Book: Introduction to Astronomy (Lumen)

The LibreTexts libraries are Powered by NICE CXOne and are supported by the Department of Education Open Textbook Pilot Project, the UC Davis Office of the Provost, the UC Davis Library, the California State University Affordable Learning Solutions Program, and Merlot. This material is based upon work supported by the National Science Foundation under Grant No. 1246120, 1525057, and 1413739.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation nor the US Department of Education.

This text was compiled on 04/15/2025

TABLE OF CONTENTS

Licensing

A detailed breakdown of this resource's licensing can be found in ***Back Matter/Detailed Licensing****.*

CHAPTER OVERVIEW

1: Introduction to Astronomy

1.1: Module Introduction

“I just looked up at a fine twinkling star and thought that a voyager whom I know now many days sail from this coast, might possibly be looking up at that same star with me. ”

–Henry David Thoreau
Personal Log Entry c. 840’s

Astronomy is one of the most-fascinating subjects; the Universe in which we live is simply a beautiful and incredible place!

As one of the oldest sciences, astronomy is also one of the fastest-progressing sciences today. In centuries past, people used the stars to tell stories through patterns in the sky. They used the positions of the Sun and Moon to tell time and the seasons, and the positions of the stars to navigate.

With the advent space exploration starting in October 1957, satellites have added to our knowledge of the Universe, from the surface of Mars to the beginning of the Universe itself. It hardly seems a week passes without a new discovery, either from earth-based observations or the myriad of satellites.

Images of the Universe, from galaxies containing billions of stars to the rings of Saturn, inspire both the casual and professional stargazer alike. Astronomy is a passion for many and today is a mainstream hobby, as in years past.

Introduction to Astronomy will provide you with an opportunity to explore both the significant historical aspects of astronomy, as well as contemporary exploration of the Universe. Common topics, such as the phases of the Moon, tides, seasons and the space program, will also be explored.

This module starts with the question, “What is Astronomy? ” Simply stated, Astronomy is the study of the Universe. Astronomers classify objects into various groups based on characteristics and locations in our Universe. Some of these classifications, such as stars, are easy to understand scientifically. Other objects are more difficult to classify, and in some instances, to entirely understand. This module identifies basic objects in our Solar System and those beyond, the overall scale of the Universe, and patterns in the night sky.

So welcome to your Universe: a beautiful and incredible place, as you will soon learn.

Objectives

Upon completion of this module, the student will be able to:

- Describe the characteristics of the major classes of objects in the Universe
- Recognize the scale of the Cosmos, using Astronomical Units and Light travel
- Identify specific Constellations
- Describe the characteristics of specific Constellations
- Identify specific Asterisms
- Differentiate between Constellations and Asterisms

1.2: Basic Objects in the Universe

This module starts with the question, “What is Astronomy? ”Simply stated, Astronomy is the study of the Universe. Astronomers classify objects into various groups based on characteristics and locations in our Universe. Some of these classifications, such as stars, are easy to understand scientifically. Other objects are more difficult to classify, and in some instances, to entirely understand. This module identifies basic objects in our Solar System and those beyond, the overall scale of the Universe, and patterns in the night sky.

Stars

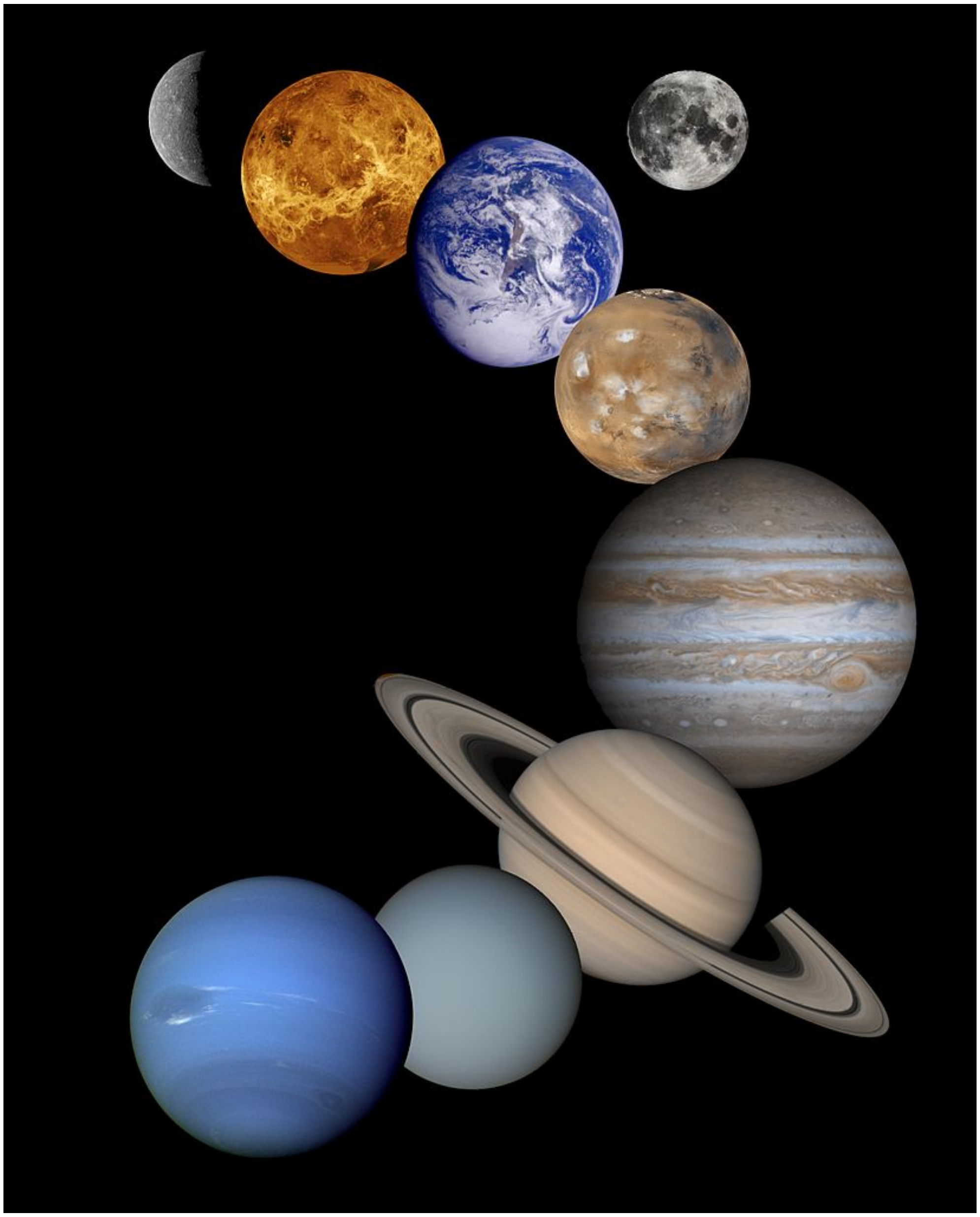
Stars are glowing balls of gas that undergo nuclear fusion; the Sun is a star.

Public Domain | Image courtesy of NASA / ESA.

Planets

Planets are moderately large objects orbiting a star. We see planets because they reflect the light of their central star, or in some cases, stars. Planets are generally rocky or gaseous in nature and spherical-shaped.

A new group of objects has been recently defined: the Dwarf Planets or Plutoids. These are objects that orbit the Sun, but have not cleared their orbits. Pluto is an example of a Dwarf Planet.



Public Domain | Image courtesy of NASA.

Satellite

A **satellite** orbits a planet; these objects are also called moons. For example, the Earth’s satellite is the Moon – a proper name.


Public Domain | Image courtesy Pixabay. com.

Asteroid

An **asteroid** is a relatively small, rocky/metallic object *usually* orbiting a star.

Public Domain | Image courtesy of NASA.

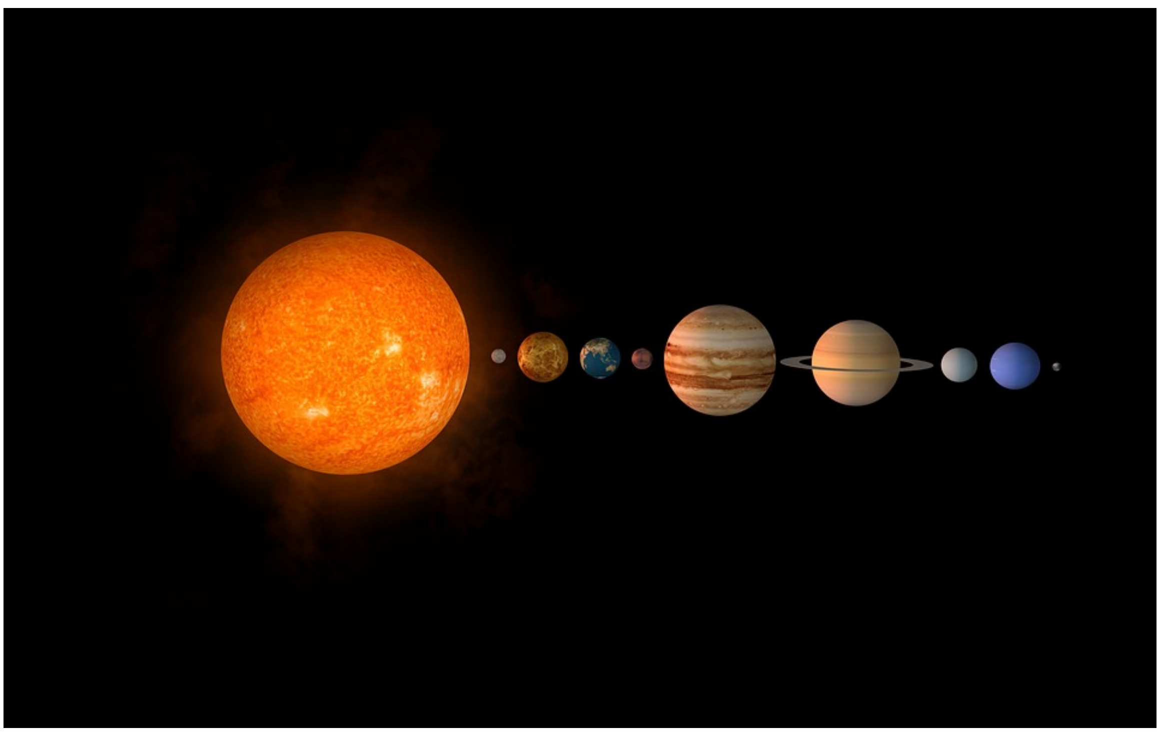
Comet

A **comet** is a relatively small, icy object usually orbiting a star. Asteroids, comets, and miscellaneous small/irregular objects and "dust" are often categorized as Minor Bodies.

Public Domain | Image courtesy of NASA.

Solar System

The **Solar System** is the Sun and all the objects that orbit the Sun, including the planets and their moons.



Public Domain | Image courtesy of Pixabay. com.

Stellar System

A **Stellar System** is a star and other objects such as planets and/or other stars and other materials that orbit it.

Galaxy

A **galaxy** is a large island of stars, a few hundred million to over a trillion stars.

CC BY 3. 0 | Image courtesy of ESA/Hubble. NASA, ESA Acknowledgements: Ming Sun (UAH), and Serge Meunier

Galactic Cluster

A **Galactic Cluster** is a collection of galaxies gravitationally bound.

Supercluster

A **Supercluster** is a region where galaxies and galactic clusters are tightly packed.

Universe

The **Universe** is all matter and energy, and is also called the Cosmos.

Public Domain | Image courtesy of Pixabay. com.

1.3: Scale of the Cosmos

Perhaps you have heard the phrase that a large number is **astronomical**. Astronomical comes from the fact that the size of the Universe is so big, it is often hard to comprehend. Even distances between the planets and the Sun in our own Solar System are numbers we are not custom to using. To understand the scale of the Cosmos, we will start with several examples in our Solar System. First, the distance between the Earth and Moon is about 230,000 miles. The closest distance between Earth and Mars is about 32,000,000 miles. The distance between the Earth and Sun is about 93,000,000 miles. The distance between Mercury – the closest planet to the Sun – and the Sun is about 36,000,000 miles. The distance between Neptune – the farthest planet from the Sun – and the Sun is about 2,797,770,000 miles. It is often useful to make a scale model of large systems. Some cities, museums, and parks will create a scale Solar System, based on something like 1 foot equals 1 million miles.

To simplify *distance* in our Solar System, astronomers use the Astronomical Unit (1 AU), which equals 93,000,000 miles or the average distance from Earth to the Sun.

As for other numbers, these are the diameters of three Solar System bodies. First, our Earth's diameter is just less than 8,000 miles. Jupiter's diameter – the largest planet in our Solar System – is around 88,000 miles. And the Sun's diameter is about 850,000 miles.

The idea here is *not* to memorize size and distance; rather, it is to appreciate the grand scale of the Universe within which we live.

Going beyond our Solar System, the closest star is Proxima Centauri, part of the Alpha Centauri triple star system. It is about 24,340,000,000,000 miles (that is 24 trillion, 340 billion miles) away or about 270,000 times more distant than Earth to the Sun. And that is the closest star beyond our Sun. Because of these great distances, astronomers will use another measure: the distance light travels in one year, or the light year. This sounds like a time measure, but it is not.

Light travels 186,000 miles in one second, or 2. 99 x 108 meters per second. That is 5,869,713,600,000 miles in a year. So the Sun is about 8 light minutes from Earth and Proxima Centauri about 4. 24 light years distant.

1.4: The Constellations

Early peoples told stories about the shapes and patterns they saw in the stars, like connect-the-dots. These shapes are called Constellations. Today astronomers recognize 88 “official” Constellations. These are taken from many of the historical constellations. Many of today’s 88 official constellations are Western European in design and history.

Whereas some Constellations are easy to recognize, most are not. Constellations are basically connecting the dots or stars that make up these constellations. To be able to see all 88 Constellations, we would need to be at the equator.

CC BY 3. 0 | Image courtesy of Anirban Nandi.

Many peoples throughout civilization identified patterns in the stars. For example, the constellation we now call Orion the Hunter was seen as different shapes by different people around the world, including:

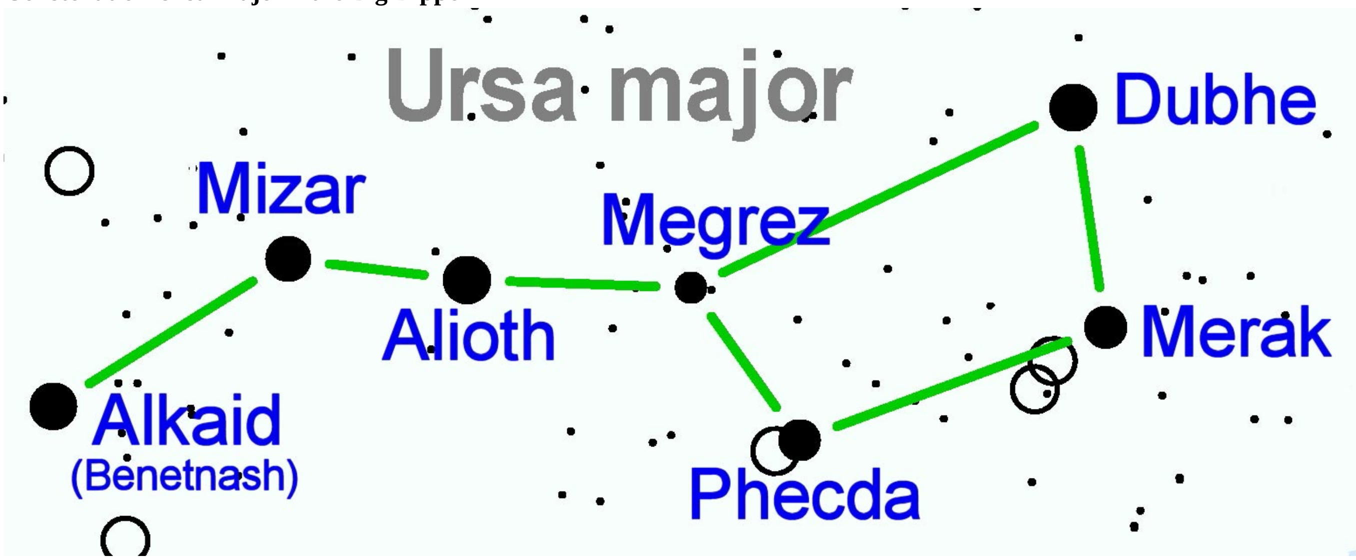
- China: Shen, the supreme warrior
- Egypt: Orion or Osiris in Ancient Egyptian traditions
- India/Hindus: Skanda, a celestial General riding a peacock

1.5: Other Patterns

An **Asterism** is a star pattern within a Constellation, but not an official Constellation. These are even more like connecting the dots or stars than the constellations. Some examples of Asterisms within the constellations of Ursa Major and Ursa Minor include the commonly named Big and Little Dippers. In other parts of the world, they have been called the Cart, Plow, and the Drinking Gourd.

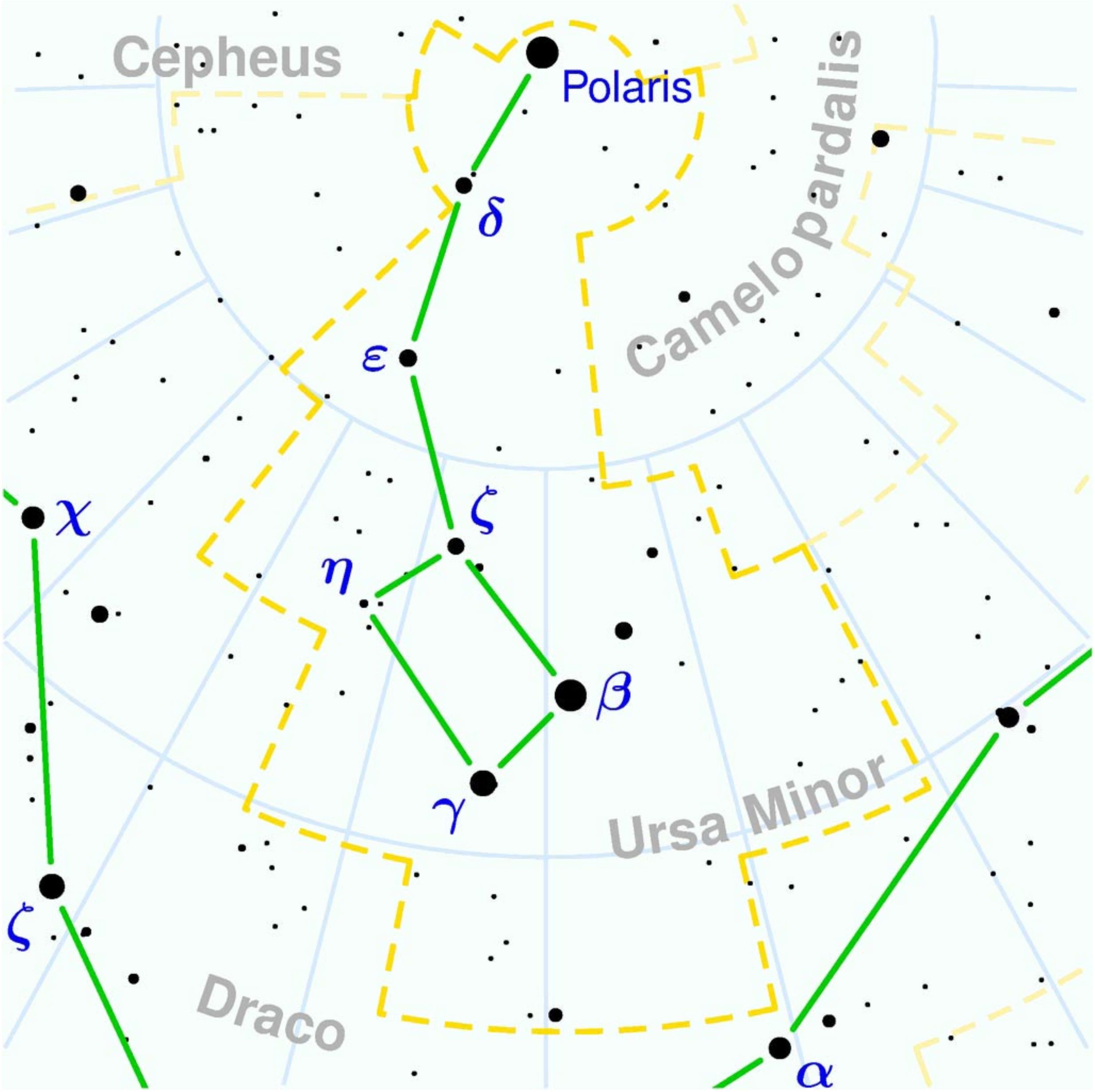
Another example of an Asterism is the Pleiades, within the Constellation Taurus. It is often called the Seven Sisters. In Japan the Pleiades is called Subaru. The Navajo referred to it as Dilyehe, and Hawaiians call the star grouping Makahiki or *many little eyes* .

Constellation Ursa Major—the Big Dipper



GFDL and CC BY-SA 3. 0 | Image courtesy of Luigi Chiesa.

Ursa Minor—the Small Dipper



Public Domain | Image courtesy of Torsten Bronger.

Consider this…

“Ralph Waldo Emerson once asked what we would do if the stars only came out once every thousand years. No one would sleep that night, of course. We would be ecstatic, delirious, made rapturous by the glory of God. Instead the stars come out every night and we watch television. ”

Pawl Hawken (1946 –) Environmentalist, Entrepreneur, and Author

---

CHAPTER OVERVIEW

2: Historical Astronomy

2.1: Module Introduction

Night comes leaking out of the sky.
Stars come peeking.
Moon comes sneaking silvery-sly.
Who is shaking, shivery – quaking?
Who is afraid of the night?
Not I.

Beatrice Schenk de Regniers
As Night Comes

This module, Historical Astronomy, looks at some of the earliest history of astronomy and sky gazing, the contributions of the Greeks, and the individuals whose contributions to modern astronomy stands upon.

Objectives

Upon completion of this module, the student will be able to:

- Identify the processes of science
- Identify historical contributions to astronomy by civilizations
- Describe how astronomy has effected such things as the days of the week and the month
- Differentiate between the geocentric and the heliocentric solar system models and their contributions
- Differentiate between astronomy and astrology
- Discuss the contributions by Copernicus, Brahe, Kepler, Galilei, and Newton to modern astronomy
- Define Newton's 3 Laws of Motion

2.2: The Study of Science

The study of science involves **observation**, **logic**, and **skepticism**, which lead to investigating phenomena using the **Scientific Method**. Simply stated, the scientific method is an organized approach to "figuring out something" or acquiring knew knowledge or understanding of the world around us.

Two steps of the scientific method involve constructing a **hypothesis** and proposing a **theory**. A hypothesis is a collection of testable ideas that appear to explain what is observed. A theory is a body of related and rigorously tested hypotheses pieced together into a larger, consistent description of nature. Scientists test and retest hypotheses and theories. If a hypothesis cannot be tested and verified, it does not qualify as a law or a theory. As technology emerges and advances in science occur, new revelations and discoveries are found. To maintain the integrity of science, it is critical for scientists to *always* be open-minded to discover the unknown.

The purpose of this module is to learn of the early pioneers who used the scientific method to study our Earth and stars, and of the scientists—Copernicus, Brahe, Kepler, and Galileo, whose scientific work revolutionized the birth of modern astronomy.

2.3: What Time Is It?

As one of the oldest sciences, if not the oldest, astronomy was important in people's day-to-day lives. The calendar was important due to agriculture and the influence of seasons and time. The oldest calendar dates back to 4800 BC and was found along the Egyptian-Sudanese border. Some of the African calendars even marked predictions of lunar phases.

Astronomy and **time** had a major link for early civilization. Before the clock, people depended on the positions of the Sun, Moon, and stars to tell the time, both daily and the time of year. During the day, people observed the Sun's path, looking at shadows – pre-sundials. During the night, the Moon's position and phase and star positions were observed. And throughout the year, people looked at the Sun's seasonal position.

The days of the week that we still use are named after astronomical objects.

OBJECT

- Sun
- Moon
- Mars
- Mercury
- Jupiter
- Venus
- Saturn

TEUTONIC NAME (Germanic Tribe)

- Sun
- Moon
- Tiw
- Woden
- Thor
- Fira
- Saturn

ENGLISH

- *Sunday*
- *Monday*
- *Tuesday*
- *Wednesday*
- *Thursday*
- *Friday*
- *Saturday*

Why is there a 24-hour Day? Why not break the day into 10 segments? **Or** 1,000,000? We can attribute it to the Sumerians, over 4000 years ago. First, they used their fingers with three divisions each to count and their thumb as a counter. The **Sumerians** divided the day into 12 units (2 hands) and night into 12 units. The **Ancient Babylonians** inherited the Sumerian 24 hour day and presumably added their 'base 60' counting system; one hour into 60 minutes, one minute into 60 seconds.

There were – and still are – calendars based on the **Moon**. These Lunar calendars have periods of 29 or 30 days. Think of our common word month: from **Moonth**.

Some examples of Moon-based Calendars include the Metonic and Jewish calendars. The Jewish Passover, thus New Testament Easter is also based on this calendar. Other calendars include the Saros, based on eclipse cycles of 18 years, and the Mayan calendar, 260 days based on eclipse seasons.

2.4: Ancient Observations

Many of the ancient civilizations observed positions of specific stars and planets, like the rising and setting times of these objects. Ancient observatories were built to do this fairly accurately. For example, the **Mayan** observatory at Chichén Itzá had windows placed for observations of Venus. The **Polynesians** were some of the best observers for their island-to-island sailing navigation. The **Chinese** made incredibly detailed observations of the skies. This was done for their Emperor, the “son of the heavens. ” They needed to accurately predict events to show the Emperor’s “divineness. ” The Chinese were the first to record observations of comets, meteor showers, meteorites, eclipse predictions, and supernovae. It was the Chinese as well who built instruments to conduct these studies.

Other contributions of these early civilizations included the **Mesopotamians**, who were the first to develop a comprehensive catalog of the night sky, circa 750 BC, and the **Babylonians**, who combined the practice of astrology and astronomy.

The **Egyptians** also had an infatuation with the heavens. They developed the first recorded sundials in the form of Obelisks, and around 3500 BC recognized the seasons, and had implemented a day clock. The Pyramids also had astronomical implications; the Great Pyramid at Giza completed in 2680 BC, aligned with stars of Osiris and in a specific compass direction.

2.5: Contributions to Science

There are also a number of **Jewish** and **Christian** traditions. The Bible's Old and New Testaments contain numerous astronomical references. The Jewish Bible, or Old Testament, refers to stars, constellations, and eclipses. The Christian New Testament has astronomical references, such as the Star of Bethlehem, denoting the birth of Jesus. The **Greeks** were credited with development of scientific principles, starting around 500 BC. Alexandria, Egypt was a great library and research center that opened around 300 BC, and survived until it was destroyed by fire. A couple of Greeks, to note, included Eratosthenes, who determined Earth's circumference by measuring the Sun's shadow at two points on Earth around 240 BC, and Hipparchus, who developed a stellar brightness magnitude scale that is still in use today. There were also a number of significant **Islamic** contributions from around the 8th and 9th Centuries AD. Muslims kept and translated historical records, developed Algebra, and developed many constellation and star names. Some examples of star names still used today are Aldebaran and Algol (Al: "the"). The researchers were not only Muslims, but also included Jews and Christians. Hindus also worked with the team of researchers and indirectly with the Chinese.

2.6: The Wanderers

The word planet is from the Greek **planete**, meaning **“wanderer”**. All of the known planets moved against the background stars; the historically-known planets included Mercury, Venus, Mars, Jupiter, and Saturn (and Earth, of course). Mercury and Venus stayed close to the Sun. Mars, Jupiter, and Saturn could be tracked as they moved across the sky. But occasionally the planets were observed to move backwards against the stars. This phenomenon is called **retrograde**. At the time, the thinking was that the Earth was the center of the Solar System and even the Universe. So the Sun, Moon, and known planets revolved around Earth – called the **Geocentric Solar System** ; Geo means Earth. *How could this retrograde motion occur if Earth was the center of the Solar System and even the Universe? Thus, the planets presented problems.*

2.7: Claudius Ptolemy

Another ancient Greek astronomer and philosopher, Claudius Ptolemy (100-170 AD), developed a Geocentric Solar System which placed the "stellar" universe on a crystal sphere. Earth stood still (didn't rotate) and the Sun orbited Earth, producing our day and night cycles. To account for the retrograde of the planets, Ptolemy used looping small circles called epicycles on the orbits. It was an ingenious system accepted, as Law… except a Geocentric Universe was wrong!Even though Ptolemy was Greek, he was born in Egypt. All of his observations and work was done from Alexandria, Egypt. He was also a geographer and mathematician, and Ptolemy's*"Almagest"* (1515) is one of the most influential scientific texts of all times.

If Ptolemy's Geocentric Universe is incorrect, why do we see Retrograde Motion? Each planet orbits the Sun at a different velocity; the closer the planet to the Sun, the faster it orbits. Earth catches up then passes planets further away from the Sun, giving the illusion that the planet is moving backwards for a while. The planet does retrograde, but due to the two bodies' orbital motions.

