of these subatomic particles came together to create helium nuclei. However it was not cool enough for electrons (which formed soon after protons and neutrons) to join with protons (hydrogen nuclei) or helium to make the first neutral atoms until about 380,000 years later. Matter in the early universe was smoothly distributed across space. However some of the hydrogen and helium were drawn together by gravity into clumps. These clumps were the seeds that eventually became countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

These stars provide us with another piece of evidence that the universe is aging. The hydrogen in stars is being changed by fusion into helium and bigger elements. As time goes on the hydrogen continues to be used up and turned into helium. When the first elements formed after the Big Bang about 92% were hydrogen, with the rest being 8% helium and traces of lithium. Today we have about 74% hydrogen and 24% helium as well as the 90 other naturally occurring elements. By measuring how much hydrogen the universe started with, and the rate that stars use it, we can determine when stars began fusing. We can also use this rate to estimate how much longer fusion will continue. Right now you live in the middle of the universe’s life. Hundreds of billions of stars in hundreds of billions of galaxies are using up hydrogen and turning it into heavier elements as the universe continues to age.

Approximate light signal travel times	
Distance	Time
one foot	1.0 ns
one metre	3.3 ns
from geostationary orbit to Earth	119 ms
the length of Earth's equator	134 ms
from Moon to Earth	1.3 s
from Sun to Earth (1 AU)	8.3 min
from nearest star to Sun (1.3 pc)	4.2 years
from the nearest galaxy (the Canis Major Dwarf Galaxy) to Earth	25,000 years
across the Milky Way	100,000 years
from the Andromeda Galaxy to Earth	2.5 million years

From this table we see that the light we are seeing in our current night sky from the Andromeda Galaxy is actually 2.5 million years old!

After the publication of the Big Bang hypothesis, many astronomers still thought the universe was static (or not changing). However, the Big Bang Theory made a prediction that was different from what was expected in a static universe. It predicted that there should be some heat energy left over from the Big Bang. With the continued expansion of the universe, the temperature should be very low today, only a few K (Kelvin) above absolute zero (Kelvin is an absolute temperature scale). In 1964, two researchers at Bell Laboratories built a microwave receiver for telecommunications research. Using it, they discovered microwave radiation in all parts of the sky. The radiation had a temperature of 3 K (Figure below). This is evidence in favor of the Big Bang and is called the cosmic background radiation.



This image shows the cosmic background radiation in the universe as observed from Earth and Space Probes.

How we know about the early universe:

http://www.youtube.com/watch?v=uihNu9Icaeo&feature=channel

History of the Universe, part 2:

http://www.youtube.com/watch?v=bK6_p5a-Hbo&feature=channel

Lesson Summary

- The universe contains all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe also includes all of space and time.
- Redshift is a shift of element lines toward the red end of the spectrum. Redshift occurs when the source of light is moving away from the observer.
- Light from almost every galaxy is redshifted. The farther away a galaxy is, the more its light is redshifted, and the faster it is moving away from us.
- The redshift of most galaxies is evidence that the universe is expanding.
- According to the Big Bang theory, the universe was squeezed into a very small volume and then began expanding explosively about 13 to 14 billion years ago.
- Cosmic background radiation is left over energy from the Big Bang.

Think Like A Cosmologist

1. What is redshift, and what does it tell us about the universe?

2. Identify and explain three or more pieces of evidence for the big bang theory.

3. How old is the universe, according to scientists?

4. What did Galileo's telescope reveal?

What Fuels A Star?

Standard 1, Objective 2:
Analyze Earth as part of the solar system, which is part of the Milky Way galaxy.

Lesson Objectives

- Relate the composition of objects in the solar system to their distance from the Sun.
- Compare the size of the solar system to the Milky Way galaxy.
- Compare the size and scale of objects within the solar system.
- Evaluate the conditions that currently support life on Earth (biosphere) and compare them to the conditions that exist on other planets and moons in the solar system (e.g., atmosphere, hydrosphere, geosphere, amounts of incoming solar energy, habitable zone).

Section 1: Our Solar System

Astronomers now recognize eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects (See the figure on the following page). These objects move in regular and predictable paths around the Sun.