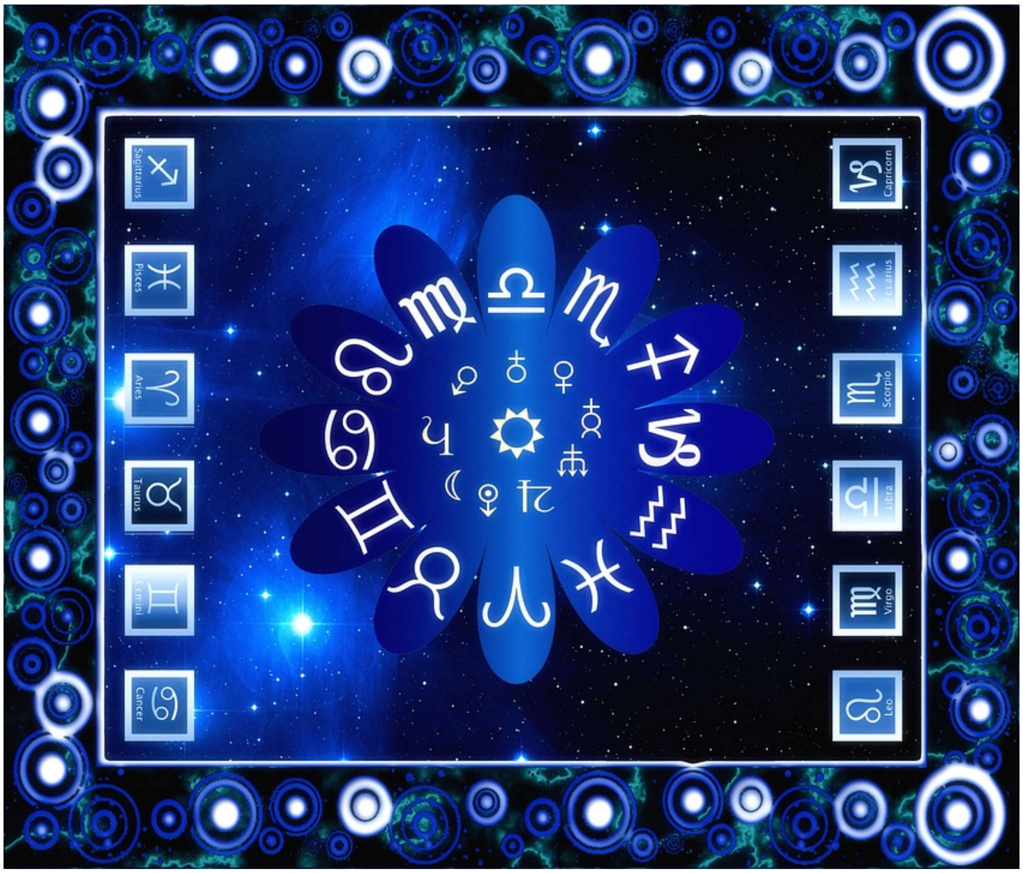
The correct solution would ultimately come nearly 1,500 years later. However, the Geocentric Solar System was deemed Scientific Law – and in some cases Church Law; no one could challenge the Geocentric Solar System until overwhelming evidence made accepting it impossible.

Public Domain

2.8: Astronomy and Astrology

Historically **Astronomy** and **Astrology** went hand-in-hand, but is there scientific evidence to support this theory? No. Astronomy is the scientific examination of the Universe, whereas Astrology attempts to predict one's future due to the positions of specific celestial bodies. The premise of astrology is that celestial objects affect us here on Earth. The question scientists and astronomers ask is what scientific evidence backs astrology?

First, do celestial objects affect us here on Earth? Yes, for example, the Sun and the seasons, daylight, the Moon and tides, asteroids, and comets affect us on Earth. *What does astrology claim?* Basically through unknown forces the arrangement of celestial objects can determine human characteristics and fates.



Public Domain | Image courtesy of Pixabay. com.

Astrology today is based primarily on the influence of the planets on individual lives. Yet the planets are so far away that their gravitational influence is nil. For example Jupiter's gravitational influence on Earth raises our tides 0. 0001 inch! Why not include closer-by asteroids? And why do astrologers now include Uranus, Neptune and Pluto when they were not included prior to their discovery? And for Pluto: a planet or dwarf planet?

Sun-Sign Astrology is the most-popular form; this is based on the Sun's position in the sky relative to background stars. *What is your Sign?* Capricorn, Aquarius, Leo, Sagittarius, Ophiuchus? Astrologers claim you are born under the sign in which the Sun is in that constellation. However the Sun is *not* in that constellation due to the Earth's precession. **Precession** is the circular motion of a planet's tilted axis, much like a top or a gyroscope. For Earth this is a slow process– 26,000 years to complete one precession.

2.9: The Birth of Modern Astronomy

Public Domain | Image courtesy of Pixabay. com.

The **Copernican Revolution** was based on the works of four men — Copernicus, Brahe, Kepler, and Galileo.

Nicolaus (or Nicolas) Copernicus was a Polish astronomer who believed there were too many errors in the Ptolemaic Geocentric Universe. Copernicus noted, as did some others, that Ptolemy's "retrograde" was too complicated. So Copernicus developed a Sun-Centered Solar System, that is, a **Heliocentric Solar System**.

2.10: Observations of Motion- Brahe, Kepler, and Galilei

Public Domain

Tycho Brahe made numerous measurements of the positions of astronomical objects until his death in 1601. His measurements were accurate to better than 1/100 of a degree.

Johannes Kepler was Tycho's assistant. Kepler tried to obtain Tycho's data to fit the Copernican Heliocentric Solar System Model. (Kepler's and Tycho did not get along.) But Tycho's data did not exactly work for a Heliocentric Solar System! So Kepler looked for a new model, and from that he developed Kepler's Laws.

Kepler's First Law

The planets travel around the Sun in elliptical orbits. Copernicus thought the planets moved in perfect circles, whereas Kepler defined these as ellipses, based on Brahe's data.

Kepler's Second Law

As a planet orbits the Sun, it sweeps out equal areas of its ellipse in equal periods of time. The closer the planet to the Sun (or its star), the faster it moves.

Kepler's Second Law is stated as:

$$v = \sqrt{\left(\frac{4\pi^2 \cdot a^3}{P^3}\right)\left(\frac{2}{r} - \frac{1}{a}\right)}$$

Where:

- **v** is the orbiting object's velocity
- **a** is the semimajor axis of the object's orbit
- **P** is the sidereal period of revolution
- **r** is the distance between the orbiting object and the body being orbited, such as Earth orbiting the Sun, or the Moon orbiting Earth

Kepler's Third law

A relationship exists between the planet's period and its distance from the Sun.

Kepler's Third Law is stated as:

$$a^3 = kP^2$$

Where:

- **a** is the orbiting object's semimajor axis
- **P** is the orbiting object's period to orbit
- **r** is a constant, referred to as Kepler's constant

2.11: Observations of the Heavens- Galileo

Public Domain | Image courtesy of Pixabay. com.

Italian astronomer and physicist Galileo Galilei first used the telescope astronomically in 1609. He was the first to see such wonders as sunspots, which he described as blemishes on the Sun, and features on the Moon like *Mare* —seas or bodies of water.

Galileo's observations of the planets were monumental.

- Mercury and Venus showed *phases* , which meant Mercury and Venus orbits the Sun *between* Earth and the Sun
- Four bright moons around Jupiter
  - Galileo's continued observation of Jupiter's moons was important in the Geocentric-Heliocentric Solar System debate.
- Milky Way and found it had countless stars

An interesting note about Galileo…

Galileo also worked on several problems in physics, in addition to his pioneering astronomical observations. He was a deeply religious man, as his daughter who was a nun. Galileo was held on house arrest by the Church and made to recant his theory of a Heliocentric Sun-centered Solar System. Galileo's right hand middle finger was removed after his death and is on display in the Science Museum of Florence, along with some of his telescopes.

2.12: The Mathematical Finish- Newton

The next major leap was that of Sir Isaac Newton, an English physicist and mathematician. Newton is credited with developing the **Laws of Motion, Law of Universal Gravitation**, building the first **Reflecting Telescope** (still called the Newtonian Reflector), and developing a **Theory of Color**.

The Theory of Color was based on Newton's observations that a prism breaks sunlight into component colors. Newton also shares credit for the development of Calculus with Gottfried Leibniz, as well as developed other ideas in physics, including an empirical law of cooling, studies the speed of sound, and the idea of a Newtonian fluid.

Newton's First Law of Motion

An object remains at rest or in motion at a constant velocity unless acted upon by an outside force. A force is any influence that can change the speed or direction of motion of an object.

Newton's Second Law of Motion

The relationship between acceleration of an object, force placed on the object, and the object's mass.

Newton's Second Law of Motion is stated as:

F = ma

Where:

- **F** is force
- **m** is the mass
- **a** is acceleration

Units in the Metric System:

- Mass is kilograms, **kg**
- Acceleration is meters per second squared; **m/s** ^{2}
- **f = kg-m/s** ^{2} = Newton **(N)**

An object's weight is the force with which the object is attracted by a body's gravitational pull.

F = ma w = mg

Where:

- **w** is the object's weight
- **m** is the mass
- **g** is acceleration due to gravity, 9. 8 m/s ^{2} (metric system) or 32 ft/s ^{2} (English system)

Newton's Third Law of Motion

When one object exerts a force on a second object, the second object exerts an equal force in the opposite direction on the first object. This is sometimes called the **Action–Reaction Law**. Examples include a rocket "blasting off" (action is force of the combustion/flame, reaction is the rocket moving in the opposite direction of the flame) and a book pushing against a table (a force); the table pushes back (opposite and equal force).

Centripetal Force, Fc

Inward force on an object moving that object in a curved path. Understanding Circular Motion is important due to planets orbiting stars, moons orbiting planets, or a satellite orbiting Earth.

The relationship is stated as:

$$Fc = \frac{mv^2}{r}$$

Where:

- **Fc** is the centripetal force
- **m** is the object's mass
- **v** is the object's velocity
- **r** is the radius of the circular path

Newton's Law of Universal Gravitation

Every object in the Universe attracts every other object with a force proportional to both of their masses and inversely proportional to the square of the distance between them.

The relationship is stated as:

$$F = \frac{Gm1m2}{R^2}$$

Where:

- **F** is the Gravitational force
- **G** is the Gravitational Constant; 6. 67 x 10-11 N-m ^{2} /kg ^{2}
- **m1** is the first object's mass
- **m2** is the second object's mass
- **R** is the distance between the two objects

This is often called an **Inverse Square Relationship**, where the greater the distance between the two objects, the smaller the force between these two objects – squared. If the first distance was 1 meter and the second distance was two meters, the variation in the force would be ¼ at the second distance.

Consider this…

"Do not worry about your difficulties in mathematics; I can assure you that mine are still greater. "

Albert Einstein (1879-1955)

CHAPTER OVERVIEW

3: Motions of the Moon, Sun, and Stars

3.1: Module Introduction

The Earth,
Though, in comparison of Heaven, so small
Nor glistering, may of solid good contain
More plenty than the Sun that barren shines.

John Milton,
Paradise Lost, 1665

This module will overview movements of Earth, the Moon, and other astronomical bodies and the effects these movements have on what we observe from here on Earth.

Objectives

Upon completion of this module, the student will be able to:

- Define motions of objects, including rotation, revolution, and precession
- Identify parts of the points on the Celestial Sphere, such as the celestial poles, meridian, zenith, celestial equator, and ecliptic
- Identify measurement systems used by astronomers
- Explain why we experience seasons, and the descriptions used to discuss seasons
- Explain why the Moon goes through its phases, and the terminology used to explain the phases of the Moon
- Identify types of eclipses
- Explain why eclipses occur

3.2: Motions of Objects

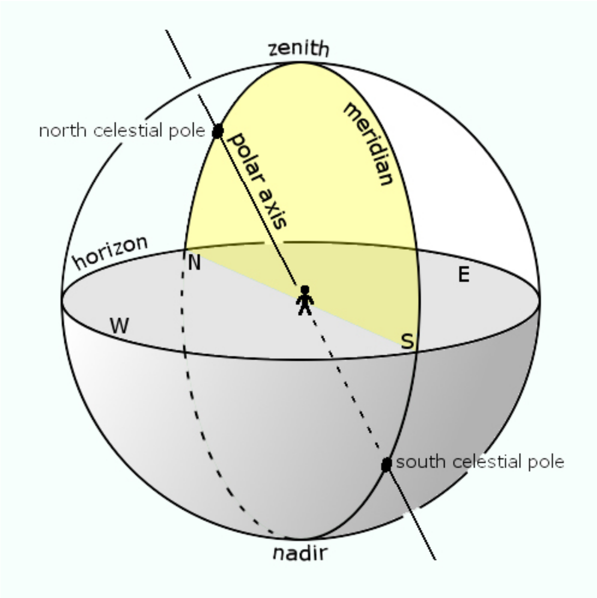
Public Domain | Image courtesy of Pixabay. com.

There are several basic motions of bodies. Rotation is the spinning of an object around its axis. Earth rotates once approximately every 24 hours, whereas Jupiter rotates once approximately every 10 hours.

At any moment, half of the Earth is illuminated by the Sun, because of the fact that most of our light comes from the Sun. As the Earth rotates from west to east, your location moves from the dark (night) hemisphere into the illuminated (day) hemisphere and back again. The diurnal (daily) motion of the stars, the Sun, and the Moon is a consequence of Earth's rotation.

Another motion is Revolution; that is, one object orbiting a second. Earth revolves around the Sun approximately every 365. 24 Earth Days (1 Earth year), and Jupiter revolves around the Sun approximately every 11. 86 Earth Years (1 Jovian year). As the Earth revolves or orbits around the Sun, the nighttime side of the Earth (or any other body orbiting the Sun) gradually turns toward different parts of the night sky.

3.3: Our Night Sky



CC BY-SA 3. 0 | Image courtesy of Wikimedia Author, Tfr000.

The Celestial Sphere is an imaginary sphere on which all the objects in the sky appear when observed from a specific place, which also appears to move. This sphere appears to surround the Earth. The Sun and Moon, as well as the bright planets, also appear on the Celestial Sphere, moving independently from the background of stars.

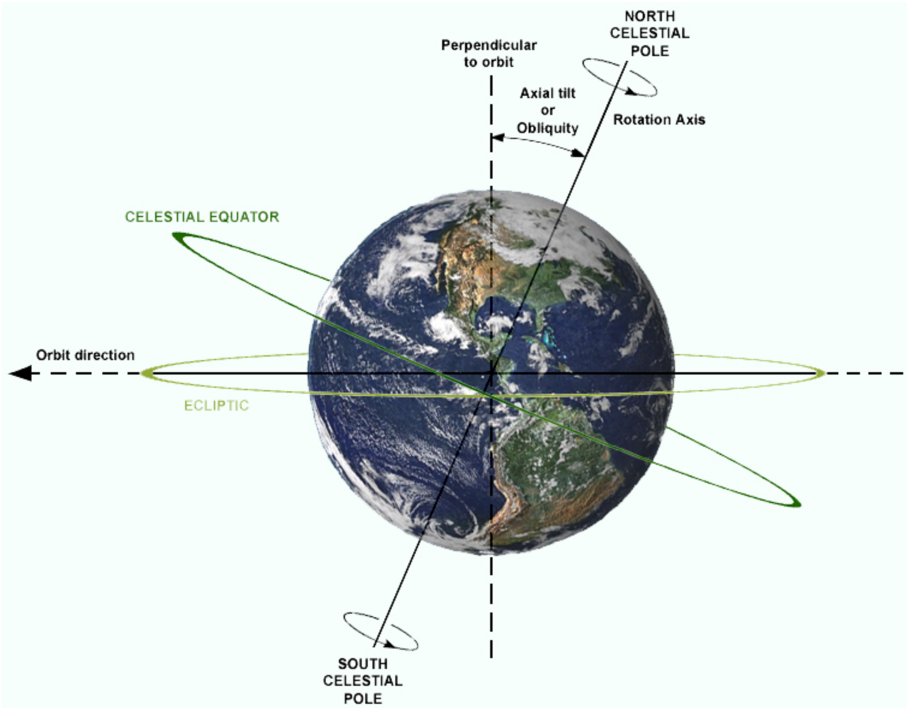
Directions on Earth, in the Universe

On the Earth we use several directional indicators. We use North, East, South, and West. North is 0o, East is 90o, South is 180o, and West is 270o. We use latitude and longitude. Latitude is an imaginary line that runs north or south from the Earth's equator, and longitude runs east or west from the Earth's meridian. We use similar directional and positional indicators for other Solar System bodies.

There are also Celestial Sphere directions. The North and South Celestial Poles are the points at which the Celestial Sphere appears to turn or rotate. This is an extension of the Earth's axis; the stars rotate about these points. Astronomers us Celestial Pole shorthand for these locations

- NCP is North Celestial Pole
- SCP is South Celestial Pole

Points on the Celestial Sphere



CC BY 3. 0 | Image courtesy of Author: I, Dennis Nilsson.

There are other points on the Celestial Sphere we see when looking up to the sky. The Local Sky is the sky we see from where we stand. It is called local sky because what one would see in Jacksonville, Florida is different than what one would see in Seattle, Washington and what one would see in Brisbane, Australia.

The Celestial Equator is a projection of Earth's equator onto the Celestial Sphere. The Ecliptic is the Sun's annual path across the Celestial Sphere. Note that the Ecliptic is not the same location as the Celestial Equator due to Earth's tilt of approximately 23. 4°. The Zenith is the point directly overhead. And the Meridian is an imaginary line from due north to the zenith to due south. The Meridian divides the sky into halves and can be considered a division between rising objects – those to the east of the meridian, and setting objects – those to the west of the meridian.

Let's go back to the North, East, South, and West system. Generally speaking, objects rise in the East and set in the West. This depends on the object's location on the Celestial Sphere and the observer's location on Earth. For example, if you live at the North or South Poles, the stars will simply circle, neither rising nor setting.

3.4: The Sun and the Moon

The Sun moves along an apparent path on the Celestial Sphere called the Ecliptic. The constellations along Ecliptic – historically 12 but officially 13 – are called the Zodiac. The Moon also travels along the Ecliptic; sometimes in the evening sky, sometimes in the morning, sometimes not visible at all. And the bright planets also travel along the ecliptic.

Measurements along the Celestial Sphere

Astronomers use degrees, minutes, and seconds to measure distances across the sky or sizes. These are referred to as Angular Sizes: the angle the object appears to span or distance between objects, for example:

- The Sun and Moon appear to be about ½ degree as we see them from Earth. This is not their true size; it is just how they appear to us.

  ← → ½ degree = 30 arcminutes

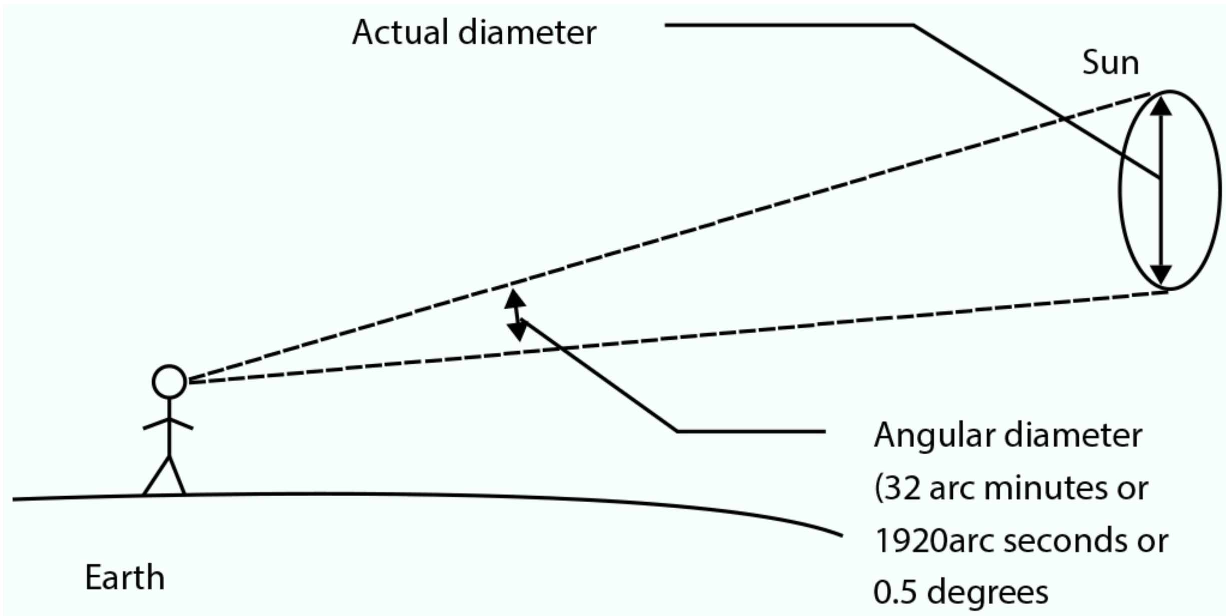
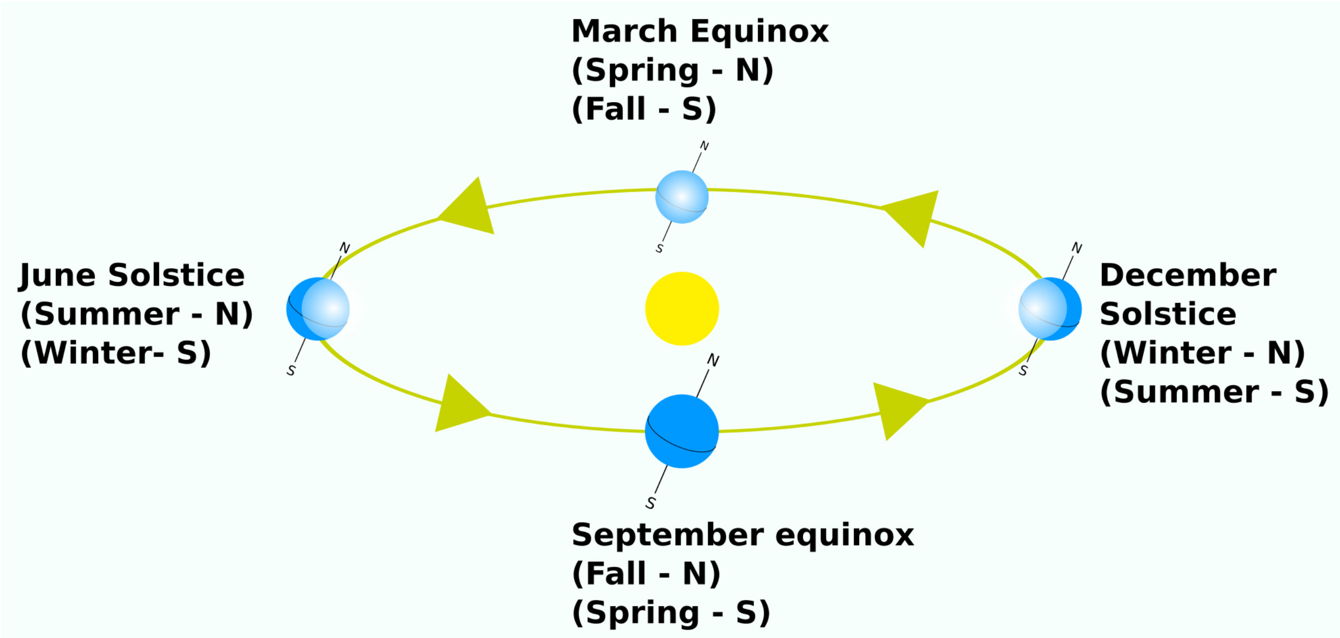


Image courtesy of Florida State College at Jacksonville.

3.5: Seasons and Seasonal Changes



Season of the Year IllustratedPublic Domain | Image courtesy of NASA.

The Seasons are the divisions of a year, which are marked by changes in weather and hours of daylight, and hours of darkness. Seasons occur on a planet or moon because the axis of rotation remains tilted in one direction during its orbit about its star; Earth about the Sun. The tilt is relative to the planet's or satellite's orbit. This tilt results in a planet or moon having Seasons. Earth's axis is tilted about 23 ½o, whereas Uranus' axis is tilted about 98o. Seasons have nothing to do with the distance to the star; for example Earth to the Sun. The distance to the Sun is often incorrectly given as the reason Earth experiences seasons. In fact, Earth is closest to the Sun in January, not June.

Seasonal Terminology include:

- **Summer Solstice** – Sun's rays are most direct
- **Winter's Solstice** – Sun's rays are least direct
- **Spring or Vernal Equinox** – Equal day and night, going from shorter to longer days
- **Fall or Autumnal Equinox –** Equal day and night, going from longer to shorter days

At the Equinoxes, the Sun rises due east and sets due west – only at the Equinoxes. An egg will not stand on end because it's the 1st day of spring (or autumn). At the time of summer solstice the day is longer and the night is shorter. This is extreme at far latitudes and creates what is called the midnight Sun. At the time of winter solstice the day is shorter and the night is longer; E=extreme at far latitudes and results in no Sun during part of the winter season!

Will the Seasons always remain the same?

No, because the orientation of Earth's axis changes over time. This is called Precession, which is the circular motion of a planet's tilted axis and similar to a top's wobble as it slows down. For astronomical bodies, it is a slow process. Earth takes 26,000 years to complete one precession. What are the effects of precession? The effects are the timing of the Seasons and changes in the Celestial poles. Precession is not a perfect path; a wobble in the precessional motion called Nutation causes a small irregularity in the precession.


Image courtesy Mike Reynolds, Ph. D. of Florida State College of Jacksonville.

3.6: The Moon in our Skies

It is the very error of the Moon; She comes more near the Earth than she wont, And makes men mad

Shakespeare – Othello

On one side lay the ocean, and on one Lay a great water, and the Moon was full.

Alfred, Lord Tennyson – Morte d'Arthur (1842)

Consider these Moon Facts…

It takes 27 1/3 days for the Moon to go around Earth one time; called the Sidereal Month. From new Moon to the next new Moon takes 29 1/2 days; called the Synodic Month. Why this amount of time? Earth has also moved through space and the Moon has to catch up with that starting position. Think of our word month – from the term Moonth.

As the Moon orbits Earth, roughly the same side of the Moon faces Earth. This means that one (1) lunar rotation equals one (1) lunar revolution. Like Earth, one half (1/2 or 50%) of the Moon is always illuminated by the Sun

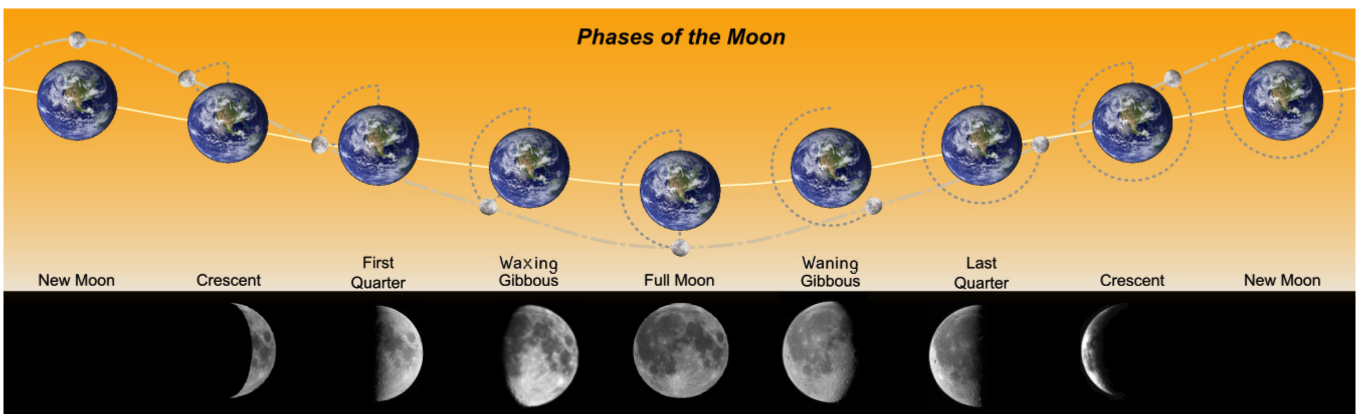
Phases of the Moon

We see the Moon go through its phases due to the position of the Earth, Moon, and Sun relative to each other, NOT due to Clouds, the Moon moving closer or the Sun farther away, or some reflection in the heavens.

Moon Phase Terminology

The descriptions are as the Moon is seen from Earth:

- **Crescent Moon** – Less than 50% illuminated
- **Gibbous Moon** – More than 50% but less than 100%
- **Waxing Moon** – "Growing" larger; New Moon up to Full Moon
- **Waning Moon** – "Growing" smaller; right past Full Moon to New Moon
- **Full Moon** – 100% illuminated- full moons rise at sunset because the Moon and Sun are on opposite sides of Earth
- **New Moon** – 0% illuminated; "no" Moon



Phases of the MoonCC BY-SA 3. 0 | Image courtesy of Wikimedia Author: Fresheneesz~commonswiki

More about the Moon…

Can we see the Moon in the daytime? Yes!

Are there times when we cannot see the Moon at all? Yes, at New Moon and sometimes right before and right after the New Moon because the thin crescent is so difficult to see.

Is there a Young Moon or an Old Moon? These are terms used to describe the Moon's phase right before (old) or after new moon (young). These are very thin crescent phases and can be difficult to see.

Does the Moon keep a constant distance from Earth? No, it varies from a Perigee of about 225,000 miles to an Apogee of about 243,000 miles. Perigee is when the Moon is closest to the Earth and Apogee is when the Moon is farthest from Earth.

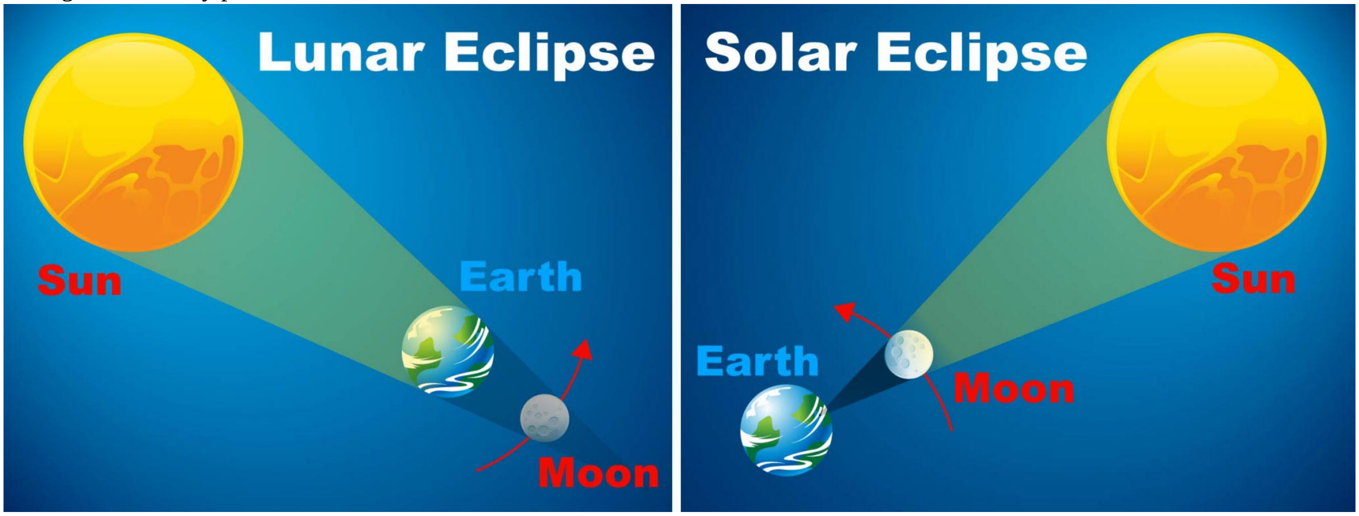
Public Domain | Image courtesy of NASA.

Thy shadow, Earth, from Pole to Central Sea, Now steals along upon the Moon's meek shine In even monochrome and curving line Of imperturbable serenity. *Thomas Hardy – At a Lunar Eclipse,1926*

And it shall come to pass in that day, Saith the Lord God, That I will cause the Sun to go down at noon, And I will darken the Earth in a clear day. *Amos 8:9 – The Bible*

3.7: Eclipses

An eclipse is an event that happens when one body is temporarily hidden, either by passing into the shadow of another body or by having another body pass between it and the observer.



Lunar Eclipses

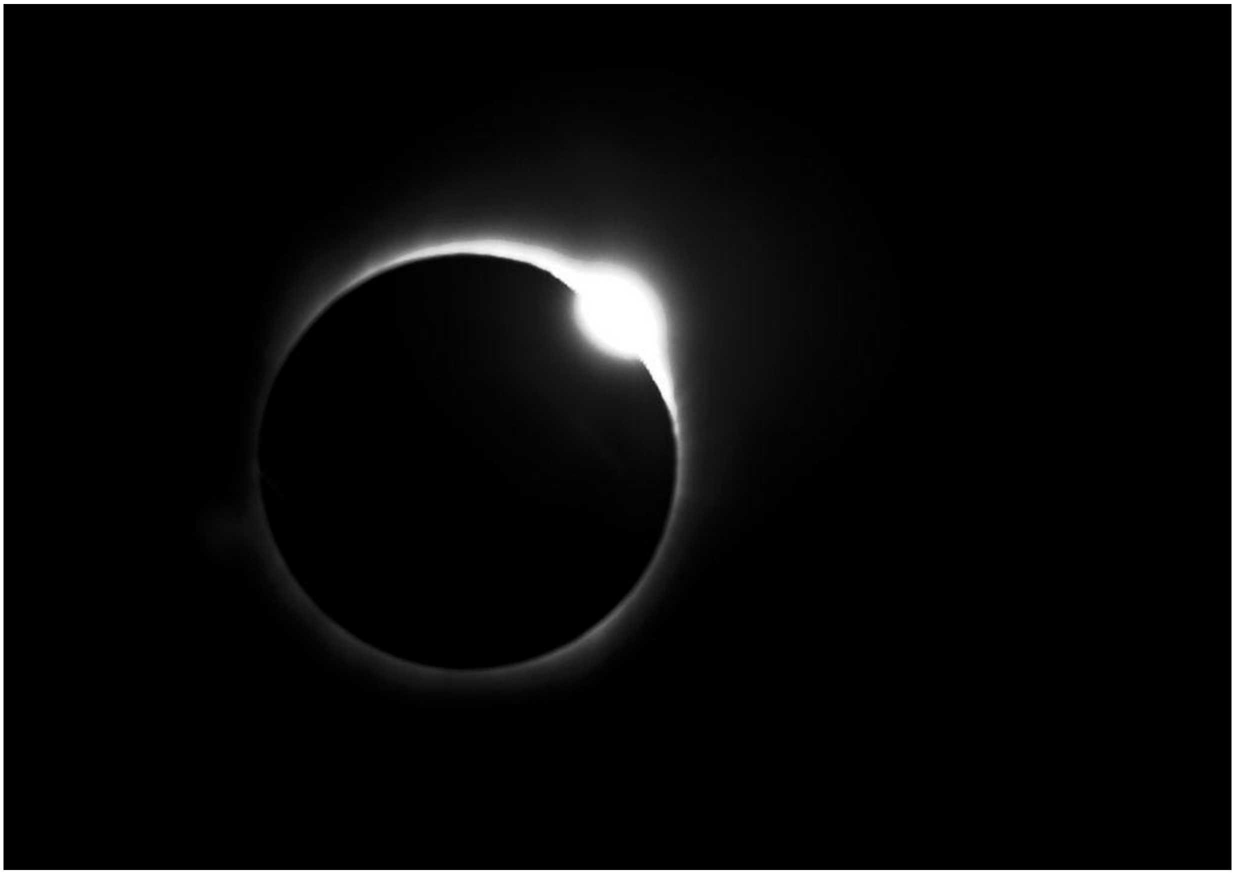
A lunar eclipse occurs when Earth lies directly between the Sun and the Moon, so that Earth's shadow falls on the Moon. A lunar eclipse can only occur at full Moon. There are three types of lunar eclipses: Penumbral, Partial, and Total. The type of lunar eclipse depends on how far the Moon travels into Earth's shadow. The entire night side of Earth can see the lunar eclipse. Total lunar eclipses can vary in color and brightness due to Earth's atmosphere and how deep the Moon passes into Earth's shadow; Red to Copper to Orange to Black. The colors can be quite varied and spectacular.

A Solar Eclipse occurs when the Moon comes between the Earth and the Sun, partially or totally blocking off the Sun from view on Earth. A solar eclipse can only occur at new Moon (whereas a lunar eclipse can only occur at full moon). There are four types of solar eclipses:

1. You must be within the eclipse "zone" to see even a partial solar eclipse.

Total Solar Eclipses

During a total solar eclipse, the Moon totally blocks all harmful solar light and radiation at totality but not during partial. Totality is the phase of the eclipse at which the Sun is completely covered by the Moon. Right before totality, you might be able to see several stars and planets as the sky begins to darken due to decreasing sunlight. At totality, daytime becomes nighttime; the Moon's shadow passes over your site and you will see colors around the horizon, called the sunrise/sunset effect. Occasionally you might see bands of black and white running across the ground right before and after totality; these are called shadow bands and are due to Earth's atmosphere. Animals often react as if it has become nighttime.



CC BY-SA 3. 0 | Image courtesy of Wikimedia Author: Lutfar Rahman Nirjhar.

Right at totality and during totality, you will be able to see several things associated with totality.

The **Diamond ring** looks just like its name. It is the last bright sliver of the Sun visible as the Moon covers the Sun, or right after the end of totality as the Sun is being uncovered by the Moon.

Baily's Beads are spots of light that appear as the Moon is covering the Sun. The edge of the Moon is not smooth with mountains and valleys and sunlight goes through these valleys for a few seconds until they too are covered.

At totality, a couple of features become prominent at the now-totally eclipsed Sun. You will see pink-red spots along the edge of the Sun. These are solar prominences and surround the eclipse Sun you will see a whitish extension, the corona or Sun's outer atmosphere.

Eclipse: Lore and Legend

There are some interesting eclipse stories over the passage of civilization. For example, was Stonehenge a system to predict lunar eclipses or something else? In China, the term for an eclipse is chih, which also means to eat; something was eating the Sun. The ancient Chaldeans believed that an eclipse was a display of the Moon's anger. The Babylonians determined the eclipse's "quadrant" – geographical indicator of who would suffer the worst disasters as a result of the eclipse. The Peloponnesian War (5th century BC) was won on the heels of a lunar eclipse; the Athenians failed to retreat and the Syracusians routed them.

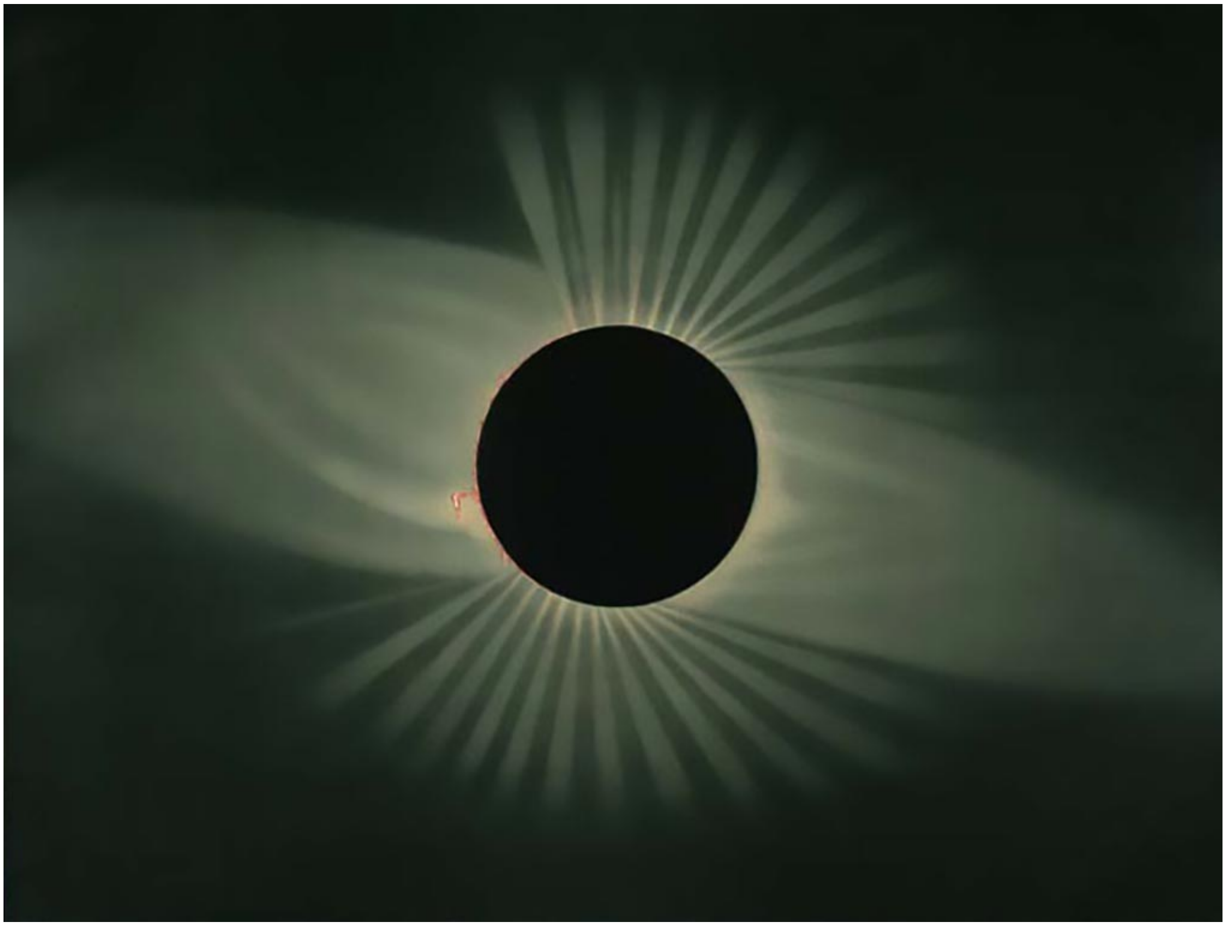
Maybe the most interesting and distressing was the story of Columbus and a total lunar eclipse. Columbus used a total lunar eclipse in 1504 to convince the Jamaican natives to supply him and his crew food – he threatened to keep the Moon dark unless the natives met his demands.

Today's World…

In much of the world, it is still common practice to make noise to frighten away whatever is attacking the Sun or Moon. Some peoples are also concerned that diseases are caused by eclipses. Some wells are covered in Japan to prevent celestial poisoning. Some Eskimos turn over utensils to avoid contamination. In India some people lock themselves in their homes to avoid evil rays. And in many parts of the world pregnant women are not allowed outside during an eclipse.

A Total Eclipse of the Sun

People have described total solar eclipses as magical, life-changing, and almost religious in nature…even in today's scientific and high-technology world.



Public Domain

CHAPTER OVERVIEW

4: Light and Spectra

4.1: Module Introduction

Red, orange, yellow, green, blue, indigo-violet mystic vision arcs
Red, orange yellow green blue indigo follow graceful violet glows
Lively prism light enchanting rainbow delights brightly dance then hides
Misty promise made sunny days ahead storm's ending I see ROY G BIV

Lorraine Margueritte Gasrel Black
Rainbow in Motion Haiku

This module covers visible light as well as other forms of the electromagnetic spectrum, which provide us information about the Universe. An object's spectrum can also provide an incredible amount of information, from the object's velocity to its distance.

Objectives

Upon completion of this module, the student will be able to:

- Describe light and the electromagnetic spectrum
- Recognize Wien's Law and Stefan-Boltzmann Law
- Differentiate among Continuous, Emission Line, and Absorption Line spectrums
- Describe Doppler Effect, both in sound and light
- Identify the astronomical implications of spectral observations

4.2: Looking at a rainbow, what do you see?

The rainbow – with all of its myths and legends – is an indicator of the data astronomers examine.

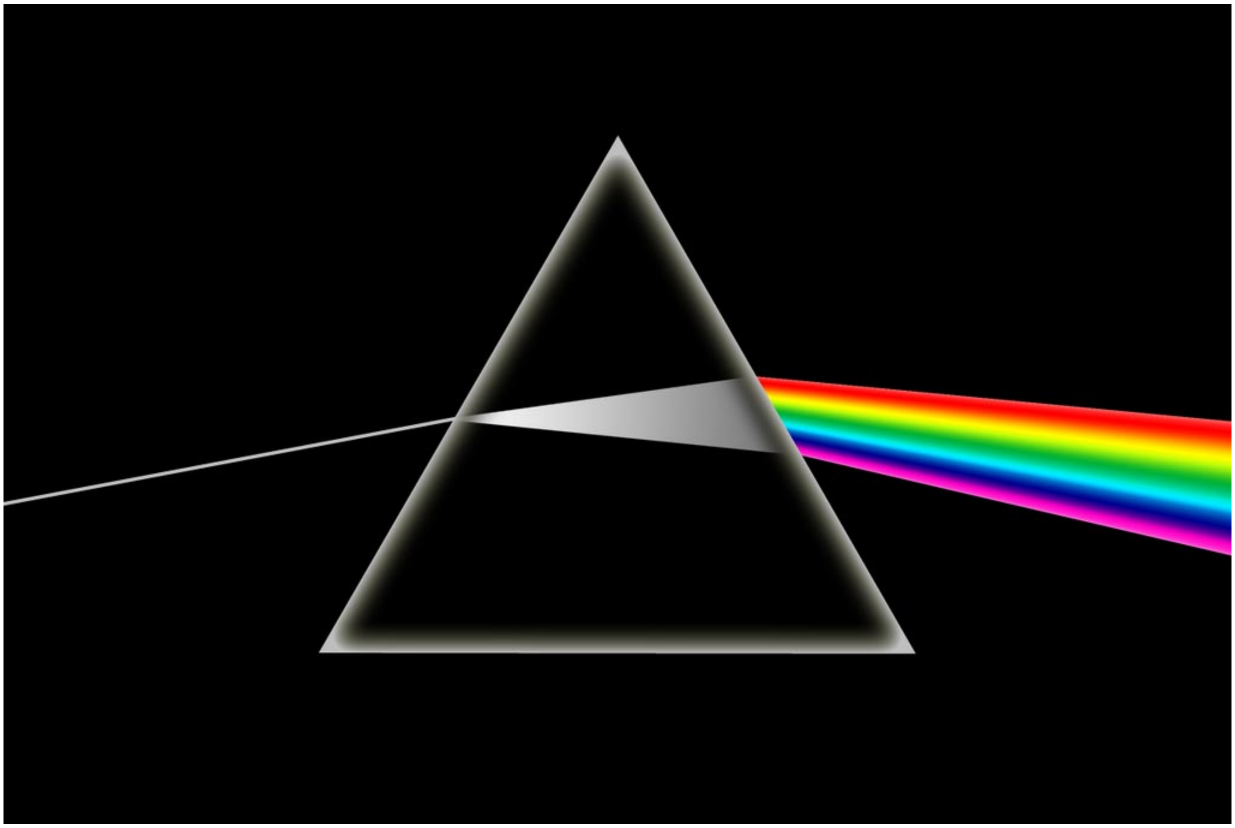
Public Domain | Image courtesy of U. S. National Oceanic and Atmospheric Administration.

Light

Light is **Radiative energy**, which can be split into a **spectrum**. A spectrum is the light's component colors or wavelengths. Light can be split into its component colors or wavelengths by using a prism or diffraction grating.

Light comes in particle bundles, called photons. These photons travel at **186,000 mi/s** or **300,000 km/s (3 X 108 m/s)**. The Speed of Light, c, is an absolute; you cannot go faster than c. (the speed of light).

Light also moves in **waves**. Particles moving in waves are referred to as an **Electromagnetic wave** ; a wave in which both electric and magnetic waves "interact" or vibrate. The **Wavelength** is the distance between adjacent peaks on the wave, and the wave's **Frequency** is the number of peaks that pass a specific point in a second.



CC BY-SA 3. 0 | Image courtesy of NASA / ESA.

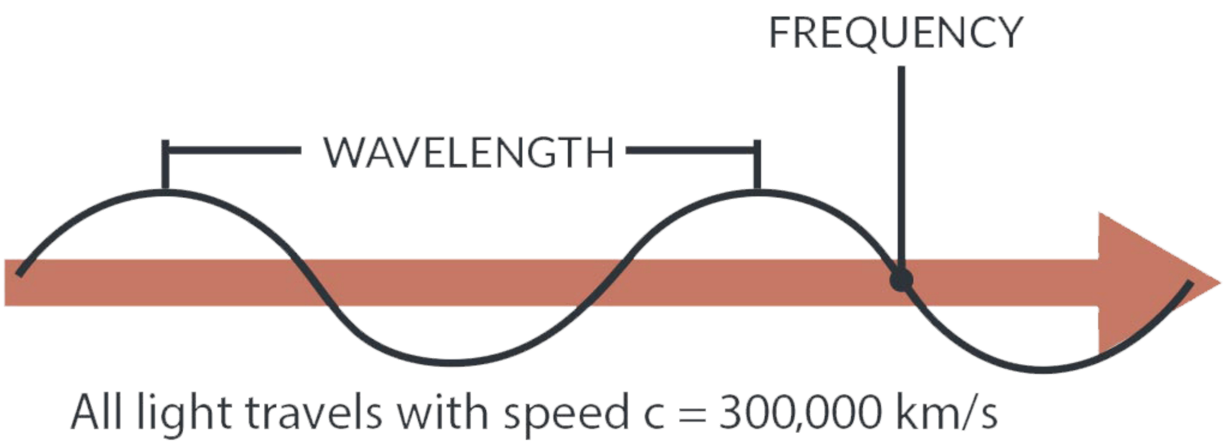


Image courtesy of Florida State College at Jacksonville.

4.3: Thermal Radiation

An object's **temperature** is the measure of the speed at which the object's particles move. To measure temperature, astronomers prefer the **Kelvin temperature scale**. This scale is much like Celsius, but 0 ^{o} is Absolute Zero – scale starts at zero, 0K. **Wien's Law** relates the color of an incandescent object to its temperature. The law states that wavelength of the brightest color is inversely proportional to the object's temperature.

$$\lambda_{max}\, \alpha \,\frac{1}{T}$$

Where:

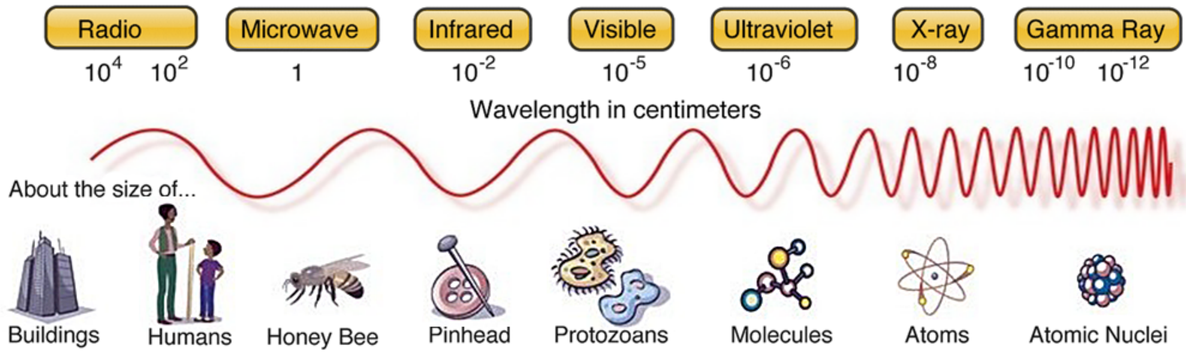
- **Stefan-Boltzmann Law** states that the power, **P**, emitted per unit of area of an object is proportional to the fourth power of its temperature, **T**. Mathematically, this is:

  $$P \alpha\, T^4$$

  - **P** is the power
  - **T** is the temperature

4.4: The Electromagnetic Spectrum

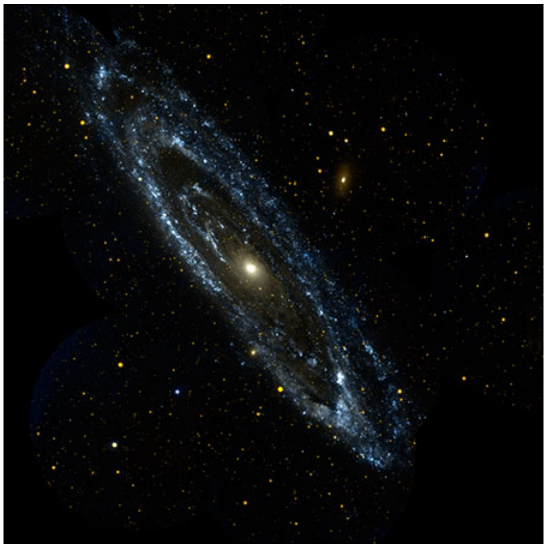
The **Electromagnetic Spectrum**, or **EMS**, is the range of frequencies of electromagnetic radiation. Electromagnetic Radiation is a fundamental phenomenon of electromagnetism, acting as waves and as particles – photons, which move through space carrying radiant energy.



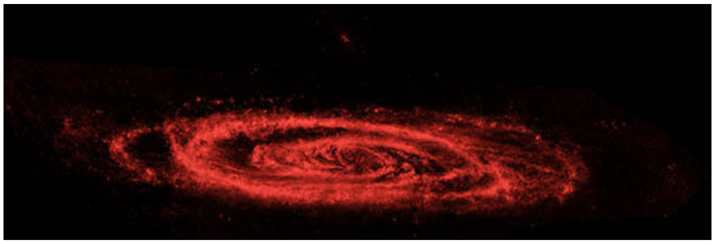
Public Domain | Image courtesy of NASA.

We see the **Visible light** portion of the EMS, wavelengths of 400 nm to 700 nm. The **wavelengths** longer than visible light include Radio, Microwave, and Infrared (IR) waves. **Visible Light** ; sometimes called **ROYGBIV**, includes Red, Orange, Yellow, Green, Blue, Indigo, and Violet. Visible light is a very small part of the EMS. **Shorter Wavelengths** than visible light include Ultraviolet (UV), X-rays, and Gamma Rays. Only radio, some IR, and visible light gets through Earth's atmosphere.

A mnemonic to remember the EMS in correct order from the longer to shorter wavelengths is **R** eal **M** en **I** n **V** irginia **U** se **X** tra **G** lue.



Andromeda Galaxy in Visible LightPublic Domain | Image courtesy of NASA / Hubble Space Telescope.



Andromeda Galaxy in IRPublic Domain | Image courtesy of NASA / Spitzer Space Telescope.

4.5: Spectra

Spectra are very important to astronomy because they can show the component wavelengths and specific elements present.

Continuous Spectrum

Public Domain | Image courtesy of Wikimedia Author: Jhausauer.

A continuous spectrum shows all wavelengths and is produced by hot, dense solid objects at high temperatures.

Emission Line Spectrum

Public Domain | Image courtesy of Wikimedia Author: Jhausauer.

An Emission Line spectrum produces a spectrum with **bright lines**. It occurs from heating an object, causing the electrons in the object's atoms/molecules to show at a specific wavelength.

Absorption Line Spectrum

Public Domain | Image courtesy of Wikimedia Author: Jhausauer.

An Absorption Line spectrum produces a spectrum with **dark lines**. It occurs when one object absorbs specific photons given off by a second object. For example, a light behind a cloud of gas absorbs photons at the cloud's energy level while the rest of the photons pass through the cloud.

4.6: Moving Objects, Spectra, and the Doppler Effect

The **Doppler Effect** is a change in an object's spectrum because the object is moving closer or away from the observer. In **sound** we experience this change in a siren's pitch. When it approaches us, the waves are being compressed, then becoming longer as it moves away. This increase in pitch can be heard as a police car approaches and then decreases as it moves farther away. **What are the Implications of Doppler Shift?**

1. **What are The Astronomical Implications and Importance of Spectra?**
   1. How do we know what a star is made up of?
      - *From the star's spectra*
   2. How do we know if an object, star, galaxy, etc., is moving towards or away from us?
      - *Look for a red or blue shift in the object's spectra*
   3. Can we tell how fast an object is moving towards or away from us?
      - *Yes, by the extent of red or blue shift*

Consider this…

Astronomer Frederick William *Herschel*Public Domain

For most of history, visible light was the single most recognized portion of the electromagnetic spectrum, EMS. The ancient Greeks noted that light traveled in straight lines and studied its properties. Over the years the study of light continued. During the 16th and 17th centuries there were conflicting theories which regarded light as either a wave or a particle. In 1800, astronomer Frederick William Herschel discovered infrared radiation while using a thermometer to measure temperatures of visible light frequencies. A year later Johann Ritter discovered ultraviolet radiation.

CHAPTER OVERVIEW

5: Telescope and Observing

5.1: Module Introduction

He burned his house down for the fire insurance
And spent the proceeds on a telescope
To satisfy a lifelong curiosity
About our place among the infinities

The strongest thing that's given us to see with's
A telescope. Someone in every town
Seems to me owes it to the town to keep one.
In Littleton it may as well be me.

Robert Frost
The Star-Splitter

This module introduces you to the primary instrument used by astronomers: the telescope, as well as how the telescope works. From its historical first use to today's modern instruments, the telescope changed forever how we look at our Universe.

Objectives

Upon completion of this module, the student will be able to:

- Identify the types of telescopes and telescope mounts
- Describe the differences between the refracting telescope and reflecting telescope, including both positive and negative features
- Describe the types of instruments astronomers use with the telescope and the function of each type
- Explain why space-based telescopes are of such importance to today's astronomers and the collection of information

5.2: The Telescope

*"The early spectacle maker – today's equivalent of an optometrist – set up shop in the open streets. The patient would try on different 'spectacles' to see which one provided the best improvement in vision. "*The **telescope**. is an instrument designed to **collect and magnify visible light** and **see detail**. Detail refers to **angular resolution** ; think of resolving into finer details. Bigger telescopes collect more light and produce better resolution. However, the bigger the better is not always true; our atmosphere can limit a telescope's resolving abilities.

CC BY-SA 4. 0 | Image courtesy of Wikimedia Author: H. Aziz KAYIHAN.

Before the Telescope

Specific discoveries led up to the invention of the telescope. Below they are divided in Year and Event.

- There are several basic terms we use when discussing telescopes. **Optics** is the science that deals with all aspects of visible light. **Primary Objective** refers to the main lens (refractor telescopes) or mirror (reflector telescopes) which gathers the incoming light. The **Eyepiece** is a lens or series of lenses which focuses the light from the telescope's primary objective for the eye. **Refraction** is the bending of waves, such as light, when it passes from one substance to another, for example, from air through glass. Refraction is the primary method of a refracting telescope. Reflection is the bending of waves, such as light or sound waves, from a surface. **Reflection** is the primary method of a reflecting telescope.

5.3: Early Telescopes

Public Domain

Jan (or Han) **Lipperhey** of Holland, a spectacle maker, is given credit for inventing the first telescope in 1608 — a **refracting telescope**. He called his telescope **Kijker**, meaning "looker" in Dutch. Lipperhey's telescope was a refracting or lens-type telescope – as were all early telescopes; this used a convex lens to focus incoming light. Lipperhey thought the telescope's best use was*military* .

Lipperhey unsuccessfully tried to patent the telescope, as well as telescope binoculars. Since Lipperhey was denied a patent – probably meaning he did not invent the telescope – who did invent the telescope? Rumor has it Lipperhey's son actually discovered the correct lens combination – *he put together two lenses and "spied" a local church steeple* . Some historians argue that Lipperhey stole the idea from **Hans and Zacharias Janssen**, other spectacle makers, who supposedly built a telescope in 1595. However, historical references are not as clear on the Janssens and their telescope.

The first to use the telescope astronomically was **Galileo Galilei**. Galileo made his first telescope in 1609, based on what he had heard about the Lipperhey telescope. However Galileo's telescope was of much-better quality than Lipperhey's telescope.