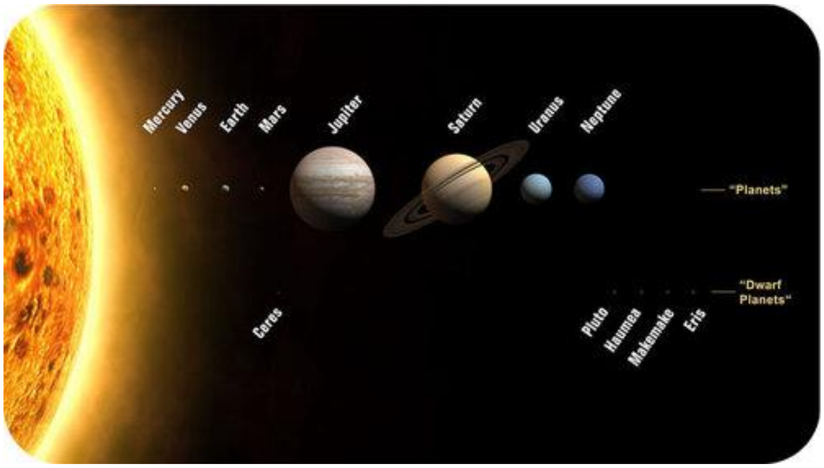
Distances in the Solar System

Distances in the solar system are often measured in astronomical units (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km (93 million miles). Listed below is the distance from the Sun to each planet in AU (Table below). The table shows how long it takes each planet to spin once on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually

Terms to know

- black hole
- main sequence star
- neutron star
- red giant
- supernova
- star

longer than a year on Venus! Our solar system is about 100,000 AU across from the Sun to the Oort Cloud or 1.87 light-years.



https://dr282zn36sxxg.cloudfront.net/datastreams/f-d%3A6811abbc13c9989627b4047c94d22e9ffaa706e232c4b98c5acab38a%2BIMAGE_THUMB_POSTCARD%2BIMAGE_THUMB_POSTCARD.1

Planet	Average Distance from Sun (AU)	Length of Day (in Earth days)	Length of Year (in Earth years)
Mercury	0.39	56.84	0.24
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

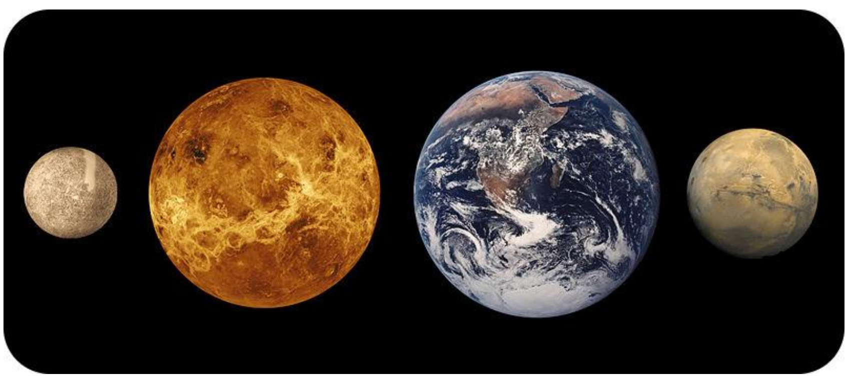
Planet Sizes

The Sun is just an average star compared to other stars. But it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! Listed below is data on the sizes of the Sun and planets relative to Earth (table below).

Object	Mass (relative to Earth)	Diameter (relative to Earth)
Sun	333,000	109.2
Mercury	0.06	0.39
Venus	0.82	0.95
Earth	1.00	1.00
Mars	0.11	0.53
Jupiter	317.8	11.21
Saturn	95.2	9.41
Uranus	14.6	3.98
Neptune	17.2	3.81

The Inner Planets

The inner planets are the four planets closest to the Sun: Mercury, Venus, Earth, and Mars. The figure below shows the relative sizes of these four inner planets.



Unlike the outer planets, which have many satellites, Mercury and Venus do not have moons, Earth has one, and Mars has two. Of course, the inner planets have shorter orbits around the Sun, and they all spin more slowly. Geologically, the inner planets are all made of cooled igneous rock with iron cores, and all have been geologically active, at least early in their history. None of the inner planets has rings. The inner planets are generally smaller than their outer planet relatives.