"…[But] perhaps his [Galeleo] most famous invention was the telescope. Galileo made his first telescope in 1609, modeled after telescopes produced in other parts of Europe that could magnify objects three times. He created a telescope later that same year that could magnify objects twenty times. With this telescope, he was able to look at the moon, discover the four satellites of Jupiter, observe a supernova, verify the phases of Venue, and discover sunsports. His discoveries proved the Copernican system which sates that the earth and other planets revolve around the sun. Prior to the Copernican system, it was held that the universe was geocentric, meaning the sun revolved around the earth"

— *The Galileo Project (1564-1642)*

5.4: Telescopic Observations

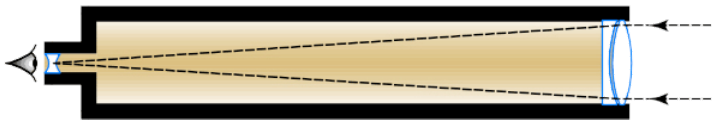
One of Galileo's first recorded telescopic observations was of Jupiter and "three fixed stars, totally invisible by their smallness"—three of the four large moons of Jupiter. Wne now call the four large moons of Jupiter the Galilean Satellites or moons. In 1668, Sir Isaac Newton designed and built the first Reflecting Telescope. It was Galileo who first described the idea for a reflecting-type telescope. The Reflecting Telescope used a concave mirror in the place of a lens to focus incoming light.

Public Domain | Image courtesy of NASA.

5.5: Telescope Optical Types

The type of telescope primarily depends on the optical combinations used to collect the incoming light or Electromagnetic Radiation (EMR). The **Refracting Telescope** or **Refractor** uses a lens or lenses as the telescope's Primary Objective. **Binoculars** are a type of Refractor; occasionally you will find reflecting binoculars.

Graphic of Refractor



The Achromatic RefractorImage courtesy Mike Reynolds, Ph. D. of Florida State College of Jacksonville.

The **Reflecting Telescope** or **Reflector** uses a concave mirror as the telescope's Primary Objective, rather than a lens or lenses. The type of reflector depends on other system mirror(s), called the Secondary Mirror.

A **Compound** or **Catadioptric Telescope** uses a combination of Refractor and Reflector characteristics. **Radio Telescopes** are attuned to the radio end of the spectrum; it turns out that many objects produce a radio emission.

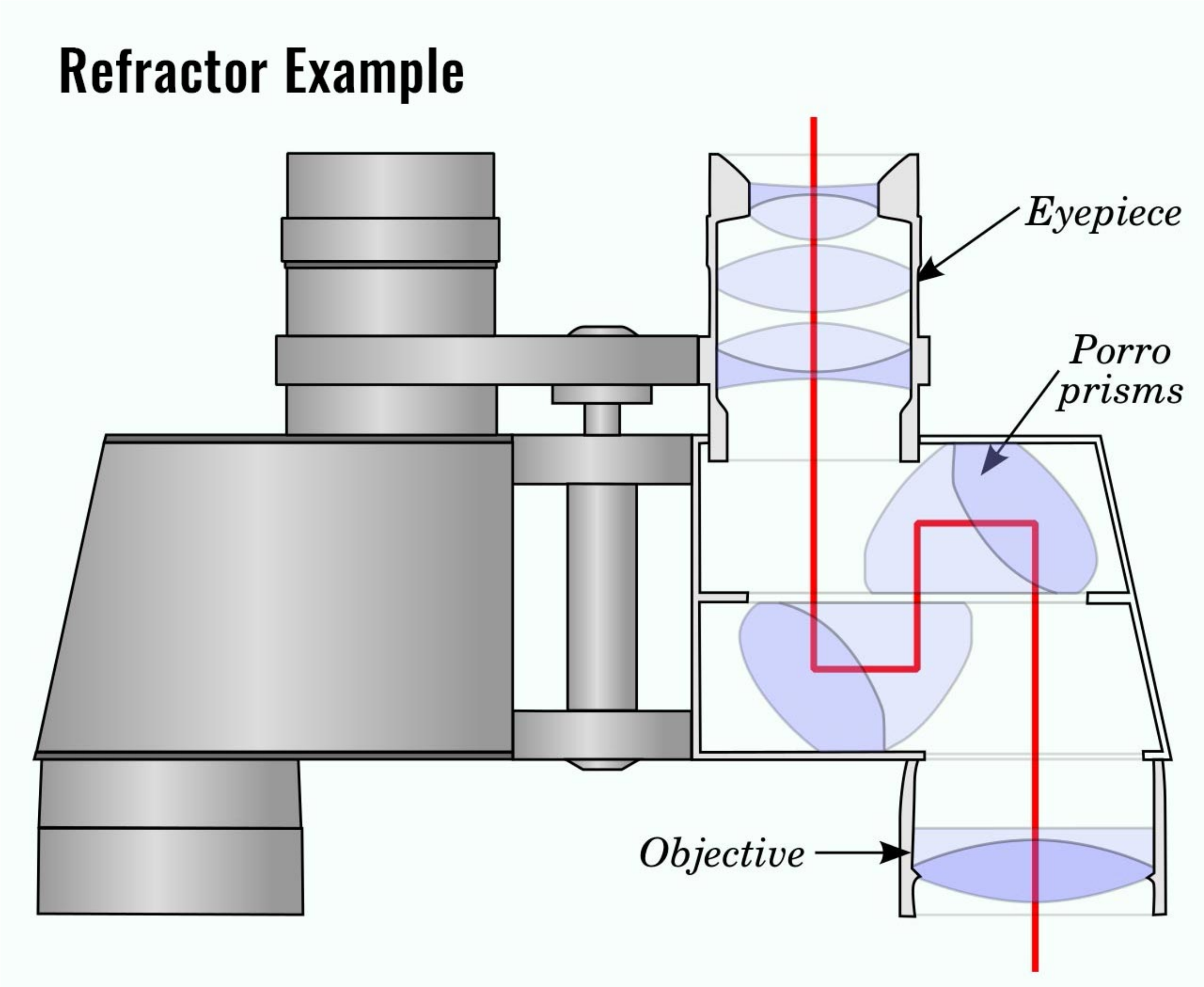
Specific Wavelength-Sensitive Telescopes are those attuned to specific regions of the spectrum; such as infrared (IR), ultraviolet (UV), and microwave.

Gamma-Ray Telescopes are used for detecting the gamma-ray part of the Electromagnetic Spectrum. These can detect very high-energy gamma-rays from radio galaxies, gamma-ray bursts from stars, supernovae events, and Quasars.

The refractor works by two lenses first gathering and directing the light (right); Galileo's refractor only used one lens. The eyepiece on the left focuses the light for the eye (or camera, spectrometer. etc.)

The binocular primarily uses refractor-like qualities with prisms to upright and fold the image.

Refractor Example



CC BY-SA 3. 0 | Image courtesy of Wikimedia Author: Turnvater Jahn.

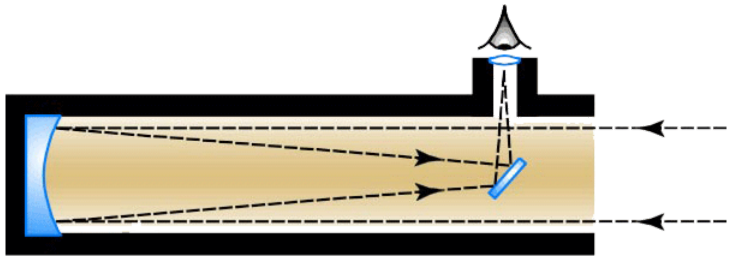
The Newtonian reflector works first by light entering the telescope at the right and traveling to a concave mirror. Graphics of a concave and convex mirror are shown as reference points.

The light is then reflected back to a smaller, second flat mirror and reflected out of the side of the telescope to the eyepiece and the eye.

The Newtonian reflector works first by light entering the telescope at the right and traveling to a concave mirror. Graphics of a concave and convex mirror are shown as reference points.

The light is then reflected back to a smaller, second flat mirror and reflected out of the side of the telescope to the eyepiece and the eye.

Graphic of Newtonian Reflector

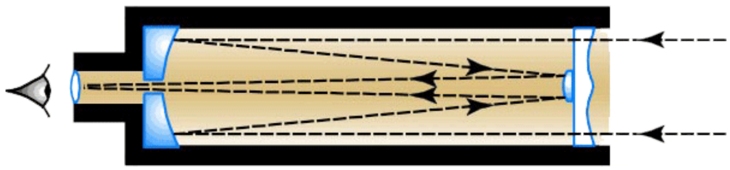


The Newtonian ReflectorImage courtesy Mike Reynolds, Ph. D. of Florida State College of Jacksonville.

Reflectors use a concave mirror as its primary objective to focus the incoming light (same optical focusing effect as a convex lens). The mirror is coated on the surface of the glass, called a First Surface Mirror; the coating is usually molecules-thick coating of Aluminum or Silver. Household mirrors are coated on the back of the glass, called a Second Surface Mirror.

Reflector telescope types differ based on what happens to the light after it is reflected from the primary.

Graphic of Newtonian Reflector



The Compound ReflectorImage courtesy Mike Reynolds, Ph. D. of Florida State College of Jacksonville.

Light enters the telescope at the right and travels to a concave mirror. The light is then reflected back to a smaller, second convex mirror. The light is then reflected back again out of the back of the telescope to the eyepiece and the eye.

Like the Reflector, uses a concave mirror as its primary objective to focus the incoming light. A corrector plate is placed at the front of the tube; it corrects for primary mirror’s shortcomings. Usually compound telescopes have a shorter tube than comparable reflectors; yet they are more expensive inch-per-inch than ian reflectors.

The Compound Reflector, or Schmidt-Cassegrai, is also Called Catadioptric Telescopes.

Refractor versus Reflector

Refractor Telescope

Positive

- *Negative*
  - *Positive*
    - *Negative*
      - *Note: The refractor’s positive features are the reflector’s negative features and vice-versa.*


Public Domain | Image courtesy of NASA.


CC BY 3. 0 | Image courtesy of Wikimedia Author: CSIRO.

5.6: Telescope Mounts

CC BY 2. 5 | Image courtesy of Wikimedia Author: Marie-Lan Nguyen.

Telescope Mount is the telescope's support structure. The two main types of telescope mounts are alt-azimuth and equatorial mounts. The **Alt-azimuth** mounts move in two directions: left to right, or up and down. The word "alt-azimuth" is a combination of altitude and azimuth. **Equatorial** mounts track the apparent motion of the stars by aligning one of its axes parallel to Earth's axis.

Go-To Telescope Mounts

Go-To's telescope mounts enable the telescope to find objects in the sky using a microprocessor, encoders and motors. A Global Positioning System (GPS) as a part of the Go-To system tells the mount and microprocessor where the telescope is located, what objects are visible, and where they are in the sky.

5.7: Images from the Telescope

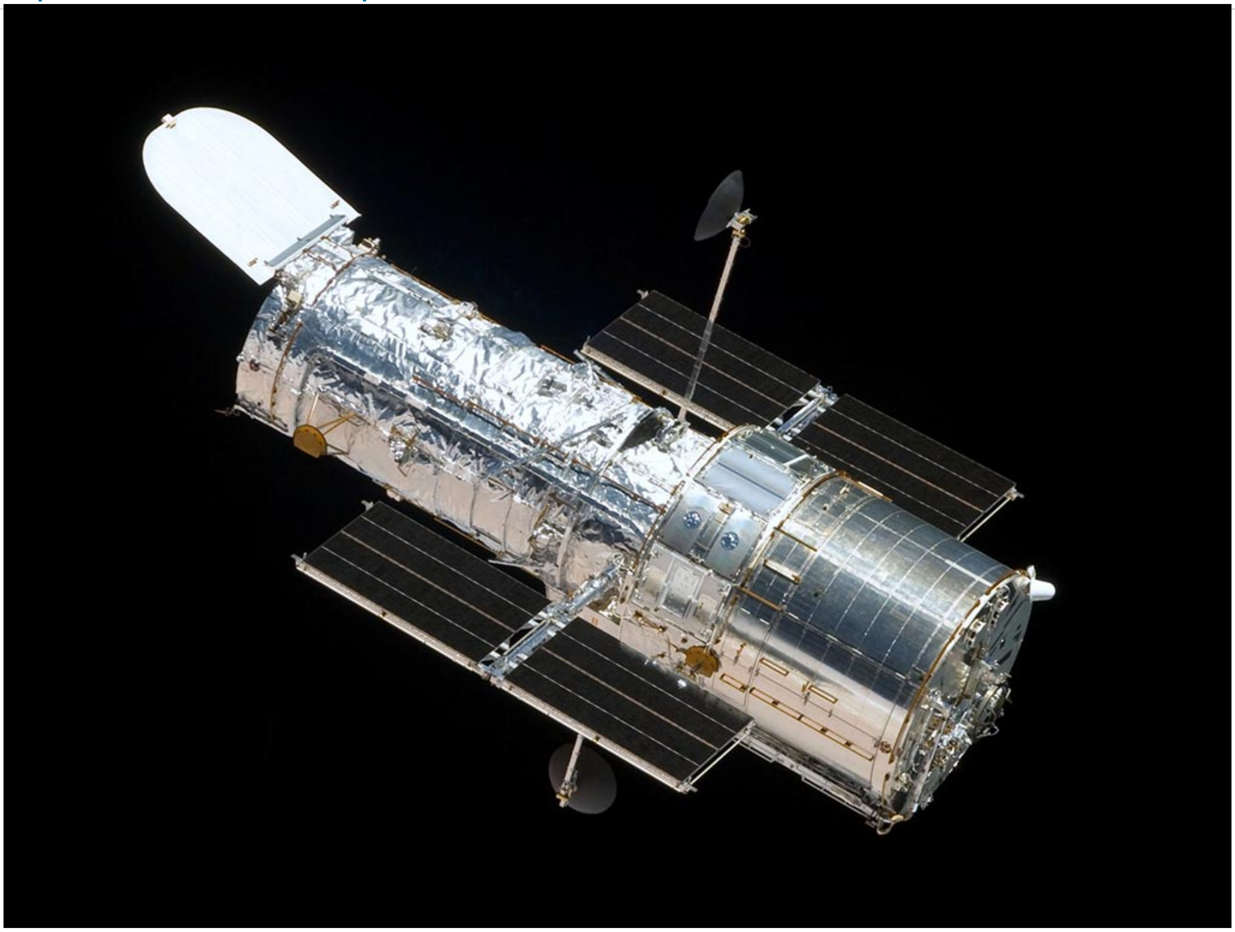
Once the image is focused and magnified by the telescope, the image can be viewed several ways. **Visually** the image can be viewed by the eye. The image can be captured by a film camera (mostly historical), digital camera or video, or Charge-Couple Device (CCD); the telescope becomes the camera lens; **Digital or Photographic astrophotography**.

CC BY 2. 0 | Image courtesy of Wikimedia Author: Roland Tanglao.

A spectroscope breaks the light of the incoming image into its component wavelengths for study, called **spectroscopy**. And a **photometer** measures the amount of incoming light.

CC BY 3. 0 | Image courtesy of Wikimedia Author: Reptonix.

5.8: Space-Based Telescopes



Public Domain | Image courtesy of NASA.

The Hubble Space Telescope

Space-based telescopes allow for observations outside the Earth's atmosphere and light pollution. Probably the most-famous of the space-based telescopes is the Hubble Space Telescope (HST). NASA plans to launch the Webb Space Telescope in 2018. There are a number of planetary and Solar System probes.

Orbiters go into orbit around a specific body to study that body over a period of time. And landers and rovers go to the body's surface, either stationary or as a rover. Scientists and engineers have also developed and launched telescopes that study objects at specific wavelengths; usually these study narrow wavelengths. These include space telescopes that study the Infrared (IR), Ultraviolet (UV), Gamma, and Cosmic rays.

5.9: Light Pollution

Public Domain | Image courtesy of Pixabay. com.

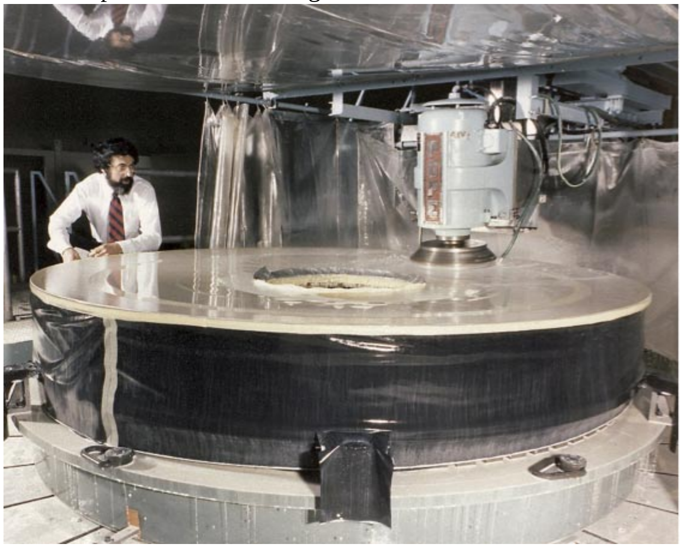
One of the biggest challenges to Earth-based telescopes is that of light pollution. Lighting interferes with the dim objects astronomers need to study. Consider how many people have actually seen our Milky Way arching across the sky. *Have you?*

Light pollution has other serious side effects. Environmentally it disrupts natural day and night patterns for many plants and animals. There are severe beach restrictions in regard to lighting in many areas due to nesting sea turtles. Another consequence of light pollution is the cost.

A number of solutions are possible. First, good night lighting is shielded; that is, directed only towards the ground. Why have a streetlight that shines in one's eyes? Second is the type of bulb used in night lighting. It has been shown that sodium vapor lamps more-efficiently light an area; both cost- and illumination-wise. As Light-emitting diode (LED) lamps are developed, better lighting solutions will follow.

5.10: Space-based Telescope

The idea of a space-based telescope can be traced back to the German rocket scientist Hermann Oberth, who noted in his 1923 work *Die Rakete zu den Planetenräumen (The Rocket into Planetary Space)* , how a telescope could be propelled into Earth orbit by a rocket. It was astronomer Lyman Spitzer, whose 1946 paper *Astronomical advantages of an extraterrestrial observatory* , became the basis for the project. Through the 1960s, reports and recommendations were prepared to support a Large Space Telescope, as the project was initially called. Congress approved funding for the Telescope in 1978. The Hubble Space Telescope (HST) as it was renamed to honor astronomer Edwin Hubble, was launched April 24, 1990, after numerous design and construction delays, along with flight delay due to the space shuttle Challenger accident.



Grinding of the Hubble Space Telescope Mirror, 1979Public Domain | Image courtesy of NASA.

5.11: Hubble Space Telescope

Within weeks of launch, the HST showed serious problems with its primary mirror, which affected the precise focus of the telescope. A fix was designed and astronauts about Space Shuttle Endeavor in December 1993 captured and repaired the near-sighted telescope. The repair was somewhat simple though—to equip the HST with glasses. The fix worked and images returned from the Hubble Space Telescope have amazed and intrigued both astronomers and the general public ever since.

Release of the Hubble Space Telescope from Space Shuttle Endeavour, 1990Public Domain | Image courtesy of NASA.

Blast-off of the space shuttle Endeavour and the Hubble Space Telescope, April 24, 1990Public Domain | Image courtesy of NASA.

CHAPTER OVERVIEW

6: Solar System Formation and Other Stellar Systems

6.1: Module Introduction

This module introduces you to our solar system and how astronomers believe it formed, based on what we see around us and around other star systems in formation. We will also look at the discovery of other planets around other stars–called *exoplanets*.

Objectives

Upon completion of this module, the student will be able to

- Explain the nebular theory of the solar system formation
- Describe the evidence which supports the nebular theory
- List the IAU's criteria to be a planet, and how this changed the status of Pluto
- Explain what an exoplanet is, as well as the history of their discoveries
- List examples of unusual stellar systems
- Explain brown dwarfs and how they differ from stars and planets
- Discuss stellar system habitable zones and what that has to do with life

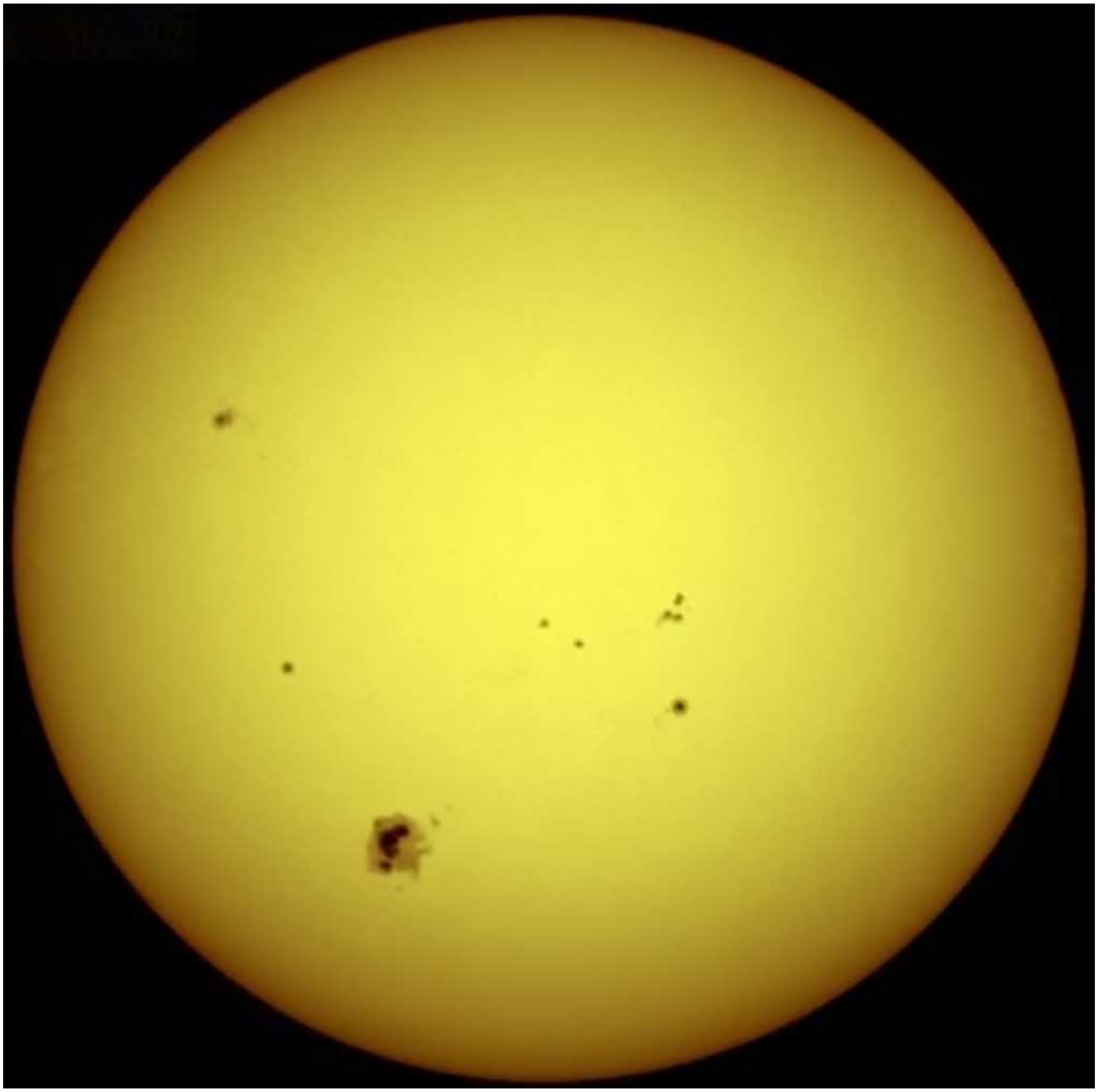
6.2: Our Solar System

Astronomers believe the solar system is about **4. 6 billion years old**. We base that idea through the study of meteorites and "dating" of these objects and observations of our Sun, as well as similar stars.

The Solar System is made up of one central star, eight (or nine, or ten…) known planets, satellites orbiting the planets, and miscellaneous debris; minor bodies; asteroids, meteoroids, comets, and dust, and what is known as the **Kuiper Belt Objects** and the **Oort cloud**.

Sun

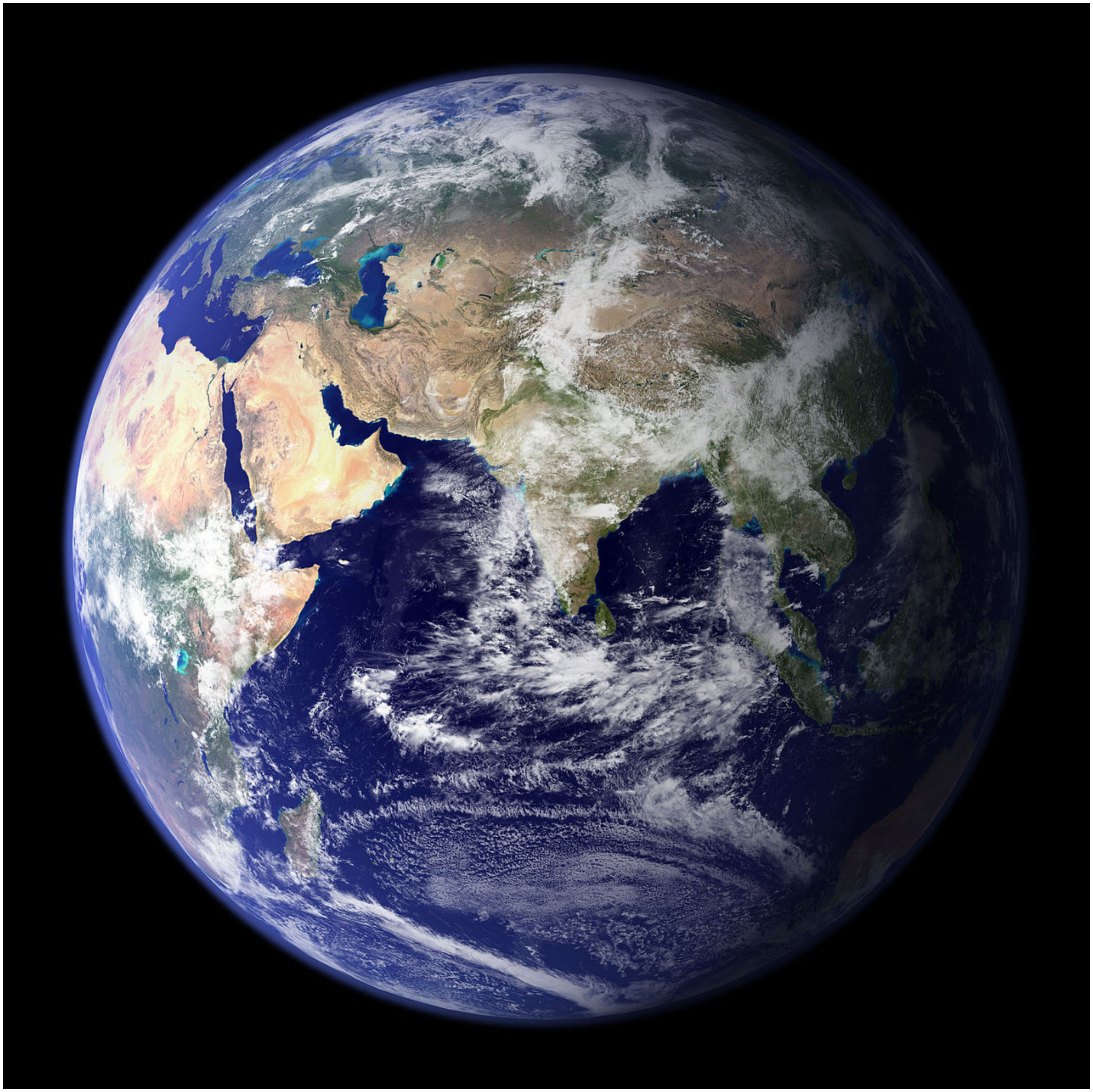
One Central Star—Sun



Public Domain | Image courtesy of NASA / ESA.

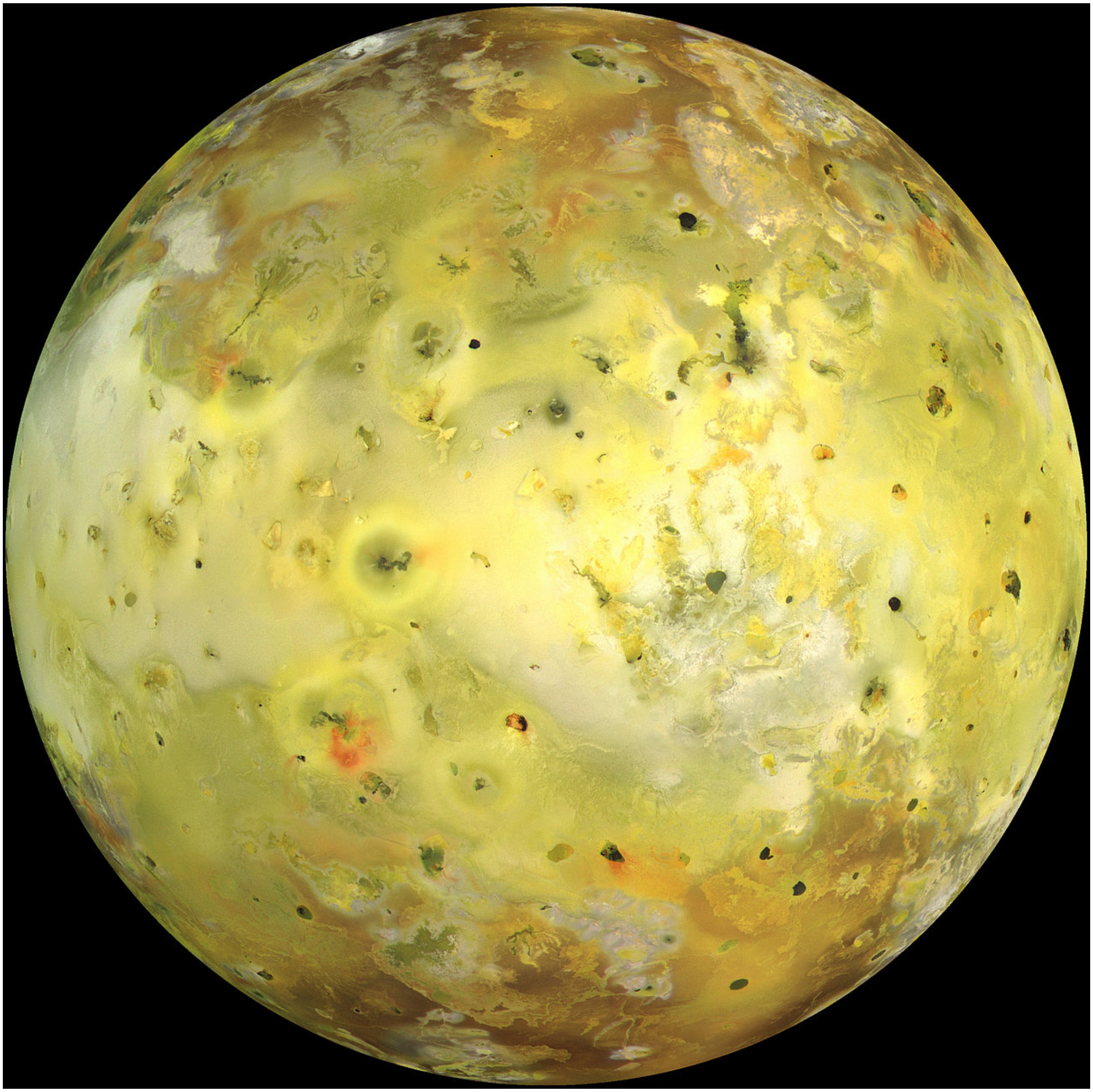
Planets

Rocky Planet Earth– Eight (or nine, or ten…) known Planets



Public Domain | Image courtesy of NASA / ESA.

Satellites
Satellite Io (Jupiter): Orbits Planets



Public Domain | Image courtesy of NASA / ESA.

Minor Bodies
Asteroid-951 Gaspra

Public Domain | Image courtesy of NASA / ESA.
Comet Hale-Bopp

CC BY-SA 3. 0 | Image courtesy of Wikimedia Authors: E. Kolmhofer, H. Raab; Johannes-Kepler-Observatory, Linz, Austria.

6.3: The Nebular Theory

So…how did the solar system form and end up with all these different types of objects? Currently the best theory is the **Nebular Theory**. This states that the solar system developed out of an interstellar cloud of dust and gas, called a **nebula**. This theory best accounts for the objects we currently find in the Solar System and the distribution of these objects. The Nebular Theory would have started with a cloud of gas and dust, most likely left over from a previous supernova. The nebula started to collapse and condense; this collapsing process continued for some time. The Sun-to-be collected most of the mass in the nebula's center, forming a **Protostar**.

A protostar is an object in which no nuclear fusion has occurred, unlike a star that is undergoing nuclear fusion. A protostar becomes a star when nuclear fusion begins. Most likely the next step was that the nebula flattened into a disk called the **Protoplanetary Disk** ; planets eventually formed from and in this disk.

Three processes occurred with the nebular collapse:

1. The orderly motions of the solar system today are a direct result of the solar system's beginnings in a spinning, flattened cloud of gas and dust.

6.4: What is a Planet?

The International Astronomical Union (IAU) ruled in August 2006 that to be a planet an object must meet three criteria:

1. It must have enough mass and gravity to gather itself into a sphere
2. It must orbit the sun
3. It must reign supreme in its own orbit, having “cleared the neighborhood” of other competing bodies

Is there a controversy?

Yes. This ruling demoted Pluto from a planet to a dwarf planet. According to the new rule, Pluto has not ‘reigned supreme in its own orbit, ‘clearing the neighborhood’ of other competing bodies.

The International Astronomical Union (IAU) has sanction over astronomical definitions and rules. Most of these are minor decisions, like adding leap seconds to a year. The decision – stating what a planet is – is a major decision. The *Pluto Planet* debate had been brewing for several years.

Yet this was not the IAU’s first vote on the subject. One week prior to the “final” planet definition vote, the IAU’s Planet Definition Committee endorsed the following:

1. It must have enough mass and gravity to gather itself into a sphere
2. It must orbit the sun

What were the implications of this *first definition?*

Pluto was still a planet, so was its moon **Charon**, the asteroid **Ceres**, and the recently discovered Eris. For about a week, the solar system would have had twelve planets instead of nine. The IAU rejected this definition and the now-infamous definition accepted.

What are the implications of the *new planet definition?*

There are now **eight planets** in our solar system, along with a new classification of objects called **Dwarf Planets**. Currently there are three Dwarf Planets: Pluto, Ceres (previously classified as an asteroid), and Eris. A subclass of Dwarf planets is called the **Plutoids** ; these ice dwarfs are trans-Neptunian (past the planet Neptune) planets that orbit the Sun and are large enough to be somewhat spherical in shape. It’s important to **note that these rulings only apply to our solar system, not to other stellar systems with planets**.

This decision is still hotly contested some ten years later. With the arrival of the **New Horizons** spacecraft at Pluto and its five known moons in 2015, astronomers will take a closer look at this icy world.

Public Domain | Image courtesy of NASA / ESA.

6.5: The Nebular Theory- Other Important Evidence

The types of objects found within the solar system provide significant clues and evidence to support the Nebular Theory. First, the types of Planets and their distributions: with the Rocky planets being close to the Sun, and Gas Giants planets being far from the Sun, Dwarf Planets or Plutoids, a class of Dwarf planets, are found far from the Sun. Comets, asteroids, and meteorites recovered on Earth also provide a number of clues and evidence of Nebular-type development. And the motions of most solar system objects orbit and rotate in an organized fashion. There are a few exceptions to what we would expect to find. For example, we would not expect to find a planet with a large moon, specifically Earth and the Moon. Uranus is tilted on its side and ‘rolls’ around the Sun. And Venus rotates in retrograde (backwards) as it orbits the Sun, contrary to the other planets in the solar system.

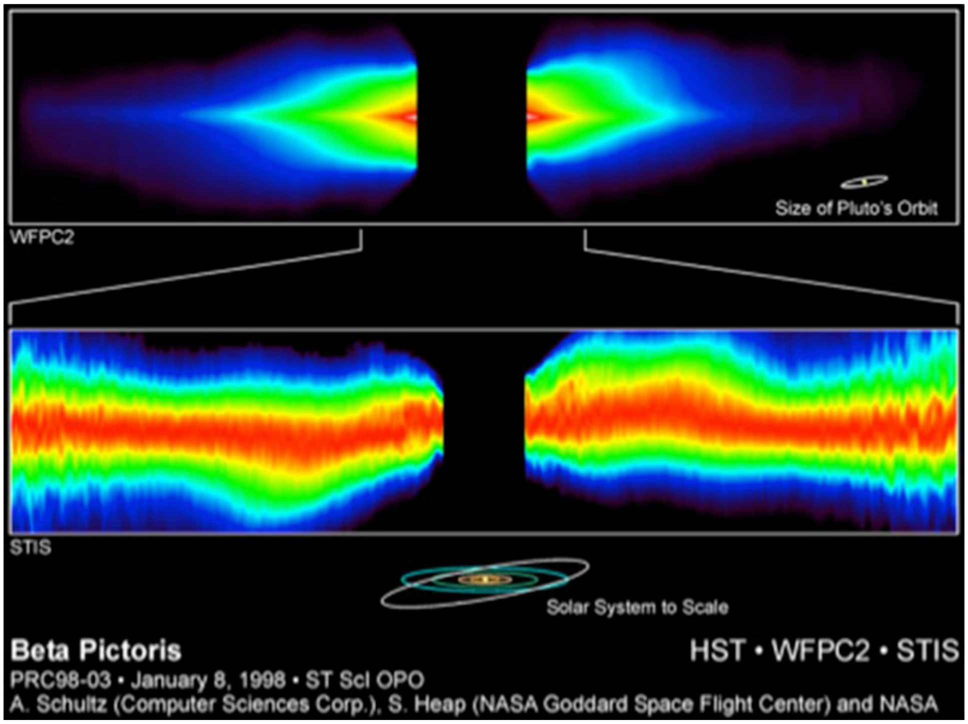
6.6: The Nebular Theory- Proplyds

What Evidence do we have of a Nebular Theory-type development?

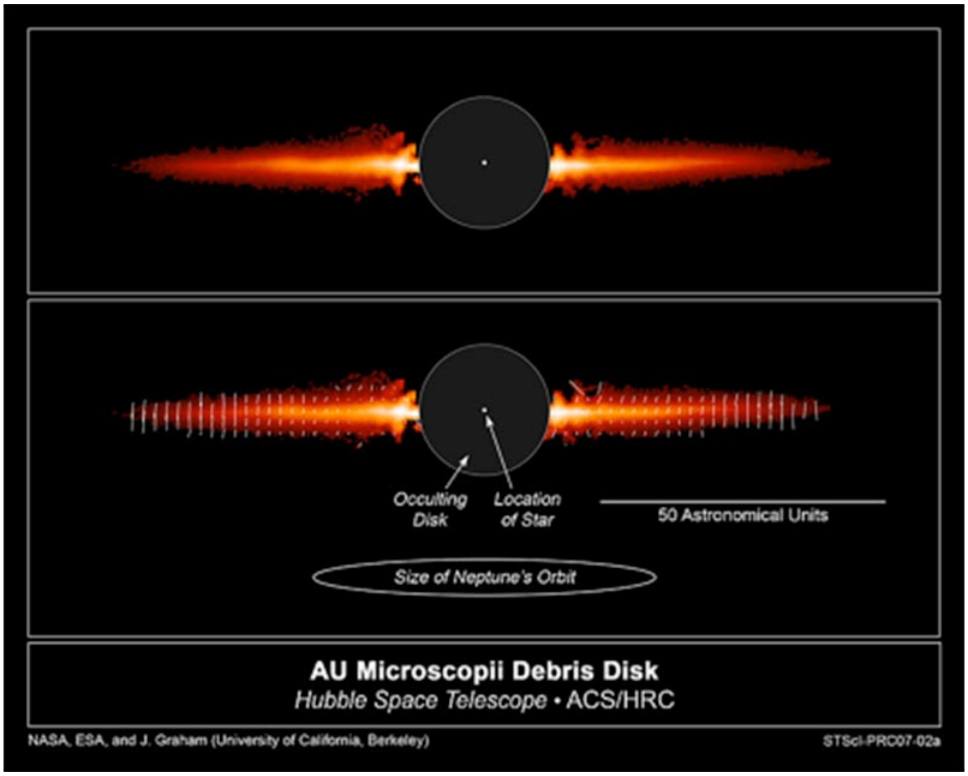
We have observed discs of gas and dust around other stars. We can also see evidence of stars and planets forming in clouds of gas and dust; young planet systems in the making are called Proplyds. Other disk-forming evidence found throughout the Universe includes spiral galaxies. Computer modeling is used to model formation of stellar systems, like our solar system.

A Hubble Space Telescope view of a small portion of the Orion Nebula, captured by the Wide Field and Planetary Camera 2, reveals five young stars. Four of the stars are surrounded by gas and dust trapped as the stars formed, but were left in orbit about the star. These are possibly protoplanetary disks, or proplyds, that might evolve on to agglomerate planets. The proplyds which are closest to the hottest stars of the parent star cluster are seen as bright objects, while the object farthest from the hottest stars is seen as a dark object. The field of view is only 0. 14 light-years across.

NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA / ESA.

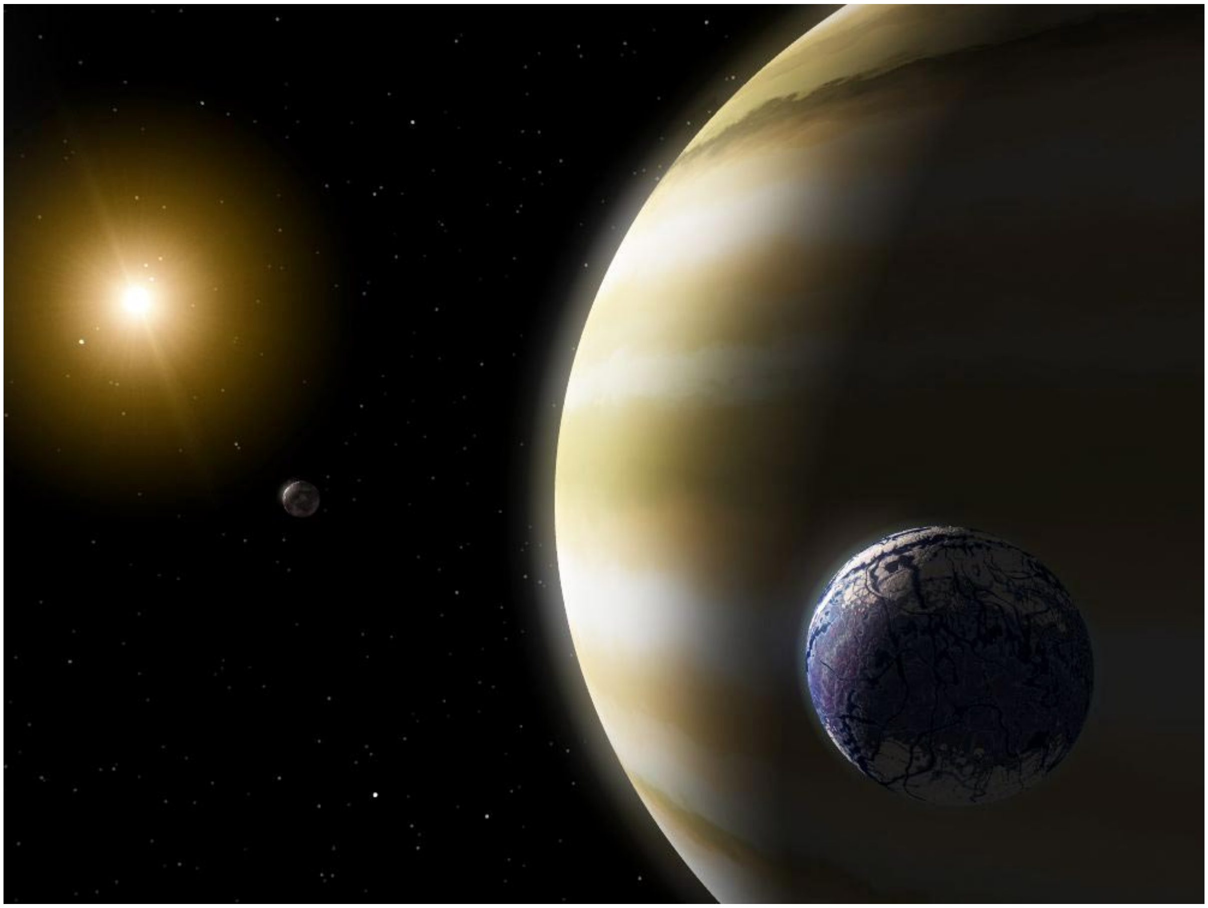


NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA / ESA.



NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA / ESA.

6.7: Systems and Extrasolar Planets



Public Domain | Image courtesy of NASA.

Are their other planets orbiting other stars?

Yes. We have found evidence of **Extrasolar Planets** (or **Extra-Solar** … *2 words*). These are planets orbiting other stars outside our solar system, thus the term “Extrasolar. ” Extrasolar planets are also called **Exoplanets**, the more-commonly used term.

Instead of calling these solar systems, they are called **Stellar Systems**. Why? Because the solar system is the proper name for our sun, its planets, satellites, asteroids, comets, debris, etc.

6.8: The Discovery of Extrasolar Planets

Dr. Geoff Marcy, UCSF-UCB (University of California San Francisco – University of California Berkeley) led the research efforts in the late 1980s to develop extrasolar planet search techniques. The main question was: What do you look for when trying to see a planet around another star?

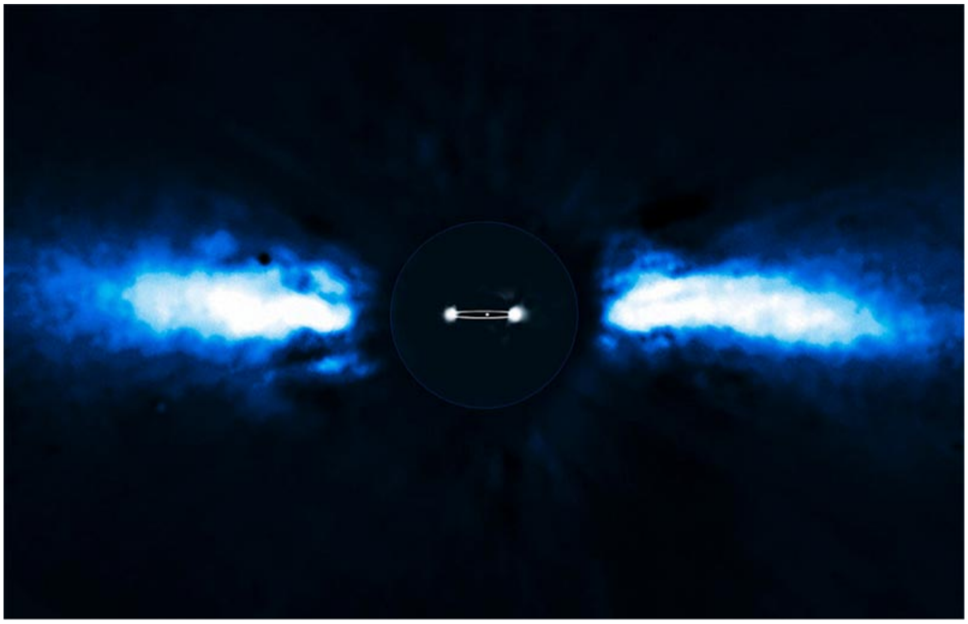


Image courtesy of ESO/A. -M. Lagrange.
The image above shows an exoplanet caught on the move. Beta Pictoris is blocked from view because it is too bright to see it *and* the planet *Beta Pictoris b* at the same time.

Several techniques have been developed:

1. Technology has allowed both amateur and professional astronomers the ability to make such observations from here on Earth. And eventually technology should allow astronomers to directly view exoplanets.

The Discovery of Extrasolar Planets

As of fall 2014, astronomers have found **1,822** planets in 1,137 planetary systems and 467 multiple planet systems. Seven planets have been discovered around the star HD10180, the largest known system outside our solar system. And currently there are thousands of candidate exoplanets.

So what are these exoplanets like?

Most are *much* bigger than Earth, more like Jupiter and even much larger than Jupiter. Many are extremely hot; they orbit quite close to their star or stars. And many of these will "lose" to their parent stars and crash into their star as the star's gravity pulls them in.

6.9: The Kepler Mission

The image above shows a size comparison of the exoplanets Kepler-20e and Kepler 20f with Venus and Earth. Image courtesy of NASA/Ames/JPL-Caltech.

The **Kepler Mission** is NASA's first mission capable of finding Earth-size and smaller planets around other stars using an orbiting space telescope. The Kepler Space Telescope has been monitoring 100,000 stars similar to our Sun since its launch in March 2009. The Kepler Space Telescope, named for astronomer Johannes Kepler, looks for planets orbiting stars by looking for changes in a star's brightness.

Kepler's primary mission is to find Earth-size exoplanets. Detecting the massive gas giant exoplanets – called **Super Jupiters** – has been relatively easy with other methods. So the Kepler Space Telescope watches transits and measures the reduction in the star's light due to the planet transiting in front of its star.

This image shows a size comparison of the exoplanets Kepler-20e and Kepler 20f with Venus and Earth.

6.10: What We Have Learned about Stellar Systems and Extrasolar Planets?

How rare are these stellar systems? We do not know yet… but many stellar systems are not made up of just one star. **Binary Stars** are systems in which physically associated star systems are made up of two stars. It appears that about half of all stars are binary star systems. And **Multiple Star Systems** have more than two stars. We have found and observed numerous multiple star systems. One such system we see in Scorpius – called **β Scorpii** – has at least **7 stars**. Binary and multiple star systems present challenges for intelligent life.

6.11: The Circumstellar Habitable Zone

The area around a star within which a planet or planets with sufficient mass and atmospheric pressure can support liquid water at the planet's surface is called the **circumstellar habitable zone** ; also called the **Goldilocks Zone**. First theorized in 1953, numerous exoplanets have been discovered within this Zone. Not all biologists and astronomers agree that a planet must exist in the circumstellar habitable zone to support life or even intelligent life; many point to **extremophiles** found on Earth; organisms which flourish in extreme Earth conditions that would be harmful to most life.

It appears that one in five stars have an Earth-sized planet in a circumstellar habitable zone. There could be as many as 40 billion circumstellar habitable zone planets in the Milky Way Galaxy.

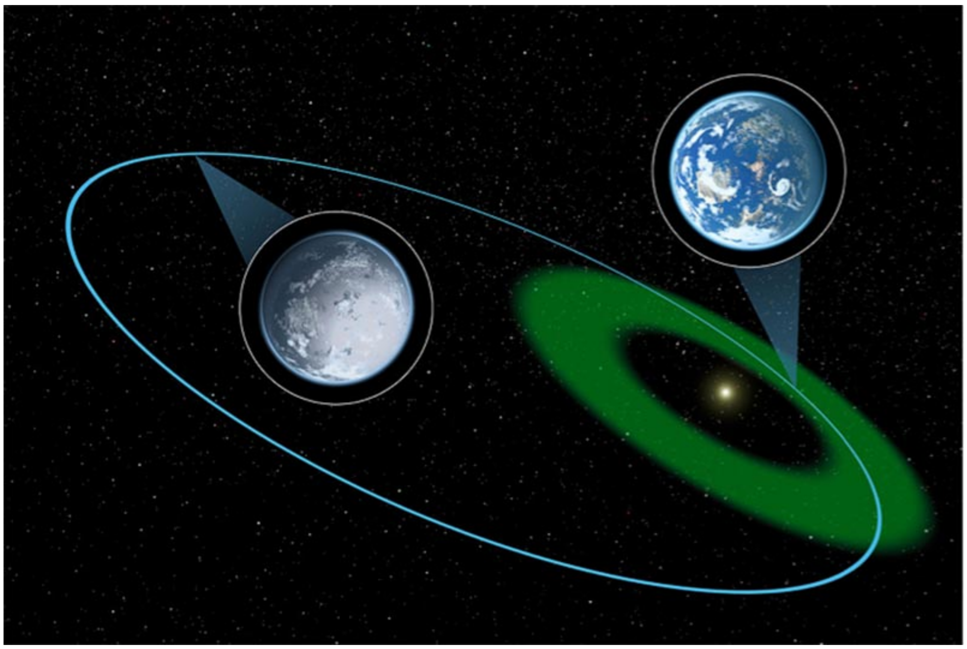


Image courtesy of NASA/JPL-CaltechThe image above shows an Eccentric Habitable Zone – a planet with a very-elliptical orbit that goes from a circumstellar habitable zone on the right to what would be considered uninhabitable during most of its orbit.

6.12: Some Interesting Exoplanets

TrES-4 was discovered when looking for transiting planets. It is about 70 percent bigger than Jupiter but less massive. TrES-4 has the density of approximately 0. 2 grams per cubic centimeter, or that of balsa wood. The **Gliese 581 System** is a red dwarf star with a mass about 1/3 that of the Sun. It is located 20. 4 light years from Earth and is among the 100 closest stars to Earth. Gliese 581 has at least four planets:

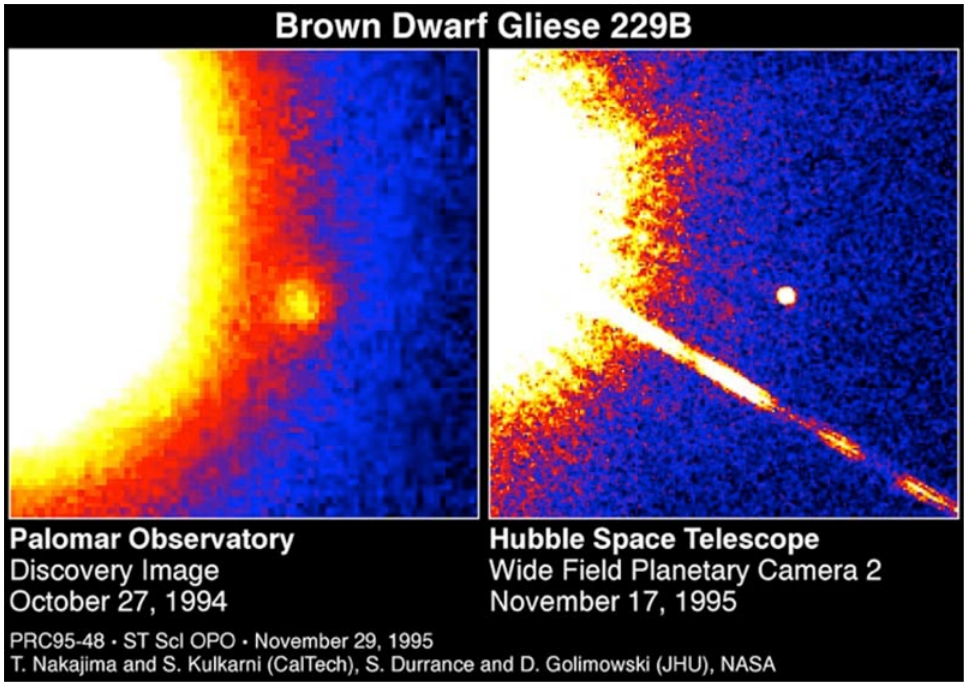
- **HD80606b** is a strange planet about four times the mass of Jupiter. It comes so close to its star, at its perihelion point HD80606b would have a surface temperature of 1,200oC.

  Then there is the strange planet, **Wasp-12b**. It takes this planet 1. 1 earth days to go around its star one time; in other words, you would celebrate your birthday every 26. 4 hours. Wasp-12b's surface temperature is estimated to be 1,500oC, and it is slowly being *eaten* by its star.

  ## Stellar System Stars and Life

  Many biologists and astronomers believe that you have to have the right type of star, as well as the right type of planet, and the right distance from its star for intelligent life.

6.13: Extrasolar Planets



These images show Brown Dwarf Gliese 229B, orbiting its star Gliese 229. Gliese 229B is in the white circle on each image. The left image was the discovery image, taken with the Palomar Telescope in California. The right image was taken with the Hubble Space Telescope. Public Domain | Image courtesy of NASA.

The extrasolar planets tell us a lot about our own solar system's formation and development. Yet, there are some significant issues at this point. First, there appears to be numerous exoplanets much larger than Jupiter. Why is this so? And many of these extrasolar planets orbit much closer to their stars than our Gas Giants, which are much further from the Sun. The thinking here is that these Gas Giants "migrated" closer to their stars during the development of their stellar systems.

Brown Dwarfs are sub-stellar objects with a mass below that necessary to maintain hydrogen nuclear fusion reactions in their cores, as do stars. Sizes of these brown dwarfs – up to 80 Jupiter masses – range from very large gas giant planets to just below the mass necessary to "turn on" as a star. Are brown dwarfs' planets? Stars? Failed stars? Two extrasolar planets have been discovered orbiting brown dwarfs.

Consider this…

Giordano Bruno (1548-1600) was an Italian Dominican Friar, poet, philosopher, astronomer, and mathematician. His theories about the Universe were considered extreme for his day, eventually leading to his being burned at the stake. Bruno thought the stars were distant suns being orbited by their own planets. He also thought these planets might even harbor life of its own. Bruno also believed the Universe was infinite.

There are countless suns and countless earths all rotating around their suns…

— Friar Giordano Bruno – (1584)

CHAPTER OVERVIEW

7: The Rocky Planets

7.1: Module Introduction

"How inappropriate to call this planet Earth when clearly it is Ocean…"

Arthur C. Clark, 1917-2008

This module presents the Rocky Planets in our solar system: Mercury, Venus, Earth, and Mars, and their moons. We will examine characteristics of each Rocky Planet, both similar and dissimilar characteristics.