The Outer Planets

The four planets farthest from the Sun are the outer planets. The figure on page 31 shows the relative sizes of the outer planets and the Sun. These planets are much larger than the inner planets and are made primarily of gases and liquids, so they are also called gas giants.

Milky Way Galaxy

The Milky Way Galaxy is our galaxy. Home, sweet home. The Milky Way is made of millions of stars along with a lot of gas and dust. It looks different from other galaxies because we are looking at the main disk from within the galaxy. Astronomers estimate that the Milky Way contains 200 billion to 400 billion stars and is 100 – 120 million light-years across.

Section 2: Stars, an introduction

When you look at the sky on a clear night, you can see hundreds of stars (or thousands, if you're away from city lights). A **star (**A self-luminous celestial body consisting of a mass of gas held together by its own gravity) is a giant ball of glowing plasma that is very, very hot. Many **stars** are like our Sun, but most are smaller than our Sun, and some are larger. Except for our own Sun, all stars are so far away that they only look like single points, even through a telescope.

Energy of Stars

Only a tiny bit of the Sun’s energy reaches Earth, but that light supplies most of the energy at Earth’s surface. The Sun is just an ordinary star, but it appears much bigger and brighter than any of the other stars. Of course, this is just because it is very close. Some other stars produce much more energy than the Sun. How do stars generate so much energy?

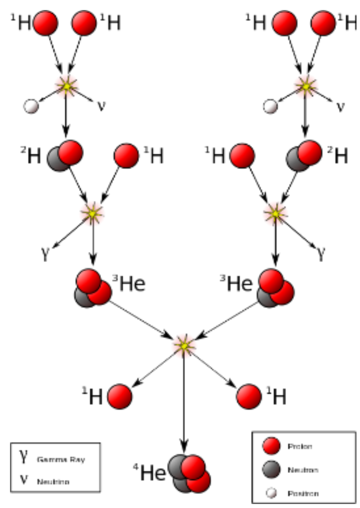
Nuclear Fusion

Stars shine because of nuclear fusion. Fusion reactions in the Sun's core keep our nearest star burning. Stars are made mostly of hydrogen and helium. Both are very lightweight gases. A star contains so much hydrogen and helium that the weight of these gases is enormous. The pressure at the center of a star heats the plasma to extreme temperatures of millions of degree. This combination of high temperature and pressure causes nuclear fusion reactions.

We call it nuclear fusion because under these conditions, the collision of atomic nuclei causes them to fuse (join) together. In stars like our Sun, four hydrogen atoms join together to create a helium atom. Nuclear fusion reactions need a lot of energy to get started. Once they begin, they produce even more energy.

Energy from Nuclear Fusion

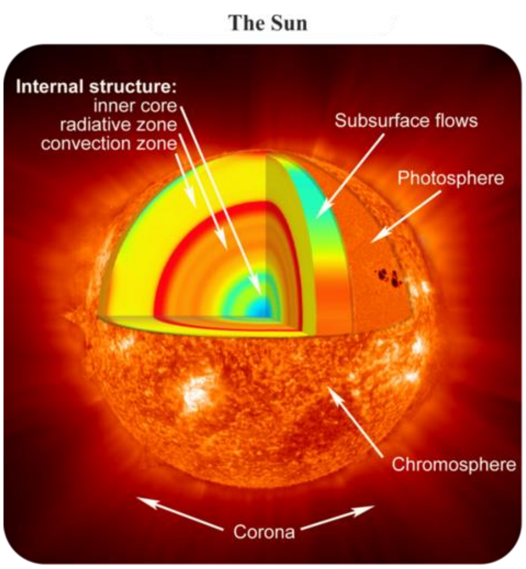
In fusion, two or more small nuclei combine to form a single, larger nucleus. An example is shown in the Figure at the right. In this example, four hydrogen nuclei fuse to form a helium nucleus. A great deal of energy is also released. When nuclei lighter than iron undergo fusion, energy is released. Energy is absorbed when iron or nuclei more massive than iron undergo fusion.



In this nuclear fusion reaction, nuclei of four hydrogen nuclei fuse together, forming a helium nucleus and energy.

The Power of Stars

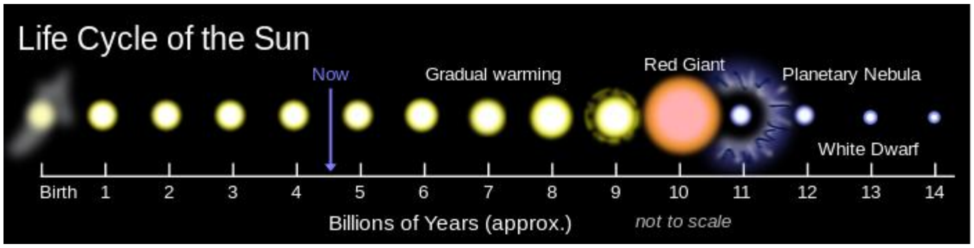
Nuclear fusion of hydrogen to form helium occurs naturally in the sun and other stars. It takes place only at extremely high temperatures. That's because a great deal of energy is needed to overcome the force of repulsion between positively charged nuclei. The sun's energy comes from fusion in its core, where temperatures reach millions of Kelvin (Figure left).



The extremely hot core of the sun radiates energy from nuclear fusion.

What happens when a star dies? We could say that stars are born, change over time, and eventually die. Most stars change in size, color, and class at least once during their lifetime.

Stars have a wide range of size, temperature and brightness. The properties of a star are determined by the star's mass. While most stars appear white, some stars have a slight blue or red color. The color relates to a star's temperature. Reddish stars are cooler than white stars and bluish stars are hotter.



Section 3: Formation of Stars

Stars are born in clouds of gas and dust called nebulas. Our Sun and solar system formed out of a nebula. A nebula is shown in the Figure left.

Stars form in a nebula like this one in Orion's sword.

For a star to form, gravity pulls gas and dust together. As mores gas continues to accumulate, the material becomes denser, the pressure and the temperature increase. When the temperature at the center becomes hot enough, nuclear fusion begins. The ball of gas has become a star!

Main Sequence Stars

A star is a **main sequence star** (hydrogen nuclei fuse to form helium nuclei) for most of its life. The mass of a main sequence star determines its properties such as how hot it is, how bright is, how big it is, and how long it will exist. Stars with more mass are hotter, brighter, and have shorter lives than lower mass stars.

Our Sun has been a main sequence star for about 5 billion years. As a medium-sized star, it will continue to shine for about 5 billion more years. Large stars burn through their supply of hydrogen very quickly. These stars "live fast and die young!" A very large star may only be on the main sequence for 10 million years. A very small star may be on the main sequence for tens to hundreds of billions of years.

Red Giants and Element Production

A star like our Sun will become a **red** giant (a very large star of high luminosity and low surface temperature) in its next stage. When a star uses up its hydrogen, the star's core starts to collapse inward and the core temperature increases. When the temperature is high enough, helium fuses into heavier nuclei like carbon and oxygen. As the core collapses, the star's outer layers spread out and cool. The result is a larger star that is cooler on the surface, and red in color.

Eventually a **red giant** fuses all of the helium in its core. At this point the star has a core filled with carbon and oxygen. Surrounding the core are two separate layers where fusion still occurs - an inner layer of helium and an outer layer of hydrogen. Nuclei within the helium-burning shell can be changed into heavier nuclei by capturing neutrons. Extra neutrons can make a nucleus unstable and one of the neutrons will suddenly change into a proton. In larger stars, this process can produce some elements as heavy as bismuth with 83 protons.

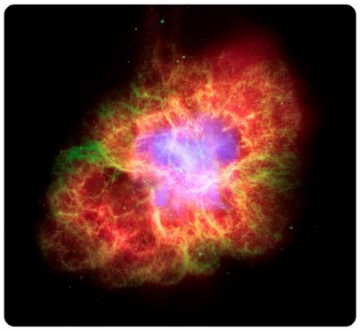
White Dwarfs

What happens next depends on the star's mass. A star like the Sun stops fusion and the core becomes a white dwarf star. A white dwarf is a hot, white, glowing object about the size of Earth. The outer layers of the star are blown into space carrying with them many of the heavier elements produced in the star. After a very long time, a white dwarf will cool down and its light will fade. This is the potential end of our star, the Sun, based on its mass.

Supergiants and Supernovas

A more massive star ends its life in a more dramatic way. Very massive stars become red supergiants, like Betelgeuse.