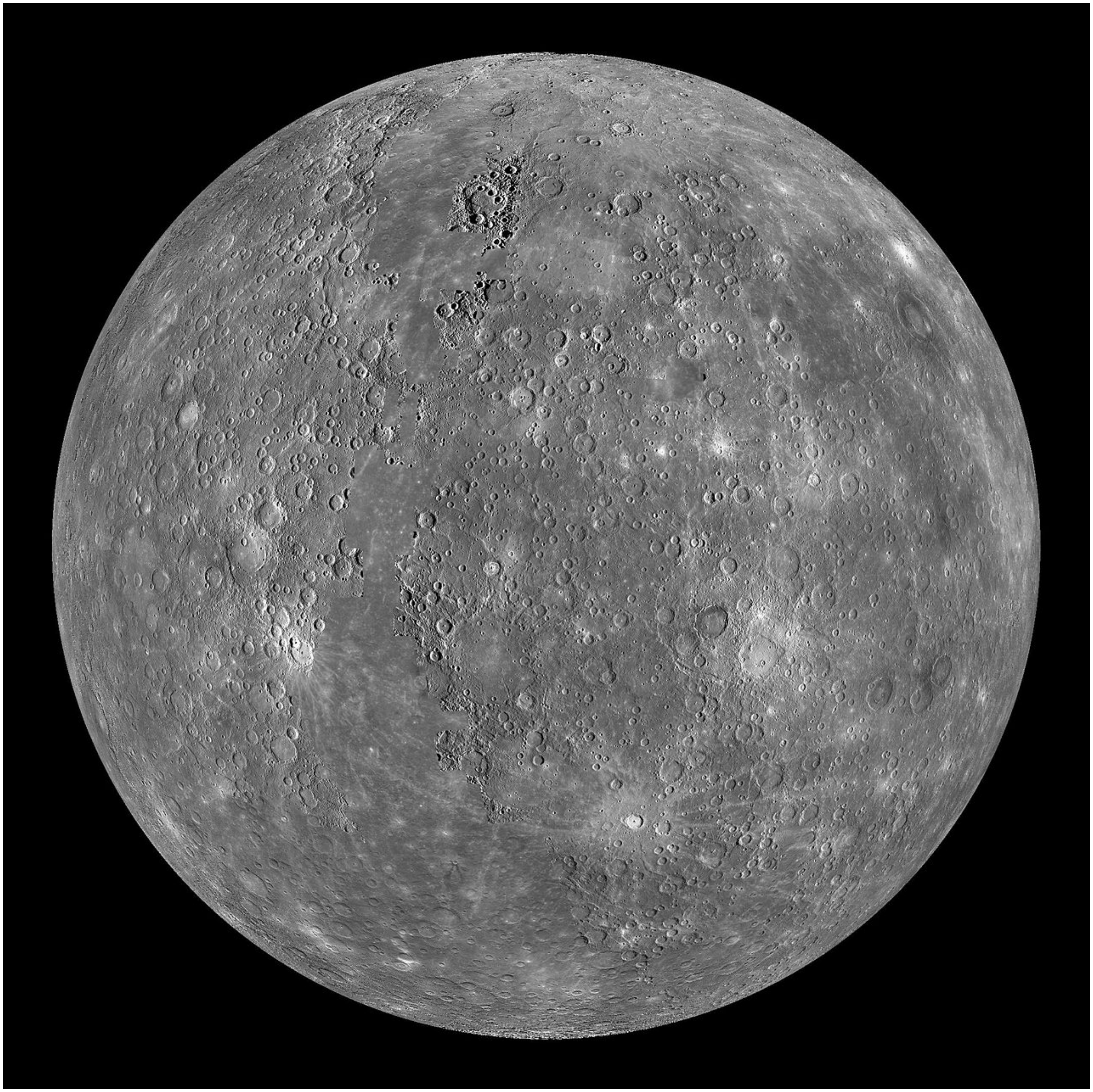
Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

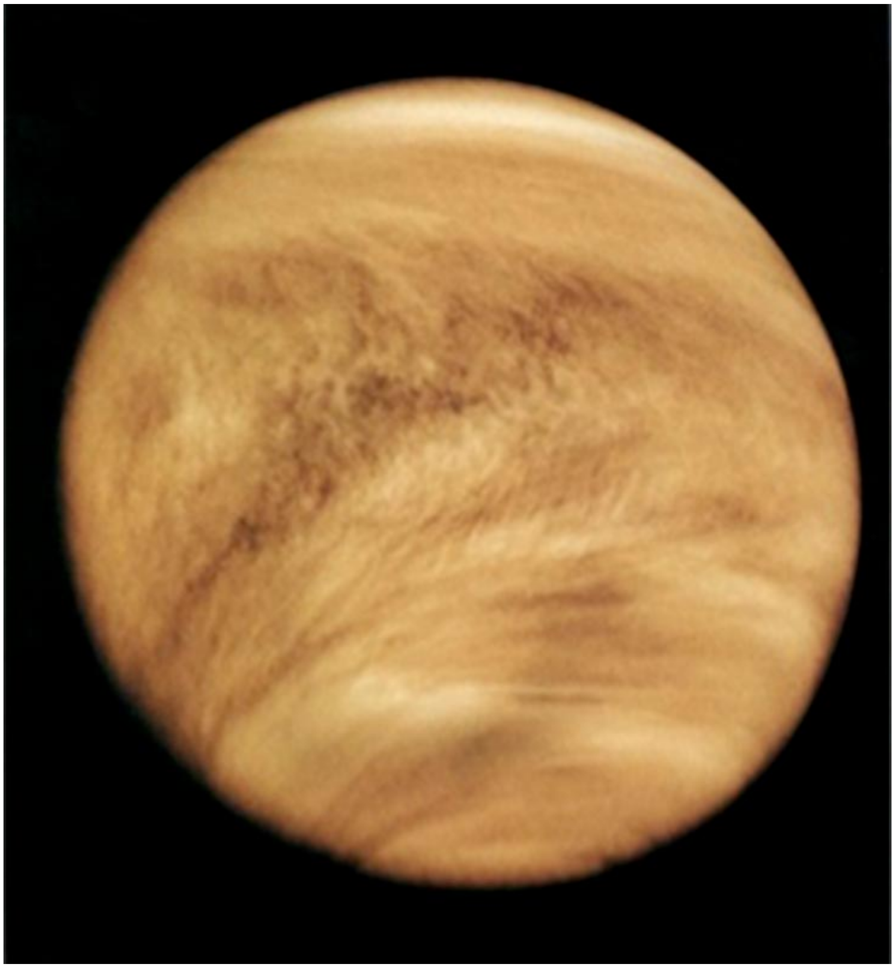
- Identify the characteristics of Rocky Planets
- Define craters and cratering
- Identify the primary characteristics of each rocky planet
- Identify the similar characteristics of each rocky planet
- Describe a circumstellar habitable zone
- Discuss the characteristics of the Moon, Deimos, and Phobos

7.2: What do you think?

Imagine that you are approaching each of our Solar System's Rocky Planets in a spaceship for the first time. Looking at photos of each of the rocky planets, what similarities do you see at first glance?



MercuryPublic Domain | Image courtesy of NASA / JPL-CALECH.


VenusPublic Domain | Image courtesy of NASA / JPL-CALECH.

EarthPublic Domain | Image courtesy of NASA / ESA.

MarsPublic Domain | Image courtesy of NASA / JPL-Caltech.

7.3: Comparing Planets

We will look at our Solar System and its worlds from a comparison perspective, called **Comparative Planetology**, rather than focus on a lot of numbers and data. To compare the planets, they will be grouped into two major types: the **Rocky** or **Terrestrial (Earth-Like) planets**, and the **Gas Giants** or **Jovian (Jupiter-like) planets**. Recall, the focus of this module will be on the Rocky Planets. The next module will focus on the Gas Giants.

The table, **Rocky Planets Vs. Gas Giant Planets**, provides a broad snapshot of the differences between the Rocky Planets and the Gas Giant Planets.

Rocky Planets Vs. Gas Giant Planets

Rocky Planets: Mercury-Venus-Earth-Mars

Characteristics:

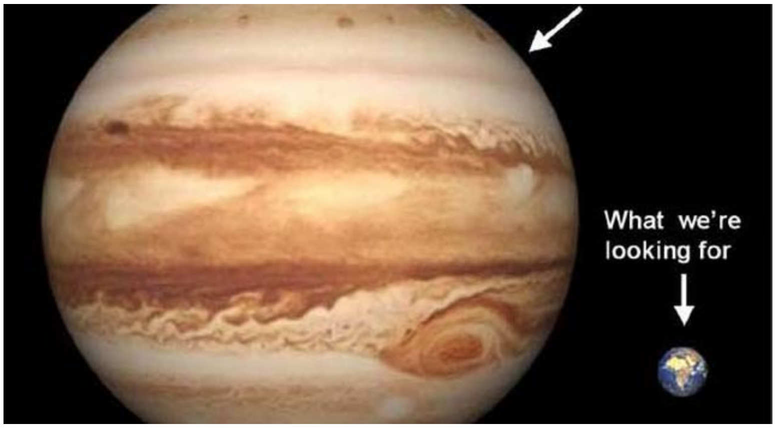
- Distance from the Sun — Close
- Revolution Length — Short
- Surface Type — Solid surface
- Diameter — Small
- Craters — Many
- Water — All except Venus
- Rings — None
- Satellites — Few or none

Gas Giant Planets: Jupiter-Saturn-Uranus-Neptune

Characteristics:

- Distance from the Sun — Farther out
- Revolution Length — Long
- Surface Type — Gas; Probably no surface or very small icy core
- Diameter — Large
- Craters — None (gas)
- Water — Yes; in the atmosphere (gas)
- Rings — Yes; from one to multiple rings
- Satellites — Many

7.4: Rocky Planets



Public Domain | Image courtesy of NASA.

Rocky Planets are relatively small when compared to the Gas Giants or many of the recently discovered Exoplanets. Rocky Planets have solid surfaces, which exhibit impacts through multiple craters. There are no rings, few or no moons, and evidence of past or current tectonic, volcanic activity. Rocky planets are sometimes referred to as the **Terrestrial Planets** (Earth-like).

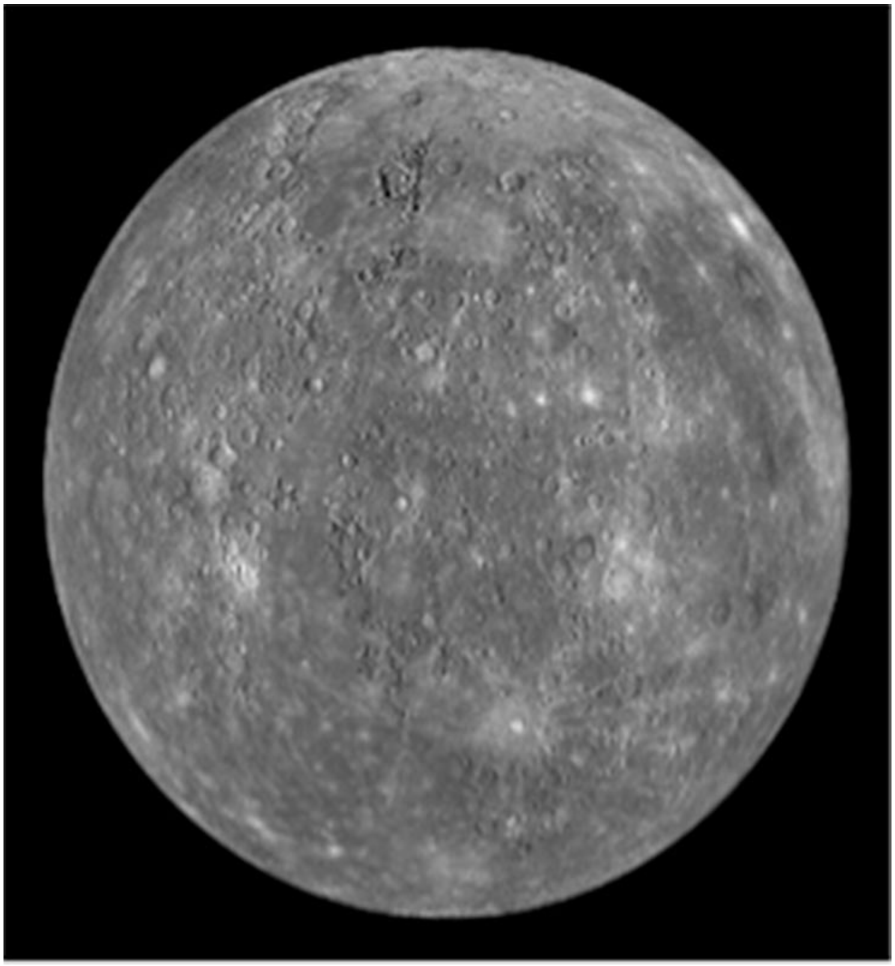
7.5: Craters

One characteristic we will find throughout the Solar System is bodies that have solid surfaces and exhibit impact or craters. **Craters** are depressions and scars on a Solar System body's surface. The word crater comes from the Greek for bowl; these are bowl-like features. Most cratering is due to impacts by space debris, called Minor Bodies. This includes asteroids, comets, and smaller debris. Planets and satellites can also have craters due to volcanic activity. Crater sizes can span from microscopic to hundreds of miles across. Occasionally an impact not only produces a crater, it produces a ray. **Rays** are impact "splash;" imagine dropping a rock into flour.

Image courtesy of Mike Reynolds, Ph. D. of Florida State at Jacksonville.

7.6: Planet Mercury

Mercury is the smallest and closest planet to the Sun. It is actually smaller than two of the Solar System's moons—Ganymede (Jupiter) and Titan (Saturn). Because Mercury has no real atmosphere, it has extreme high and low temperatures. Examining the planet, Mercury looks a lot like the Moon.

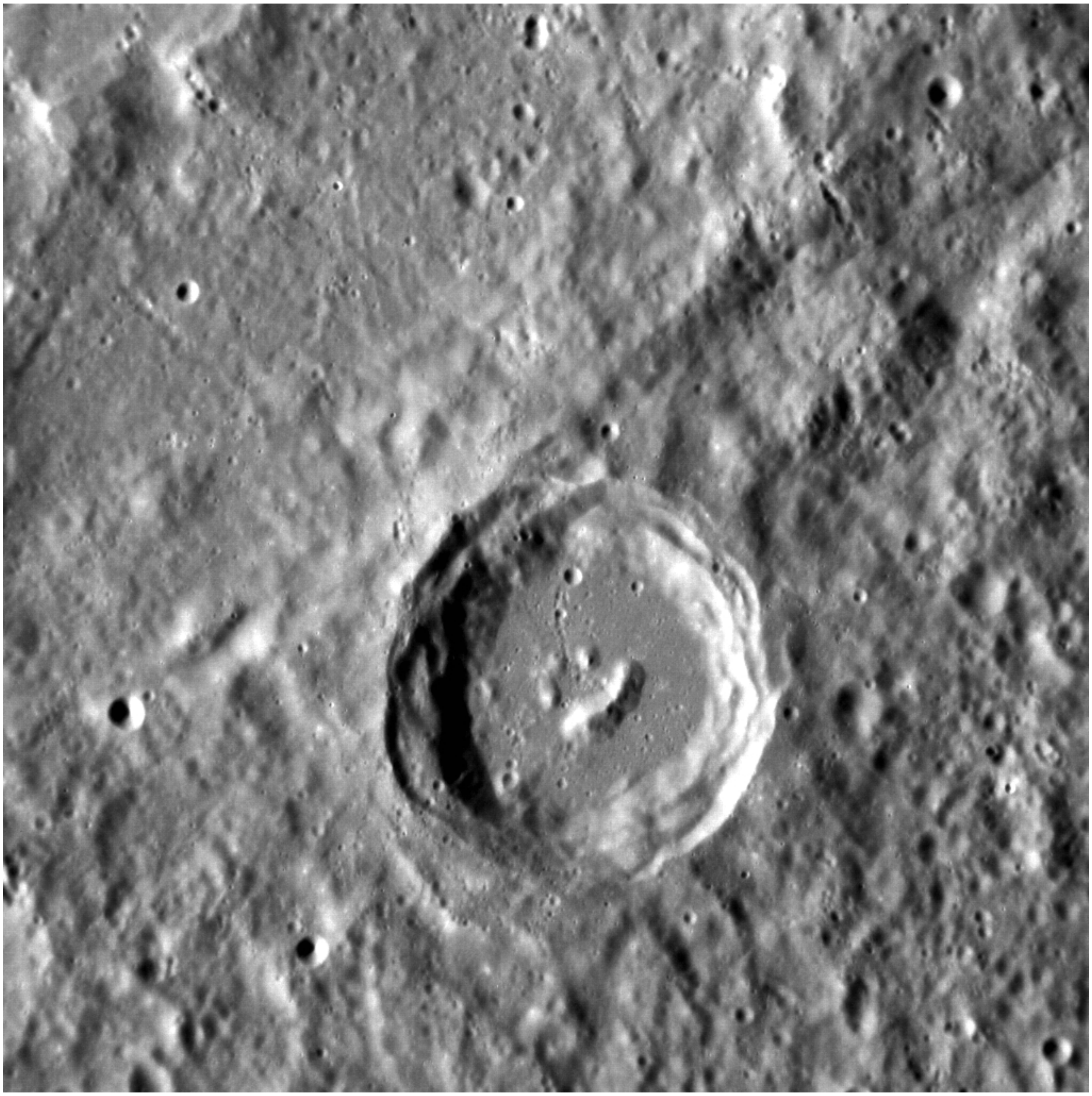


MercuryPublic Domain | Image courtesy of NASA / JPL-CALECH.

Planet Mercury at a Glance

Characteristic – Current State

- Impact Craters – Yes
- Tectonic Craters – Yes; not active
- Volcanoes – Yes; not active
- Atmosphere – No real atmosphere
- Water – Yes; water and ice in craters at the poles
- Erosion – No
- Dunes – No
- Polar Caps – No
- Satellites – No
- Life – Unknown



Craters on MercurynCC BY 2. 0 | Image courtesy of NASA Goddard Space Flight Center from Greenbelt, MD, USA.

7.7: Planet Venus

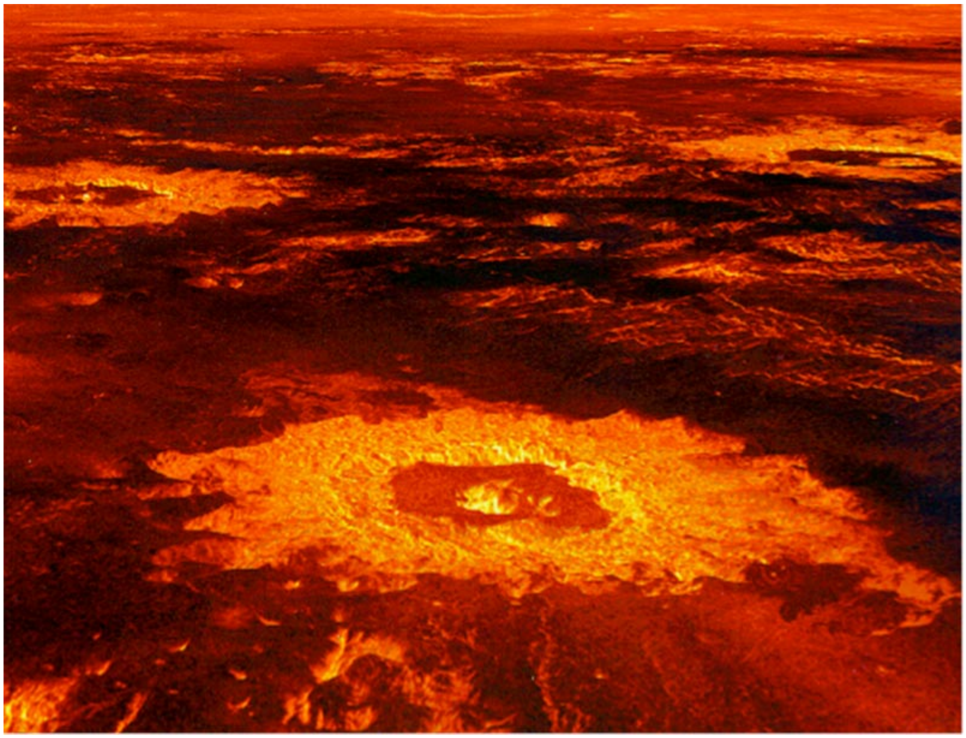
Venus is the second planet from the Sun. It is often called Earth's twin because they are similar in size and both have cloudy atmospheres. It is also the closest planet Earth approaches, and besides the Moon, usually the second brightest object in the night sky. Venus is often called the Morning Star or the Evening Star because it is very bright when seen in the morning or evening sky.

Planet Venus at a Glance

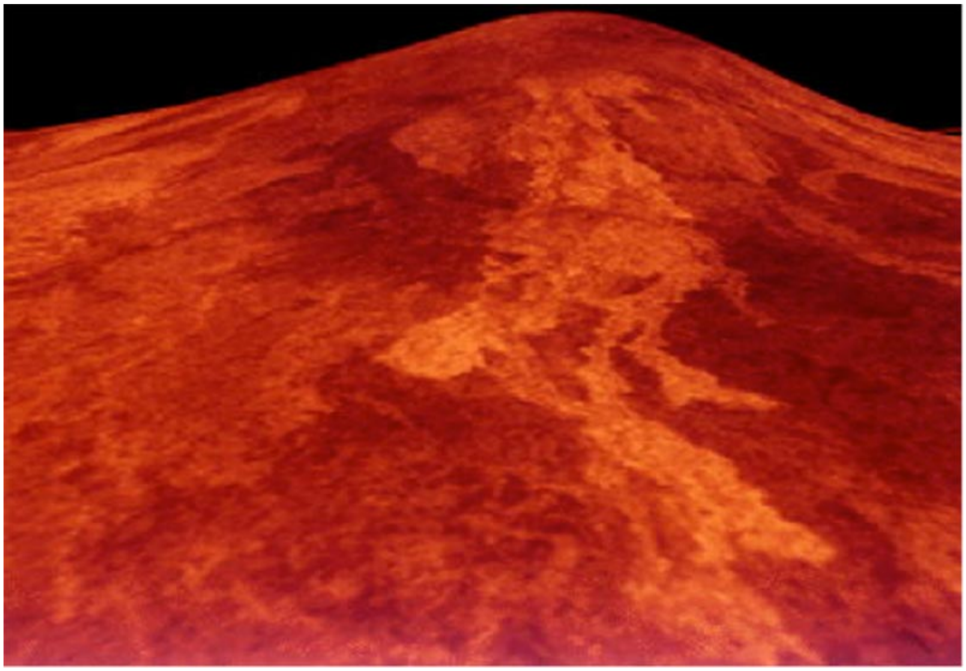
Characteristic — Current State

- Impact Craters – Yes
- Tectonic Craters – Yes
- Volcanoes – Yes; over 1,600 volcanoes – most on one body in the Solar System
- Atmosphere – Carbon Dioxide (CO_2), Sulfuric Acid (H_2SO_4), High Pressure, Clouds, Odd Polar Vortex
- Water – No
- Erosion – Yes
- Dunes – Yes
- Polar Caps – No
- Satellites – No
- Life – Unknown

VenusPublic Domain | Image courtesy of NASA.

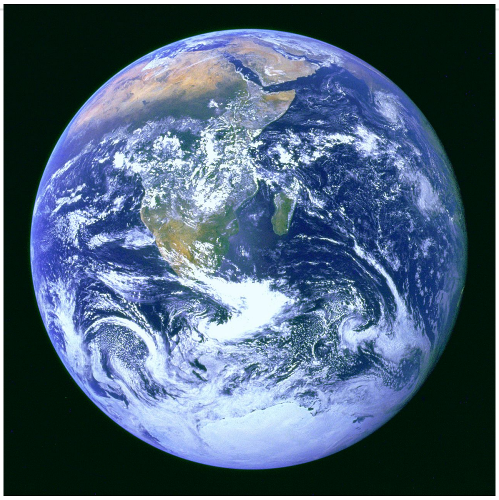


Crater on the surface of VenusPublic Domain | Image courtesy of NASA.



Sif Mons Volcano on VenusPublic Domain | Image courtesy of NASA.

7.8: Planet Earth



EarthPublic Domain | Image courtesy of NASA.

Earth is the largest of the Solar System's rocky planets and the **only known planet with liquid water**. Water makes up about 75% of Earth's surface.

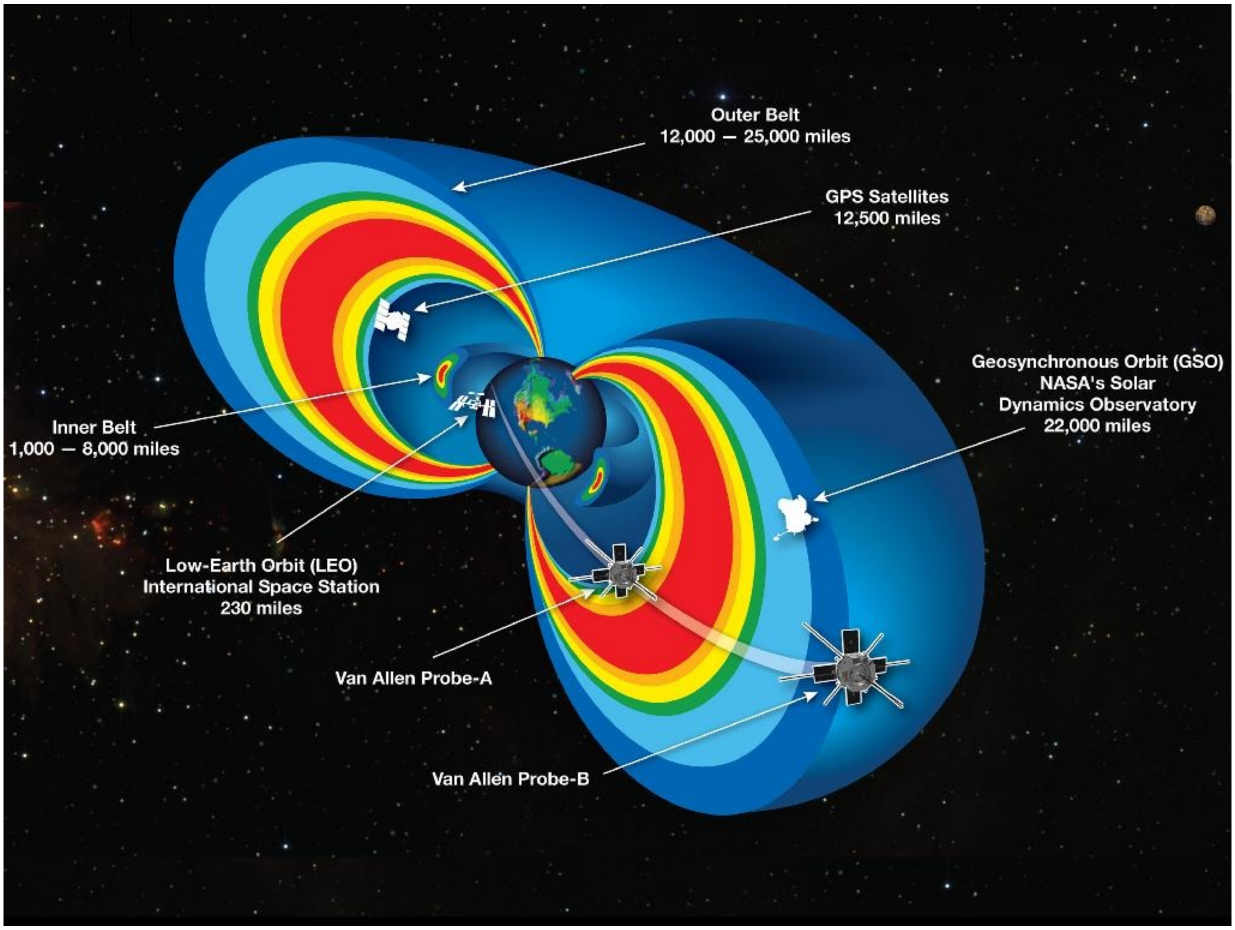
Daily changes in the level of the water – known as **tides** – are due to the Moon and Sun's gravitational influences. These gravitational effects raise tidal bulges in the oceans. The size of a specific tide primarily depends on the Sun-Moon orientations relative to Earth. Tidal interaction between Earth and Moon causes the Earth's rotation to slow and the Moon to be locked in a synchronous orbit – revolution is equal to rotation. Some "rocking" of the Moon back and forth occurs, called **librations**.

Forces that Shape Earth: Earth's Geological Processes

Impact Cratering was very intense during the early period of the Solar System; this also shaped Earth into its characteristics.

Other forces that shape Earth include **erosion, weathering, plate tectonics, and volcanism.**

- **Erosion, which is a continuous process,is** the wearing away of the surface by water, atmosphere, mechanical, and chemical processes.
- **Weathering is** a gradual physical and chemical wearing away of rocks and surface material.
- **Plate tectonics is** the motion of a body's plates driven by internal stresses.
- **Volcanism is** the eruption of molten rock from a body's interior onto its surface.



Public Domain | Image courtesy of NASA.

Earth has a dynamic and active **atmosphere**. Overall, Earth has the most dynamic weather in our Solar System. Our atmosphere is not as thick as the Gas Giants or even Venus (Rocky Planet), yet it is like looking through 30 feet of water.

Earth also has a strong **Magnetic Field**, which is unusual for a Rocky Planet. It is believed to be due to Earth's molten core undergoing rotation and convection (giving off heat). Mercury and the Moon exhibit very weak magnetic fields, whereas Venus has none and Mars virtually none; yet there is evidence of a magnetic field in Mar's early history.

The **Van Allen Radiation Belts** are charged Particle Belts made up of ions and electrons, which were predicted by James Van Allen, and discovered in 1958 by the US Satellite Explorer 1. These belts protect Earth as intense solar particles from the Sun's solar wind strikes Earth. These solar wind particles can occasionally be seen as **Aurora**, as the charged solar particles strike Earth's poles.

Earth is the only known planet with life. Earth's orbit is within the **circumstellar habitable zone** – area in a star's orbit where ideal conditions exist for life. If Earth was 5% closer to the Sun, it would be Venus-like, and 20% farther out from the Sun, Earth would be Mars-like. Earth also exists in a system that has the right type of star, only one star, good location within the Milky Way Galaxy, the right type of galaxy, etc. Astronomers, biologists, and physicists have identified over 800 identified factors necessary for intelligent life.

Planet Earth at a Glance

Characteristic — Current State

- Impact Craters — Yes
- Tectonic Craters — Yes
- Volcanoes — Yes
- Atmosphere — Nitrogen (N), Oxygen (O_2), Clouds, Rain, Snow
- Water — Vapor, Liquid, and Ice → Primarily a water planet
- Erosion — Yes

- Dunes — Yes
- Polar Caps — Yes
- Satellites — One, Moon
- Life — Yes

7.9: Earth's Moon

Earth rise from Lunar OrbitPublic Domain | Image courtesy of NASA.