In a red supergiant, fusion does not stop with carbon and oxygen. These elements fuse into heavier ones until iron nuclei form. Fusion of iron does not produce energy to sustain the star. With no more energy from fusion, the core will rapidly collapse. Collapse of the core creates a shock wave that moves outward and the star explodes violently. This is called a supernova (a star that suddenly increases greatly in brightness because of a catastrophic explosion that ejects most of its mass) explosion. The incredible energy released fuses heavy nuclei together. Astronomers think gold, uranium and other heavy elements may form in a supernova explosion. A supernova can shine as brightly as an entire galaxy, but only for a short time. The heavy elements are blown into space as shown in Figure below.



A supernova remnant, as seen by the Hubble Space Telescope.

Neutron Stars and Black Holes

After a supernova explosion, the star's core is left over. This material is extremely dense. If the core is less than about four times the mass of the Sun, the star will become a neutron star (celestial object of very small radius (typically 18 miles/30 km) and very high density, composed predominantly of closely packed neutrons.). This type of star is made almost entirely of neutrons. A neutron star has more mass than the Sun, yet it is only a few kilometers in diameter. Research indicates that a collision between two neutron stars could also be the source of many heavy elements such as gold.

A teaspoon of matter from a neutron star would weigh 10 million tons on Earth. If the core remaining after a supernova is more than about 5 times the mass of the Sun, the core collapses to become a black hole (a region of space having a gravitational field so intense that no matter or radiation can escape.). Black holes are so massive that not even light can escape their gravity. For that reason, we can't see black holes. How can we know something exists if radiation can't escape it? We know a black hole is there by the gravitational effect that it has on objects around it. Also, if a black hole is pulling in matter, collisions between particles can heat the matter to high enough temperatures for the matter to give off high energy radiation like x-rays. A black hole isn't a hole at all. It is the tremendously dense core of what was once a supermassive star.

Lesson Summary

- A star generates energy by nuclear fusion reactions in its core.
- The properties of a star are determined by its mass.
- Stars form from clouds of gas and dust called nebulae. Nebulae collapse until nuclear fusion starts.
- Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
- Sun-like stars expand into red giants, and then fade out as white dwarf stars.
- Very massive stars expand into red supergiants, explode as supernovas, and then end up as neutron stars or black holes.

Think Like A Cosmologist

1. What is nuclear fusion?

2. What is a black hole? Why is it called that?

3. Describe one process in which each of the following elements formed: Hydrogen, Helium, Iron, and Uranium?

4. Describe the Sun's life from its beginning to its eventual end.

5. How do astronomers know how stars form? What evidence do they have?

What is at the Center of the Universe?

Lesson Objectives

- Describe some early ideas about our solar system.
- Name the planets, and describe their motion around the Sun.
- Explain how the solar system formed.

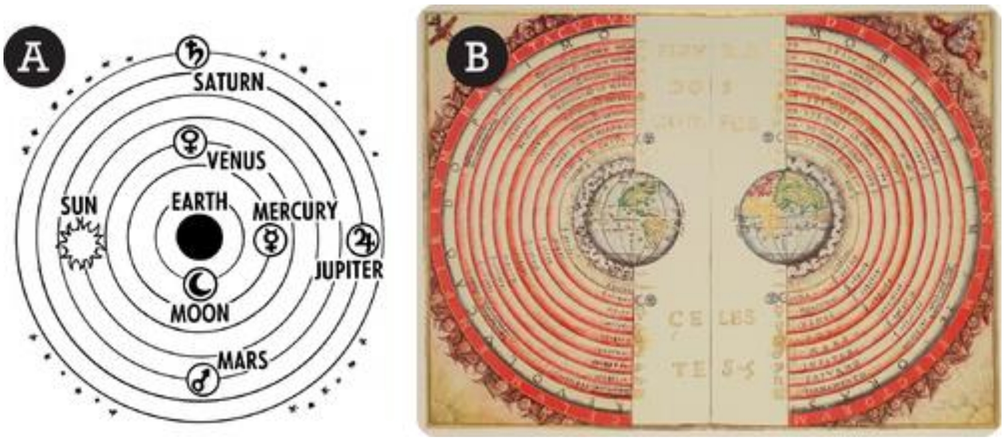
The Sun and all the objects that are held by the Sun's gravity are known as the solar system (the collection of eight planets and their moons in orbit around the sun, together with smaller bodies in the form of asteroids, meteoroids, and comets). These objects all revolve around the Sun. The ancient Greeks recognized five planets (a celestial body moving in an elliptical orbit around a star). These lights in the night sky changed their position against the background of stars. They appeared to wander. In fact, the word "planet" comes from a Greek word meaning "wanderer." These objects were thought to be important, so they named them after gods from their mythology. The names for the planets Mercury, Venus, Mars, Jupiter, and Saturn came from the names of gods and a goddess.