The Earth-Moon system is sometimes referred to as a double or twin planet, due to the size of the Moon when compared to Earth. As with all of the planets and other moons, we see the Moon due to reflected sunlight. Lunar temperature varies from 253oF in the day to -387oF at night.

How did the Moon form? There are a number of theories—from capture of the Moon by Earth, formation of the Moon in the same area as Earth, and the blob-spinning-of-early Molten Earth. However, the most widely accepted theory is the **Giant Impact Theory**. This theory posits that a Mars-sized rogue planet that astronomers call Orpheus struck early Earth. The evidence seems to highly favor the giant impact theory over others. Evidence of lava flows and a small iron lunar core are at the heart of this theory.

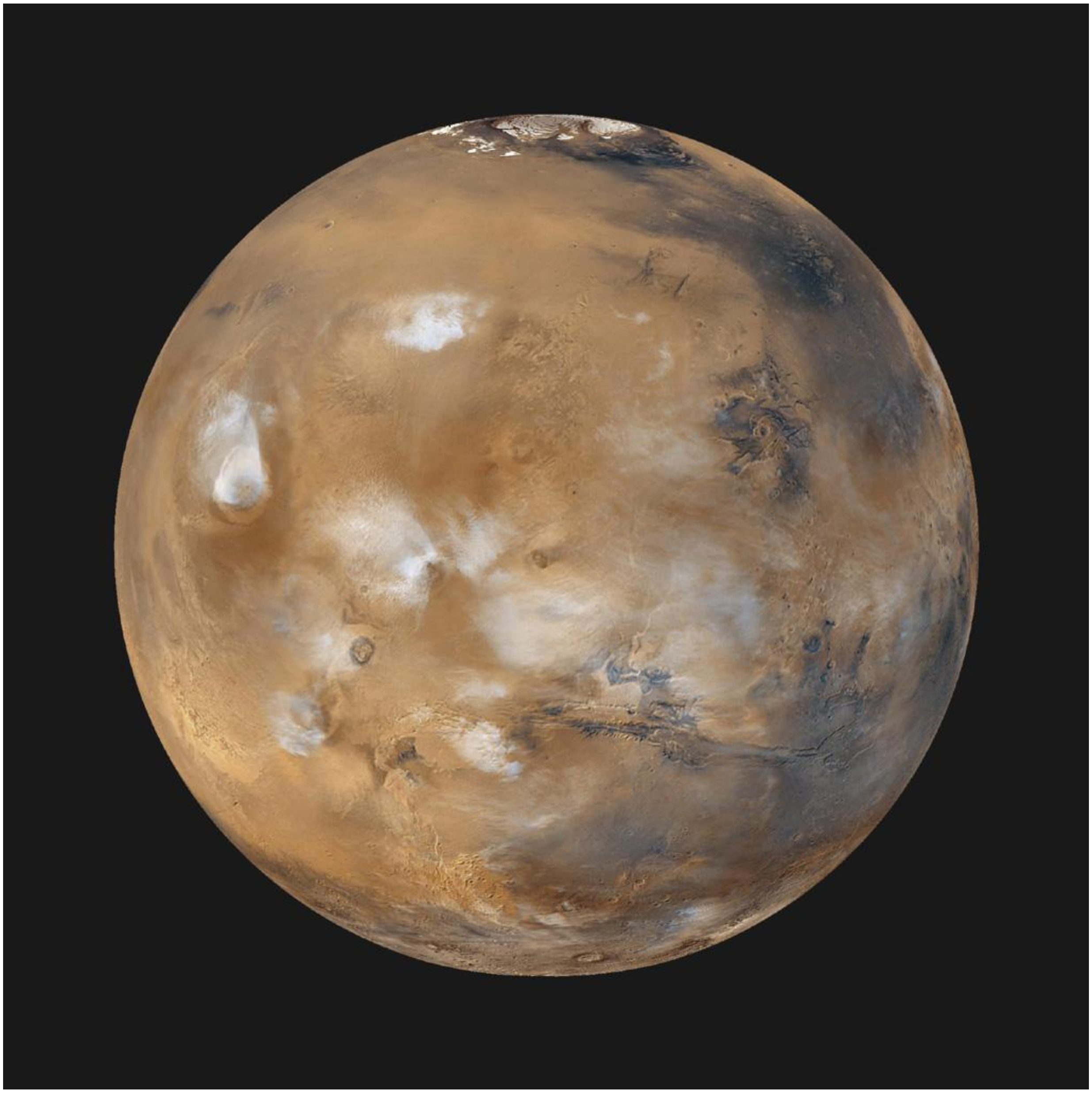
1st Quarter MoonCC BY-SA 2. 0 | Image courtesy of orrey Pines – San Diego – California – USA.

Perhaps surprisingly, water has been found on the Moon. Water ice deposits have been found in the coldest spots of the Moon's South Pole craters that are not exposed to sunlight. And astronomers have discovered the spectral signal of water and/or hydroxyl (HO-) ion from three different spacecraft. Estimates are that one ton of the lunar surface top layer would hold about 32 ounces of water.

Large Lunar Craters Eratosthenes (upper left) and Copernicus (center right)Image courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

Full *Moon*Image courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

7.10: Planet Mars



Mars – note the polar cap (top), cloudsPublic Domain | Image courtesy of NASA.

Mars is the fourth planet from the Sun. It is historically called the **Red Planet** because of its reddish appearance in Earth's night sky. Mars has some Earth-type characteristics, such as Polar Caps, clouds, and water in at least the ice or solid phase. It was very active volcanically at one time. Numerous spacecraft have successfully explored Mars from orbit and the surface. It is by far the most-visited planet (by spacecraft) in our Solar System, besides Earth.

Differences between Martian North and South Polar Caps

North Polar Cap:

- Primarily composed of water ice, H2O
- Size of Greenland
- Seasonal
- Goes through a variety of change

South Polar Cap:

- Primarily composed of carbon dioxide ice, CO_2
- 1/10 the size of the North Polar Cap
- Always there
- On one side of Pole

The differences in the Martian polar caps are probably due to different polar climates. It's important to note that Earth's Polar Caps are also different; the North Pole is floating ice versus the South Pole as a continent.

7.11: Snow on Mars

The Phoenix Mars Lander detected snow falling from Martian clouds in 2009. The snow was detected from clouds about 2. 5 miles above the spacecraft's landing site. Data show the snow vaporizing before reaching the ground. Information from the Phoenix Mars Lander also confirmed that a hard subsurface layer at its far-northern site contains water and ice.

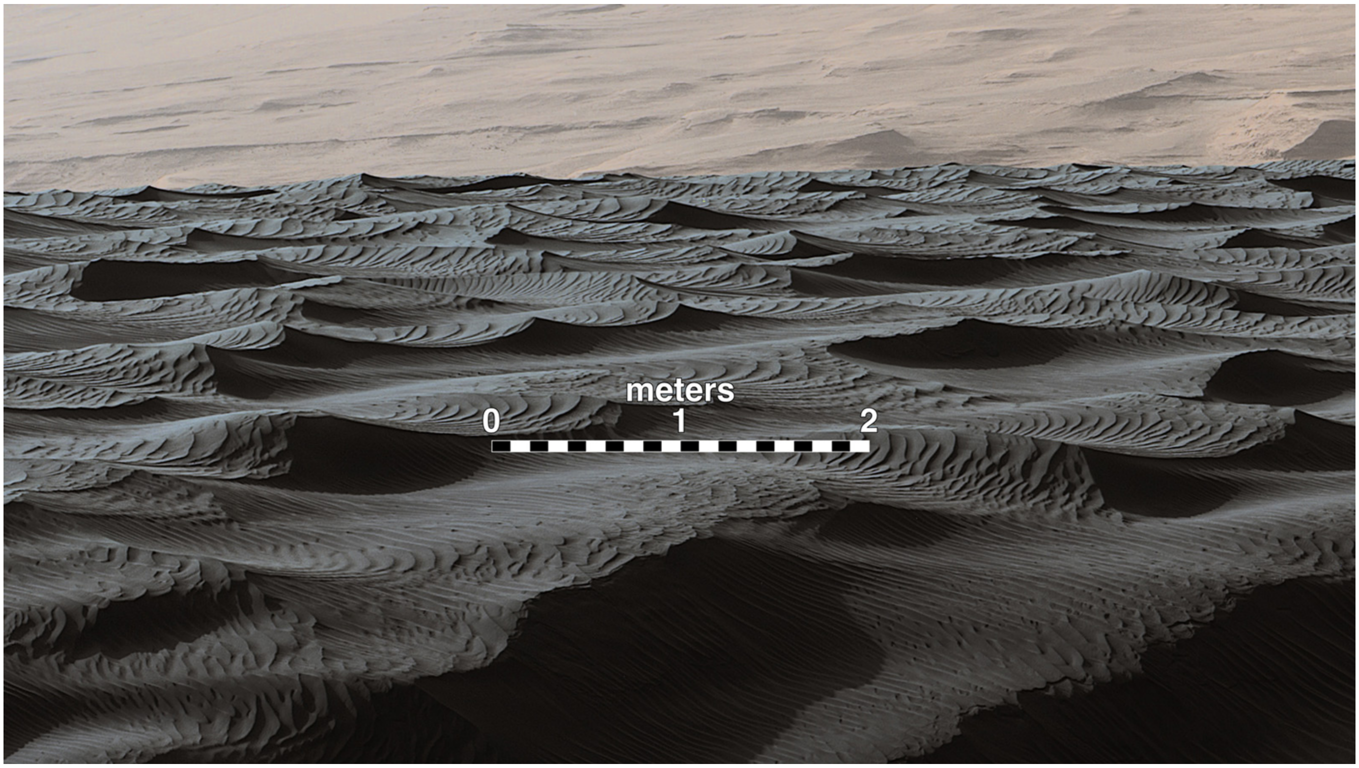
Planet Mars at a Glance

Characteristic — Current State

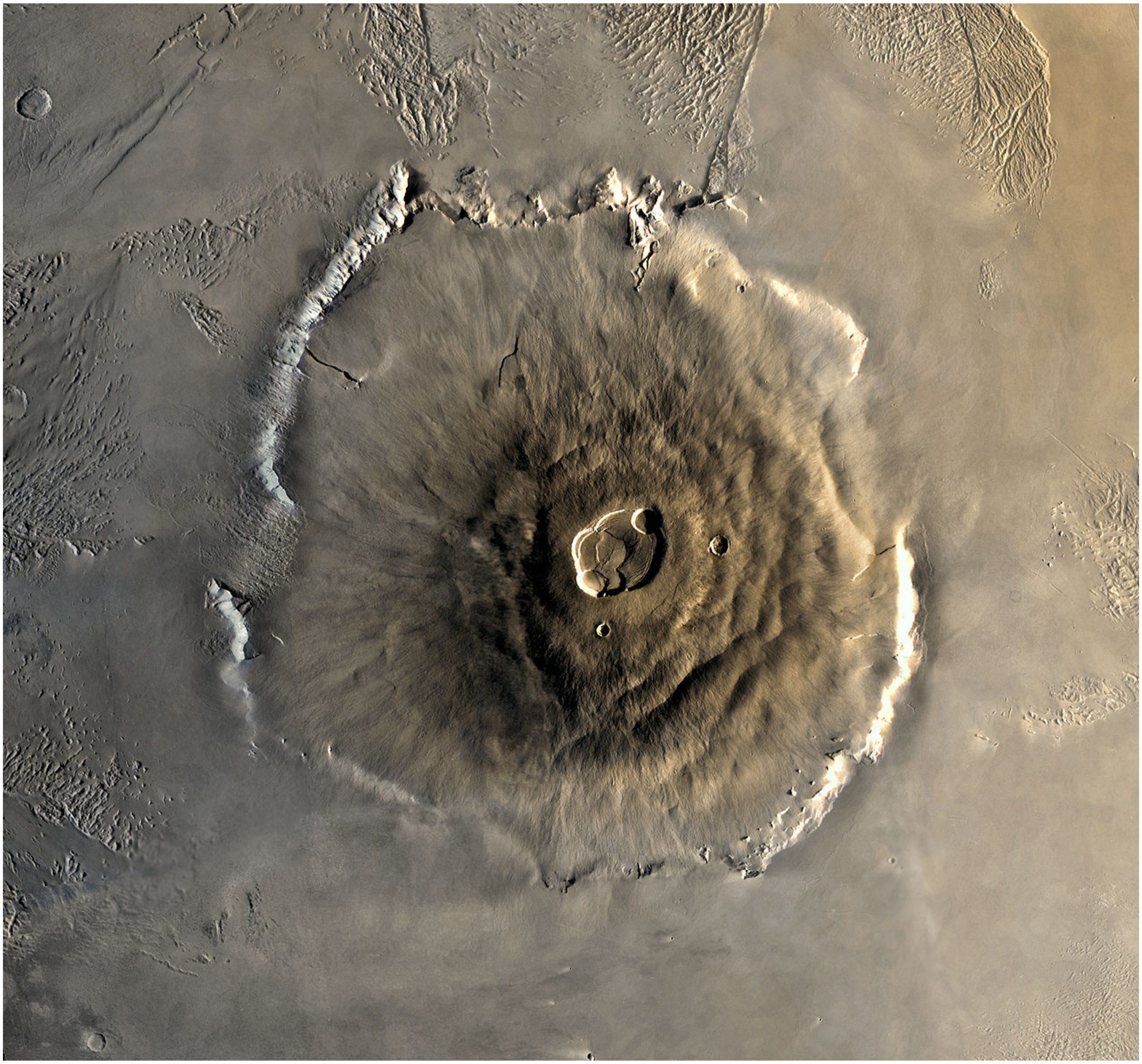
- Impact Craters — Yes; a very large impact crater **Borealis Basin** (largest known in the Solar System), 6,600 miles across
- Tectonic Craters — Yes, still active?
- Volcanoes — Yes, not active; One of the largest volcanoes in the Solar System; **Olympus Mons**
- Atmosphere — Carbon Dioxide (CO_2), Low Pressure, Clouds, Snow, Dust devils, Dust storms, Slight traces of Methane (CH_4)
- Water — Both liquid & water ice
  - Subsurface liquid water aquifers?
  - 2% water in soil
- Erosion — Yes
- Dunes — Yes
- Polar Caps — Yes
- Satellites — Two; Deimos and Phobos
- Life — Unknown; we are actively searching for life

Public Domain | Image courtesy of NASA.

Ius Chasma Floor: The layered deposits consist of dark basalt lava flows and bright sedimentary layers; likely to be from atmospheric dust, sand, or alluvium from an ancient water source. Mars Reconnaissance Orbiter, 9/18/2008Public Domain | Image courtesy of NASA.



Sand Dunes on Mars: Endurance Craters are dramatic dune fields on the crater floor. Dune crests have accumulated more dust than the flanks of the dunes and the flat surfaces between the dunes. Images courtesy of NASA



Martian Volcano Olympus Mons. Public Domain | Image courtesy of NASA.

The surface of Mars. NASA Viking SpacecraftPublic Domain | Image courtesy of NASA.

7.12: A Martian Controversy

Before spacecraft and more-advanced equipment, we depended on the eye and photography to decipher and understand what we saw in the Universe. Mars was – and it still is – interesting because it is so close to Earth and somewhat “Earth-like. ” Some astronomers focused on the planets and specifically Mars. **Percival Lowell** was one such astronomer.

Lowell Observatory in Flagstaff, Arizona

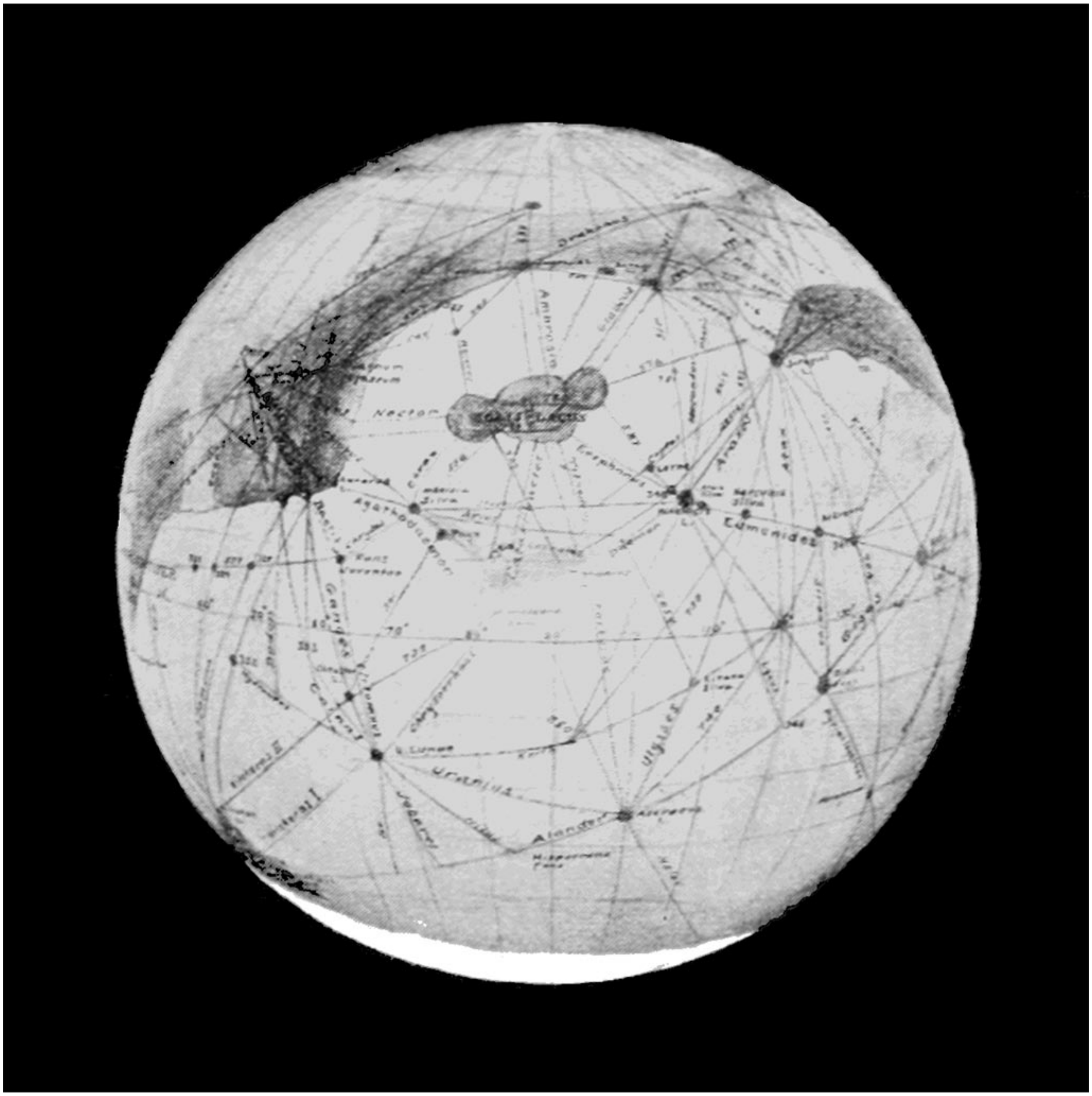
In the late 1800s, Percival Lowell was the first to seek site with good air clarity and superior seeing (steady air or lack of turbulence). After testing many different site tests, Lowell gave the lumber town of Flagstaff, AZ (population of 1,000) high marks. He selected a hill 300 feet above town and built an observatory, which is still in use today.

Lowell initiated Mars Mania; he sensationalized what he perceived as Martian **canals**. The canals were first described by the Italian astronomer Giovanni Schiaparelli during the close Martian approach in 1877. Schiaparelli gave them the Italian name ‘canali. ’ The translation was taken as canals; canals refer to something made by someone, something, but not Earth-natural…. Lowell pressed the idea that these canals were made by intelligent beings – Martians. There were books and articles that promoted the Martian canals as well as Martian seasonal vegetation growth. This, and surrounding controversy, stimulated interest in Red Planet. And in 1898, science fiction author H. G. Wells wrote “The War of the Worlds,” furthering the controversy.

Other observers also saw the Martian Canals. Lowell astronomer Earl Slipher’s book, *The Photographic Story of Mars* , shows adjacent direct photographs and drawings. In 1962, Slipher asked readers to judge:

History … shows that every skilled observer … has had no great difficulty of seeing and convincing himself of the reality of the canals. Photographs have recorded traces of so many of the canals and oases … that they should remove all doubt of the reality — E. C. Slipher (1962).

So what happened? Were the canals real? When spacecraft first started exploring Mars in 1965, Mariner 4, no canals were seen. It is now believed that the eye fooled the astronomer, he connected features on Mars that were there – but the canals were not. It was like connecting the dots, an optical illusion.



Lowell’s 1916 Map of Mars. The fine lines are the Martian Canals. Public Domain

7.13: Martian Moons

Mars has two small moons, **Deimos and Phobos**. The names are taken from the Greek for Dread (Deimos) and Fear (Phobos). They were discovered by Asaph Hall in 1877.

Phobos is the larger of the two moons (barely larger than 16 miles at its biggest point) and orbits Mars once every 11 hours and 6 minutes. Both moons are odd-shaped and very small. Both Phobos and Deimos were most-likely captured asteroids or the result of a collision with Mars. As the images show, both moons have craters. Neither moon has an atmosphere.

Photo of Deimos. Public Domain | Image courtesy of NASA/JPL-Caltech/University of Arizona.

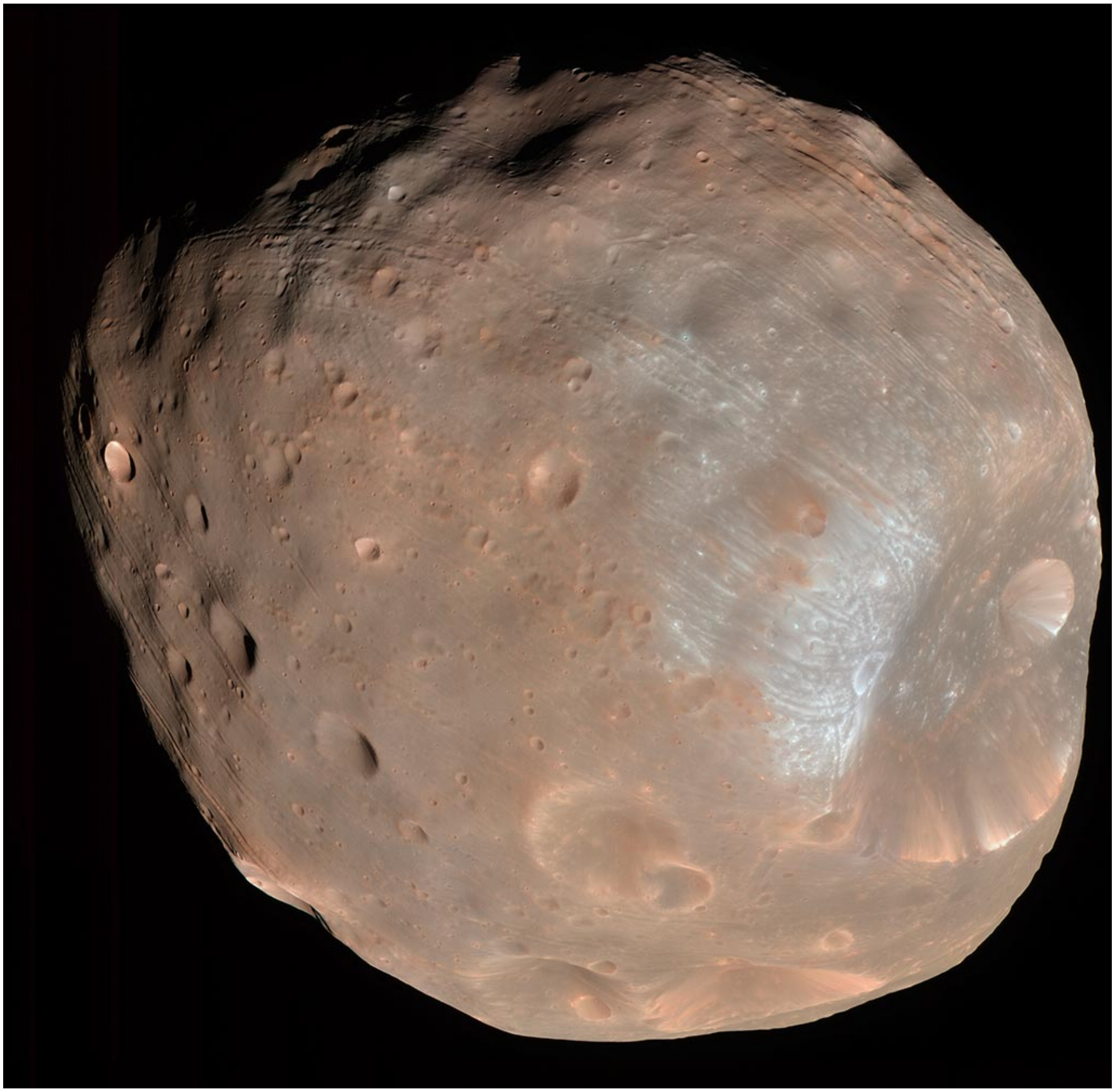


Photo of Phobos. Public Domain | Image courtesy of NASA. Taken by NASA's Mars Reconnaissance Orbiter in 2008.

7.14: Characteristics of the Solar System’s Rocky Planets

Comparison of the Rocky Planets

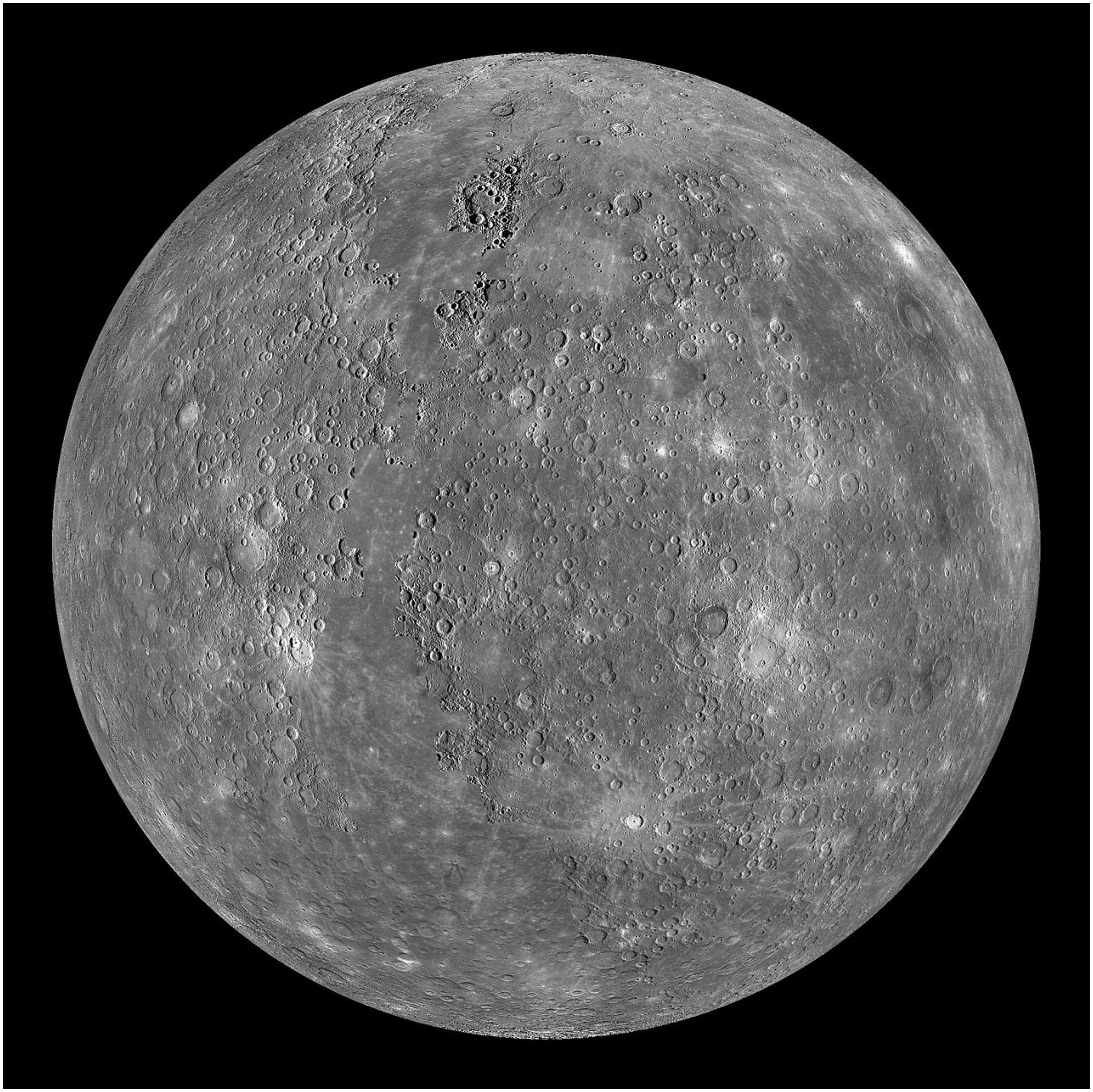
Mercury

Characteristic — Current State

- Impact Craters — Yes
- Tectonic Craters — Yes; not active
- Volcanoes — Yes; not active
- Atmosphere — No real atmosphere
- Water — Yes; water and ice in craters at the poles
- Erosion — No
- Dunes — No
- Polar Caps — No
- Satellites — No
- Life — Unknown

The Bottom Line…

- Looks like the Moon; heavily cratered
- No real atmosphere
- No seasons



Public Domain | Image courtesy of NASA / JPL-CALECH.