Section 1: Earth at the Center of the Universe

Most ancient Greeks thought that Earth was at the center of the universe, as shown in the Figure below. One model they proposed had a set of spheres layered on top of one another. Each object in the sky was attached to one of these spheres. The object moved around Earth as that sphere rotated. These spheres contained the Moon, the Sun, and the five planets they recognized: Mercury, Venus, Mars, Jupiter, and Saturn. An outer sphere contained all the stars. Greek astronomers developed mathematical models of the **solar system** that they used to predict future positions of the Sun, Moon and planets. These models and procedures were finalized by Claudius Ptolemy. He published his model of the solar system around 150 AD. It was used by astronomers for fifteen hundred years.

Terms to know

- astronomical unit
- dwarf planet
- nebula
- nuclear fusion
- planet
- solar system



On left is a line art drawing of the Ptolemaic system with Earth at the center. On the right is a drawing of the Ptolemaic system from 1568 by a Portuguese astronomer.

Section 2: The Sun at the Center of the Universe

About 1,500 years after Ptolemy, Copernicus proposed a startling idea. He suggested that Earth was not stationary but that Earth and the planets revolved around the Sun. Copernicus did not explain how he got this idea so how he thought of this model remains a mystery.

Copernicus proposed a different idea that had the Sun near the center of the universe. Copernicus did not publish his new model until he was close to death. He may have thought that it could be considered heresy to say that Earth was in motion. Most people did not accept Copernicus' model. One of the few that did was Galileo. He tried to find evidence to support the Copernican model. He discovered the law of inertia which he used to explain why we cannot easily sense that Earth is in motion. Through his telescope, Galileo saw moons orbiting Jupiter. He proposed that this was like the planets orbiting the Sun.

Today we know that we have eight planets, five dwarf planets (a celestial body resembling a small planet but lacking certain technical criteria that are required for it to be classed as such.), over 165 moons, and many, many asteroids and other small objects in our solar system. We also know that the Sun is not the center of the universe. But it is the center of the solar system.

Section 3: What is (and is not) a planet?

You've probably heard about Pluto. When it was discovered in 1930, Pluto was called the ninth planet. Astronomers later found out that Pluto was not like other planets. For one thing, it was discovered in the 1970s that Pluto was much smaller than previously thought. It was smaller than any of the other planets and even smaller than the Moon. Beginning in 1992, astronomers also discovered many objects in orbits similar to the orbit of Pluto. They were also icy and there were a whole lot of them.

Astronomers were faced with a problem. They needed to call the largest of these other objects planets. Or they needed to decide that Pluto was not a planet. In 2006, these scientists defined what a planet is. According to the new definition, a *planet* must:

- Orbit the sun.
- Be massive enough that its own gravity causes it to be round.
- Be small enough that it isn’t a star itself.
- Have cleared the area of its orbit of smaller objects.

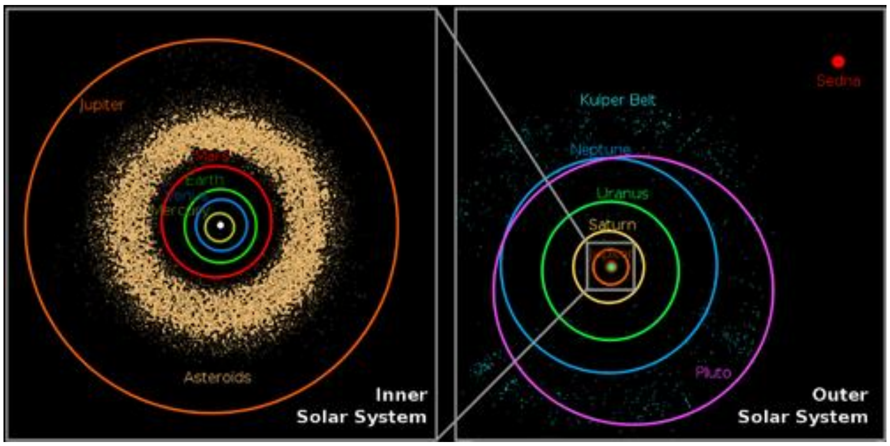
If the first three are true but not the fourth, then that object is classified as a *dwarf planet*. We now call Pluto a **dwarf planet**. There are other dwarf planets in the solar system. They are Eris, Ceres, Makemake and Haumea. There are other ways that Pluto is different from the planets in our solar system.

The Size and Shape of Orbits

The figure at the right shows the Sun and planets with the correct sizes. The distances between them are way too small. In general, the farther away from the Sun, the greater the distance from one planet’s orbit to the next.

The figure on the following page shows those distances correctly. In the upper left are the orbits of the inner planets and the asteroid belt. The asteroid belt is a collection of many small objects between the orbits of Mars and Jupiter. In the upper right are the orbits of the outer planets and the Kuiper belt. The Kuiper belt is a group of objects beyond the orbit of Neptune.

In the figure on the following page, you can see that the orbits of the planets are nearly circular. Pluto's orbit is more elliptical. Also, its orbit is tilted about 17 degrees with respect to the orbits of the planets. They all orbit the Sun in nearly the same plane.



In this image distances are shown to scale.

Section 4: Distances in Our Solar System

Distances in the solar system are often measured in **astronomical units** (AU). (One astronomical unit is defined as the distance from Earth to the Sun.) 1 AU equals about 150 million km (93 million miles). The table below shows the distance from the Sun to each planet in **AU's**. The table shows how long it takes each planet to spin on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually longer than a year on Venus!

Distances to the Planets and Properties of Orbits Relative to Earth's Orbit			
Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Mercury	0.39 AU	56.84 days	0.24 years
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00

Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

The Table below shows our solar system and gives some additional data on the mass and diameter of the Sun and planets relative to Earth.

Sizes of Solar System Objects Relative to Earth		
Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth's mass	1.00 Earth's diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter
Neptune	17.2 Earth's mass	3.81 Earth's diameter

Section 5: The Role of Gravity

Planets are held in their orbits by the force of gravity. What would happen without gravity? Imagine that you are swinging a ball on a string in a circular motion. Now let go of the string. The ball will fly away from you in a straight line. It was the string pulling on the ball that kept the ball moving in a circle. The motion of a planet is very similar to the ball on a strong. The force pulling the planet is the pull of gravity between the planet and the Sun.

Every object is attracted to every other object by gravity. The force of gravity between two objects depends on the mass of the objects. It also depends on how far apart the objects are. When you are sitting next to your dog, there is a gravitational force between the two of you. That force is far too weak for you to notice. You can feel the force of gravity between you and Earth because Earth has a lot of mass. The force of gravity between the Sun and planets is also very large. This is because the Sun and the planets are very large objects. Gravity is great enough to hold the planets in orbit around the Sun even though the distances between them are enormous. Gravity also holds moons in orbit around planets.

Extrasolar Planets

Since the early 1990s, astronomers have discovered other systems like our solar system. These “stellar” systems have one or more planets orbiting one or more stars. We call these planets “extrasolar planets,” or “exoplanets”. So named because they orbit a star other than the Sun. As of January 2013, 3649 exoplanets have been found.

See how many there are now:

`http://planetquest.jpl.nasa.gov/`

We have been able to take pictures of only a few exoplanets. Most are discovered because of some tell-tale signs. One sign is a very slight motion of a star that must be caused by the pull of a planet. Another sign is the partial dimming of a star’s light as the planet passes in front of it.

How Did the Solar System Form?

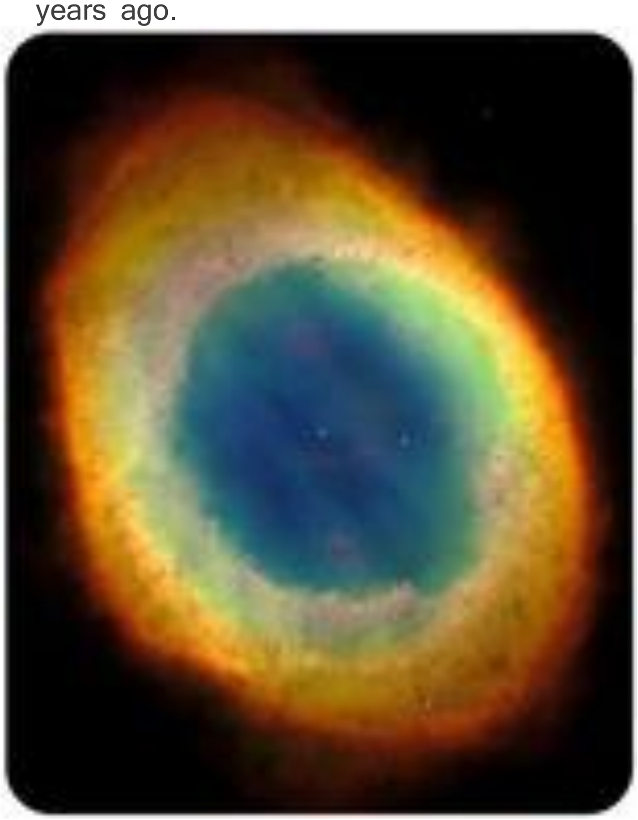
To figure out how the solar system formed, we need to put together what we have learned. There are two other important features to consider. First, all the planets orbit in nearly the same flat, disk-like region. Second, all the planets orbit in the same direction around the Sun. These two features are clues to how the solar system formed.

A Giant Nebula

Scientists think the solar system formed from a **nebula (**a big cloud of gas and dust). This is the solar **nebula** hypothesis. The **nebula** was made mostly of hydrogen and helium leftover from the big bang. There were also heavier elements that had formed inside stars and then were expelled into space (see figure). Gravity caused the nebula to contract. These nebulas may be formed from material leftover from the big bang or recycled from previous supernovas.

As the nebula contracted, it had some initial rotation. As it got smaller and smaller, it spun faster and faster. This is what happens when an ice skater pulls her arms to her sides during a spin move. She spins faster. The spinning motion and gravity caused the nebula to form into a disk shape.

This model explains why all the planets are found in the flat, disk-shaped region. It also explains why all the planets revolve in the same direction. The solar system formed from the nebula about 4.6 billion years ago.



The nebula is formed as a star blows its outer layers into space.

Formation of the Sun and Planets

The Sun was the first object to form in the solar system. Gravity pulled matter together to the center of the disk. Density and pressure increased tremendously. Nuclear fusion (a nuclear reaction in which atomic nuclei of low atomic number fuse to form a heavier nucleus with the release of energy.) reactions begin. In these reactions, the nuclei of atoms come together to form new, heavier chemical elements. Fusion reactions release huge amounts of nuclear energy. From these reactions a star was born, the Sun.

Meanwhile, the outer parts of the disk were cooling off. Small pieces of dust started clumping together. These clumps collided and combined with other clumps. Larger clumps attracted smaller clumps with their gravity. Eventually, all these pieces grew into the planets and moons that we find in our solar system today.

The outer planets – Jupiter, Saturn, Uranus, and Neptune – condensed from lighter materials. Hydrogen, helium, water, ammonia, and methane were among them. It's so cold by Jupiter and beyond that these materials can form solid particles. Astronomers call these solid particles “ices.” Closer to the Sun, they are gases. Since the gases can escape, the inner planets – Mercury, Venus, Earth, and Mars – formed from denser elements. These elements are solid even when close to the Sun.

The Age of the Solar System

Based on the age of the oldest meteorites, a group of research scientists at the Institute of Physical Earth Sciences in Paris has carried out very precise measurements of the decay of Uranium 238 to Lead 206. Using radiometric dating we can calculate the age of the Solar System at about 4.56 billion years.

The Age of the World Made Easy

http://www.youtube.com/watch?v=w5369-OobM4

The Size of the Solar System

The universe contains an estimated 100 to 400 billion galaxies, of which our Milky Way is one. The Milky Way itself contains an estimated 100 to 400 billion stars, of which our Sun is one. The Milky Way is a barred-spiral galaxy with a radius of around 50,000 light-years (a light-year being the distance that light travels in one year), and the Sun and its solar system are around 30,000 light-years from the center of the galaxy.