Venus

Characteristic — Current State

- Impact Craters — Yes
- Tectonic Craters — Yes
- Volcanoes — Yes; over 1,600 volcanoes – most on one body in the Solar System
- Atmosphere — Carbon Dioxide (CO2), Sulfuric Acid (H2SO4), High Pressure, Clouds, Odd Polar Vortex
- Water — No
- Erosion — Yes
- Dunes — Yes
- Polar Caps — No

- Satellites — No
- Life — Unknown

The Bottom Line…

- Called Earth's twin
- Extreme Greenhouse effect
- Rains sulfuric acid
- Polar Vortex

Public Domain | Image courtesy of NASA / JPL-CALECH.

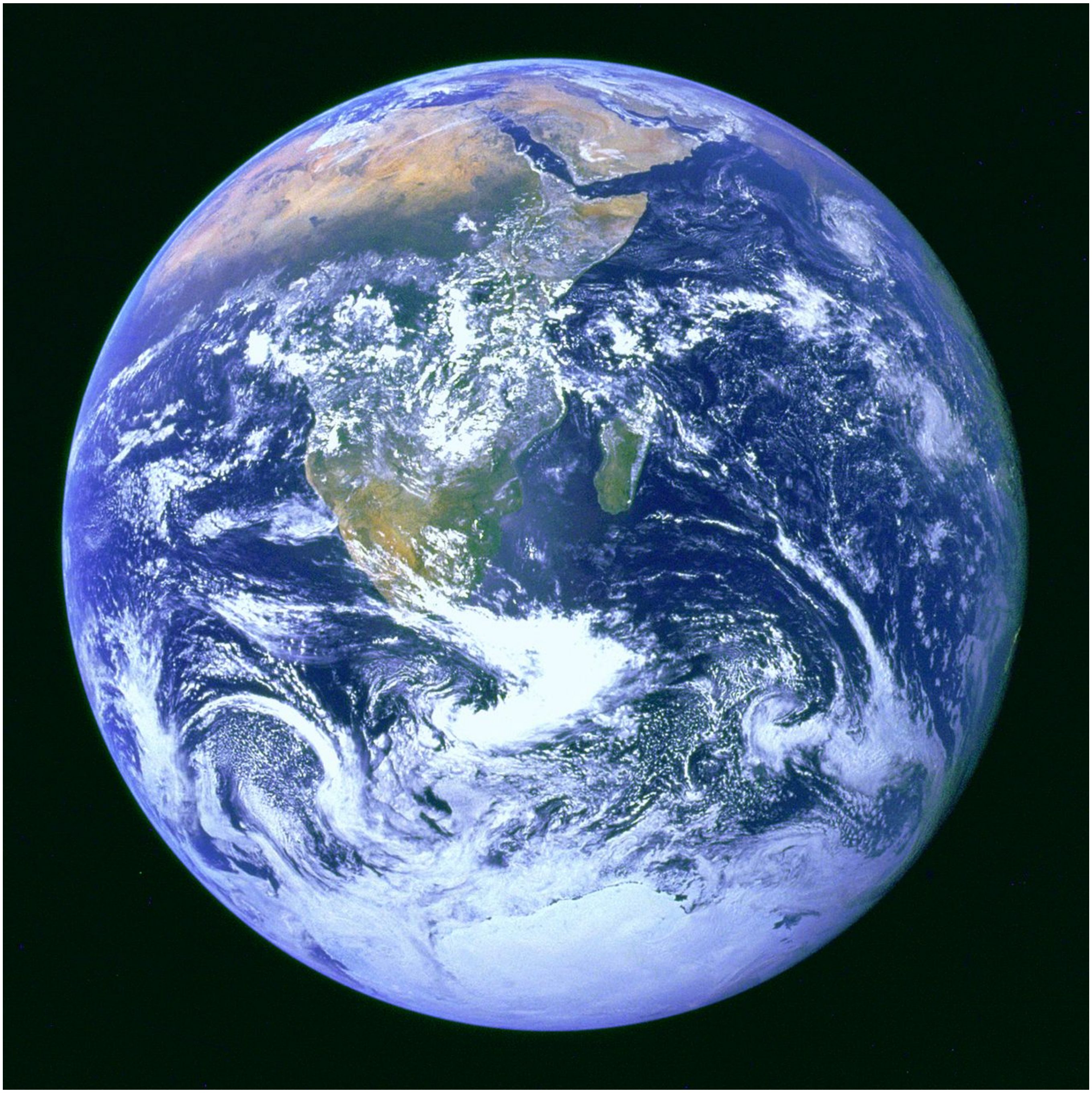
Earth

Characteristic — Current State

- Impact Craters — Yes
- Tectonic Craters — Yes
- Volcanoes — Yes
- Atmosphere — Nitrogen (N), Oxygen (O_2), Clouds, Rain, Snow
- Water — Vapor, Liquid, and Ice → Primarily a water planet
- Erosion — Yes
- Dunes — Yes
- Polar Caps — Yes
- Satellites — One, Moon
- Life — Yes

The Bottom Line…

- Water Planet
- Big moon – double planet
- Life everywhere



Public Domain | Image courtesy of NASA / ESA.

Moon

Characteristic — Current state

- Craters
- Evidence of past volcanic, tectonic activity
- No atmosphere
- Water ice found in a lunar south pole crater
- Probably formed from a collision with Earth

- Looks like Mercury…

CC BY-SA 3. 0 | Image courtesy of Wikimedia Author: Gregory H. Revera.

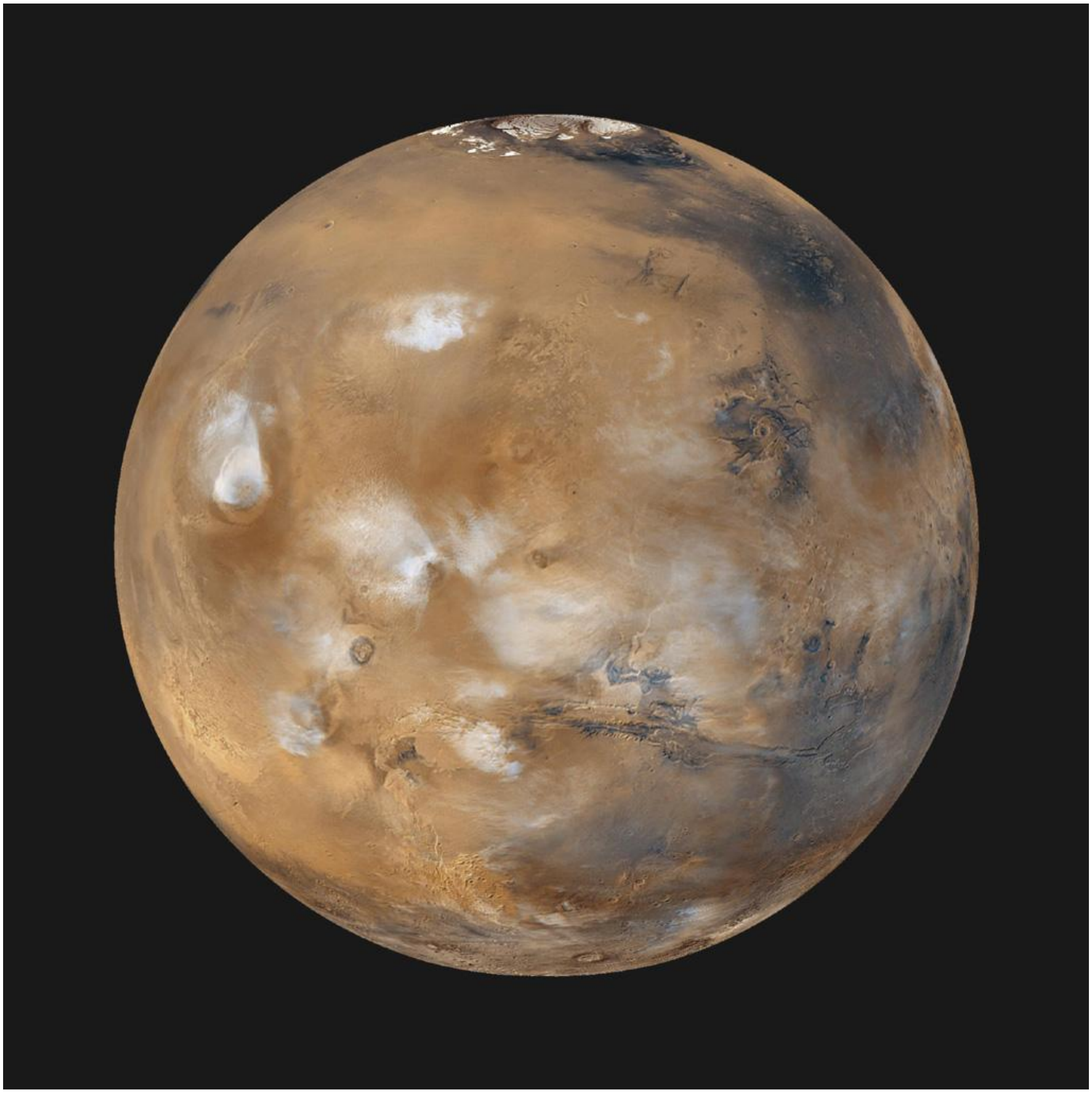
Mars

Characteristic — Current State

- Impact Craters — Yes; a very large impact crater **Borealis Basin** (largest known in the Solar System), 6,600 miles across
- Tectonic Craters — Yes, still active?
- Volcanoes — Yes, not active; One of the largest volcanoes in the Solar System; **Olympus Mons**
- Atmosphere — Carbon Dioxide (CO_2), Low Pressure, Clouds, Snow, Dust devils, Dust storms, Slight traces of Methane (CH_4)
- Water — Both liquid & water ice
  - Subsurface liquid water aquifers?
  - 2% water in soil
- Erosion — Yes
- Dunes — Yes
- Polar Caps — Yes
- Satellites — Two; Deimos and Phobos
- Life — Unknown; we are actively searching for life

The Bottom Line…

- Is liquid water still flowing?
- Very light compared to Venus and Earth (less dense)
- Life?



Public Domain | Image courtesy of NASA / JPL-CALECH.

Deimos and Phobos

Characteristic — Current state

- Craters
- No Atmosphere
- Very small
- Captured asteroids or result of collisions with Mars

Public Domain | Images courtesy of NASA/JPL-Caltech/University of Arizona.

Consider this…

How did elementary school kids used to remember the order of the planets from the Sun? A simple mnemonic: My Very Educated Mother Just Served Us Nine Pizzas! (Mercury Venus Earth Mars Jupiter Saturn Uranus Neptune Pluto) But with the demotion of Pluto as a full planet, the pizzas went away, so now it is My Very Educated Mother Just Served Us Nachos!

LibreTexts

CHAPTER OVERVIEW

8: The Gas Giant Planets

8.1: Module Introduction

“Since ’tis certain that Earth and Jupiter have their Water and Clouds, there is no reason why the other Planets should be without them. I can’t say that they are exactly of the same nature with our Water; but that they should be liquid their use requires, as their beauty does that they be clear. ”

“This Water of ours, in Jupiter or Saturn, would be frozen up instantly by reason of the vast distance of the Sun. Every Planet therefore must have its own Waters of such a temper not liable to Frost. ”

Christian Huygens– Discovered Saturn’s moon Titan in 1655

This module presents the Gas Giant Planets in our solar system: Jupiter, Saturn, Uranus, and Neptune, and their moons. We will examine characteristics of each Gas Giant planet, both similar and dissimilar characteristics.

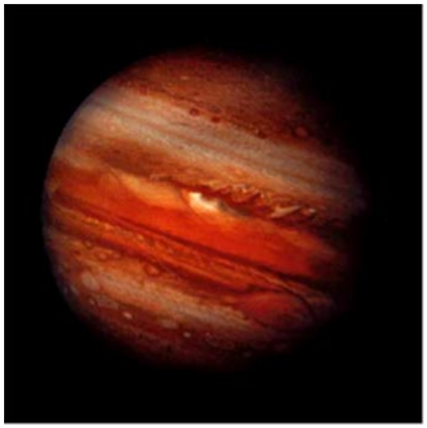
Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

- Identify the characteristics of the Gas Giant planets
- Describe the formation of rings
- Identify the primary characteristics of each Gas Giant planet
- Compare the characteristics of each Gas Giant planet is similar
- Identify the characteristics of Gas Giant satellites

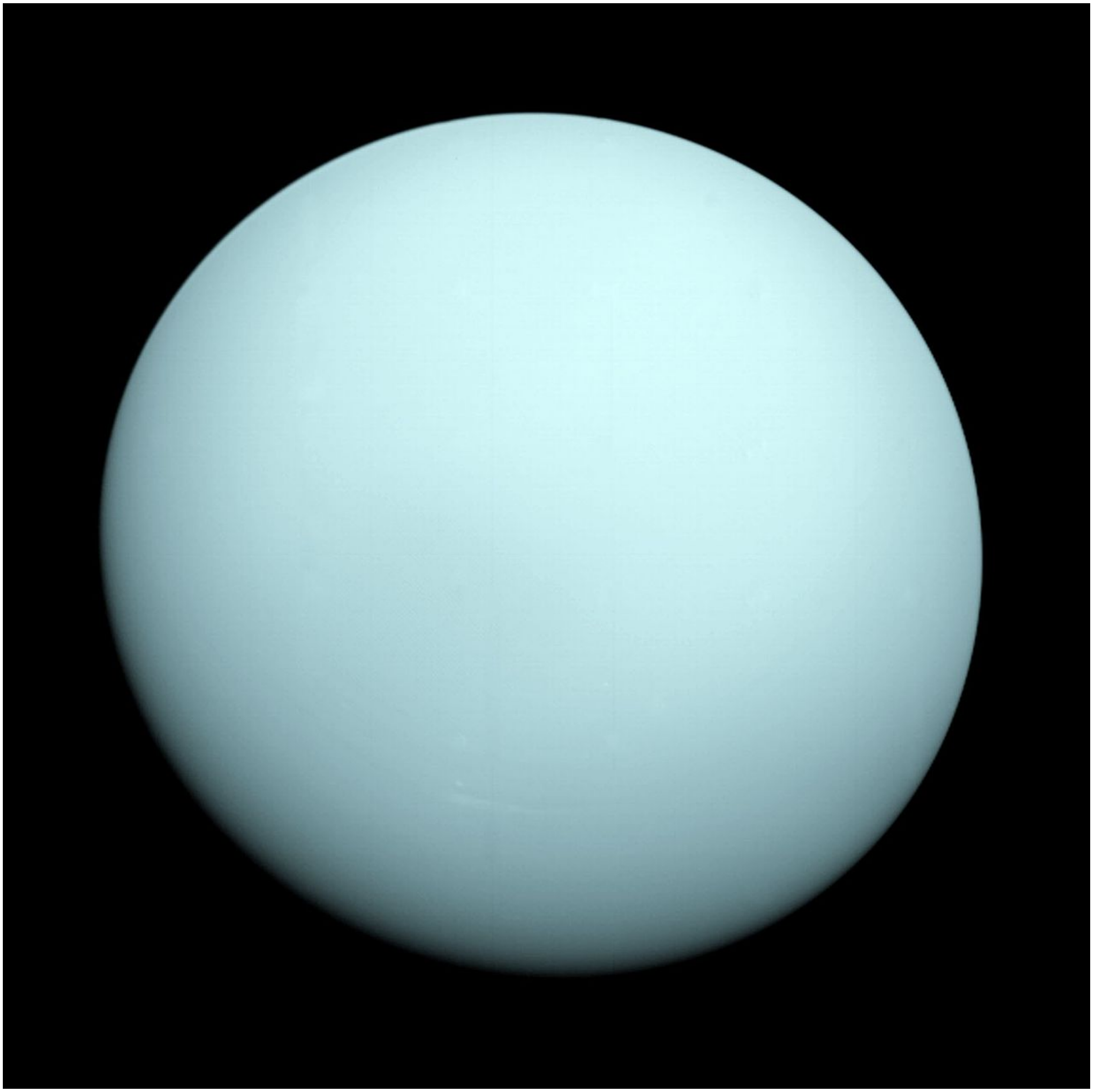
8.2: What do you think?

Again, imagine you are a first-time visitor to our solar system. You come in and pass the Gas Giant planets on your way to the inner solar system and the Rocky Planets. At first glance, what differences would you see between the Gas Giant planets and the Rocky Planets?

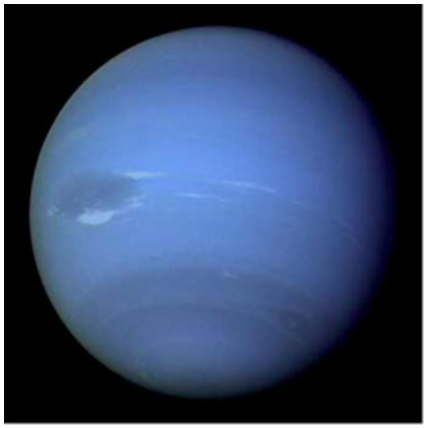


JupiterPublic Domain | Image courtesy of NASA.

SaturnPublic Domain | Image courtesy of NASA.



UranusPublic Domain | Image courtesy of NASA.



NeptunePublic Domain | Image courtesy of NASA.

8.3: Gas Giant Planets

Like the Rocky Planets, the Gas Giant planets – sometimes referred to as the **Jovian Planets** (Jupiter-like) – also have a number of general characteristics. Gas Giant planets are large in size when compared to the Rocky Planets.

Gas Giant planets are made up of primarily Gases – thus their name – with basically the same compounds and elements, but differing percentages. These worlds are not primarily composed of rock or other solid matter as the Rocky Planets.

Some other Gas Giant characteristics include short revolution periods (when compared to the Rocky Planets), many moons, rings, and farther from the Sun in our solar system thus the longer periods of revolution.

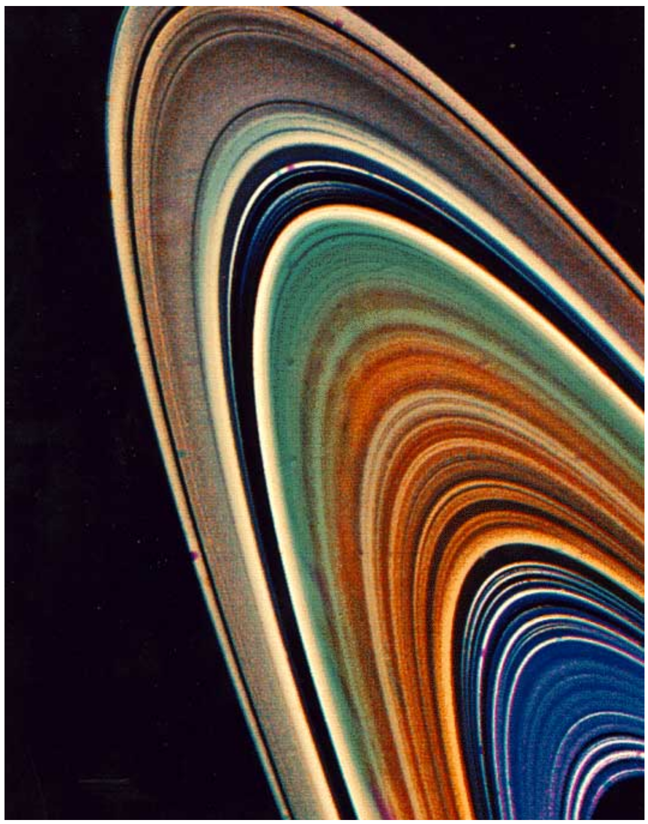
8.4: Rings

One characteristic we will find with the Gas Giant planets is rings. A **ring** is a disk of dust or small object orbiting a planet or other body. It is hypothesized that rings can form in one of three ways.

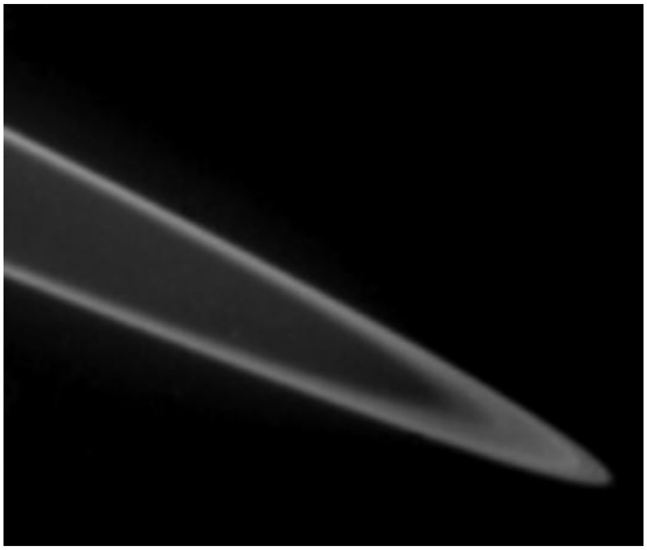
1. Material from the solar system's original protoplanetary disk that was within the planet's Roche limit, thus not forming a moon.
    - The **Roche limit** is the minimum distance to which a satellite can approach its primary body without being torn apart by tidal forces due to gravity.
2. A moon that broke apart due to Roche limit tidal stresses.
3. Debris from the moon that broke up due to a large impact.

Different forces can influence rings and ring structures. These include other rings, satellites orbiting the planet, and the planet itself.

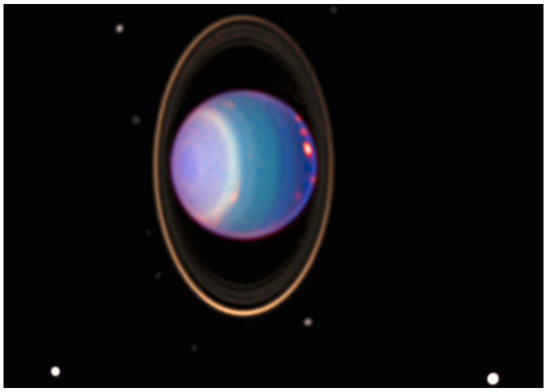
There are some objects that have rings but are not Gas Giants. For example, one asteroid has been discovered with rings; this is thought to be due to a collision or collisions. The Martian moon Deimos will eventually break up due to the gravitational tidal forces of Mars and Deimos' orbit getting too close to Mars; one hypothesis is that a ring will be formed from Deimos around Mars at that time.



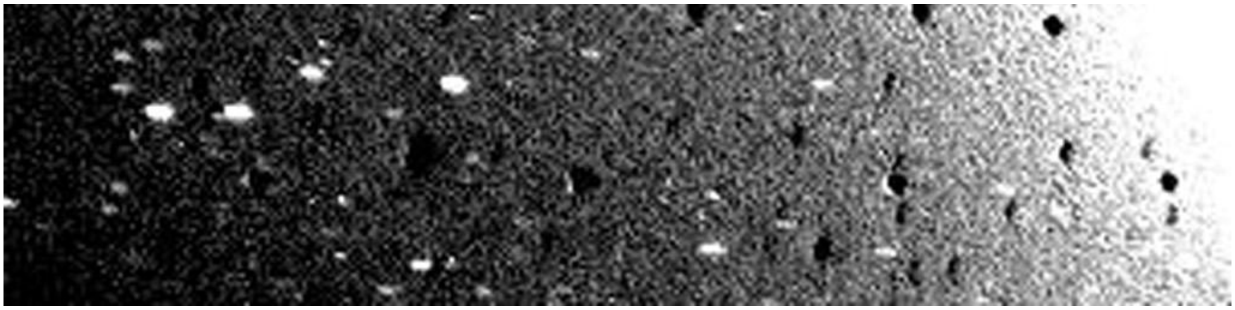
Saturn's rings via NASA VoyagerPublic Domain | Image courtesy of NASA.



Jupiter’s single ringPublic Domain | Image courtesy of NASA.



Uranus and some of its rings via NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA.



Neptune’s rings via NASA Voyager 2Public Domain | Image courtesy of NASA.

8.5: Planet Jupiter

Jupiter is the largest planet in the solar system; all of the other planets could fit inside Jupiter. One of its major atmospheric features is the **Great Red Spot –** cyclonic in nature and twice Earth's diameter. The Great Red Spot was first seen by Galileo in 1610 and has been seen to change shape and color over the past 400 years.

Lightning and thunderstorms have been observed in Jupiter's upper atmosphere.

Jupiter has some other interesting features, including:

- It gives off more heat than it receives.
- It has a small, dense rocky core surrounded by hydrogen and some helium even though it is primarily a Gas Giant planet. Some speculate the core is solid hydrogen.
- It is a natural radio source, like the Sun and other stars.
- It has aurora events, much like Earth.

Jupiter at a Glance

Characteristics to Compare

Atmosphere

- Hydrogen (H_2), Helium (H_e), Methane (CH_4), Ammonia (NH_3), Water (H_2O)

Rotation

- Short rotation — 9. 8 hours

Revolution

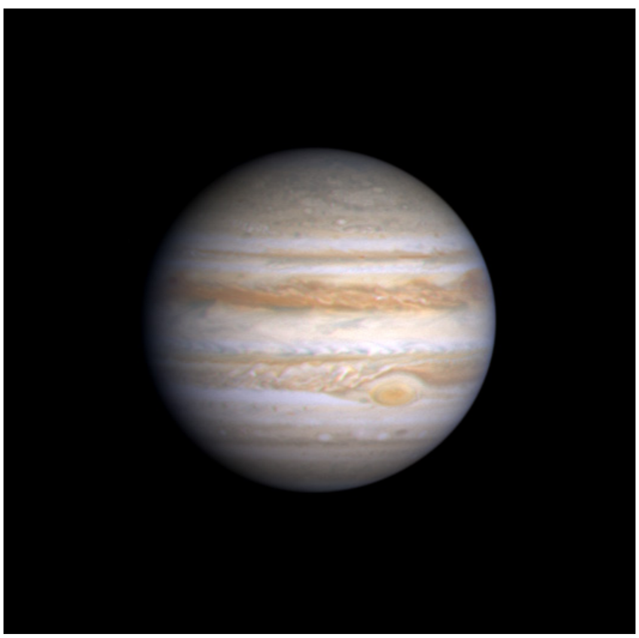
- Long revolution — 11. 86 years

Rings

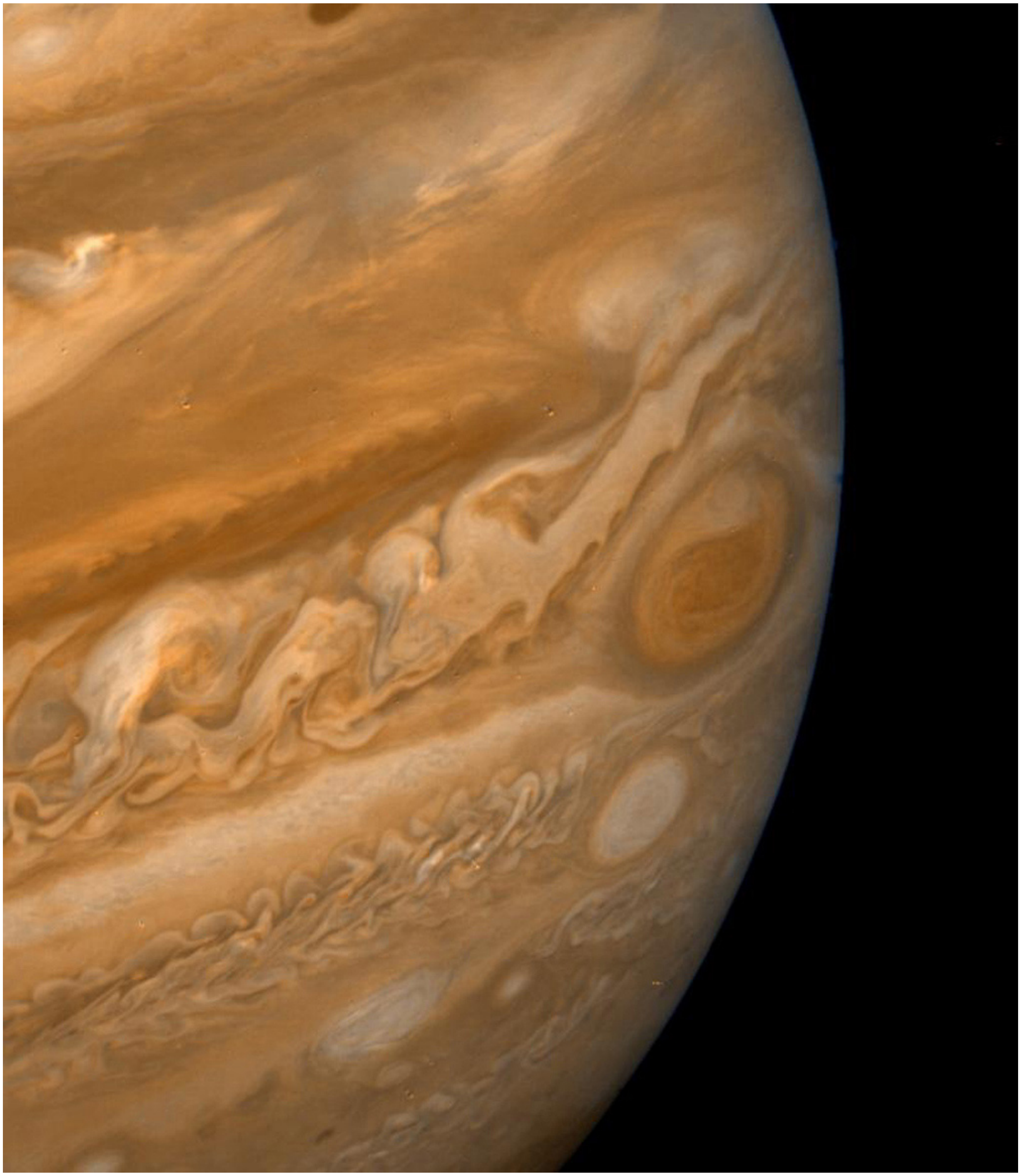
- One thin ring detected by the Voyager 2 spacecraft

Magnetic Field

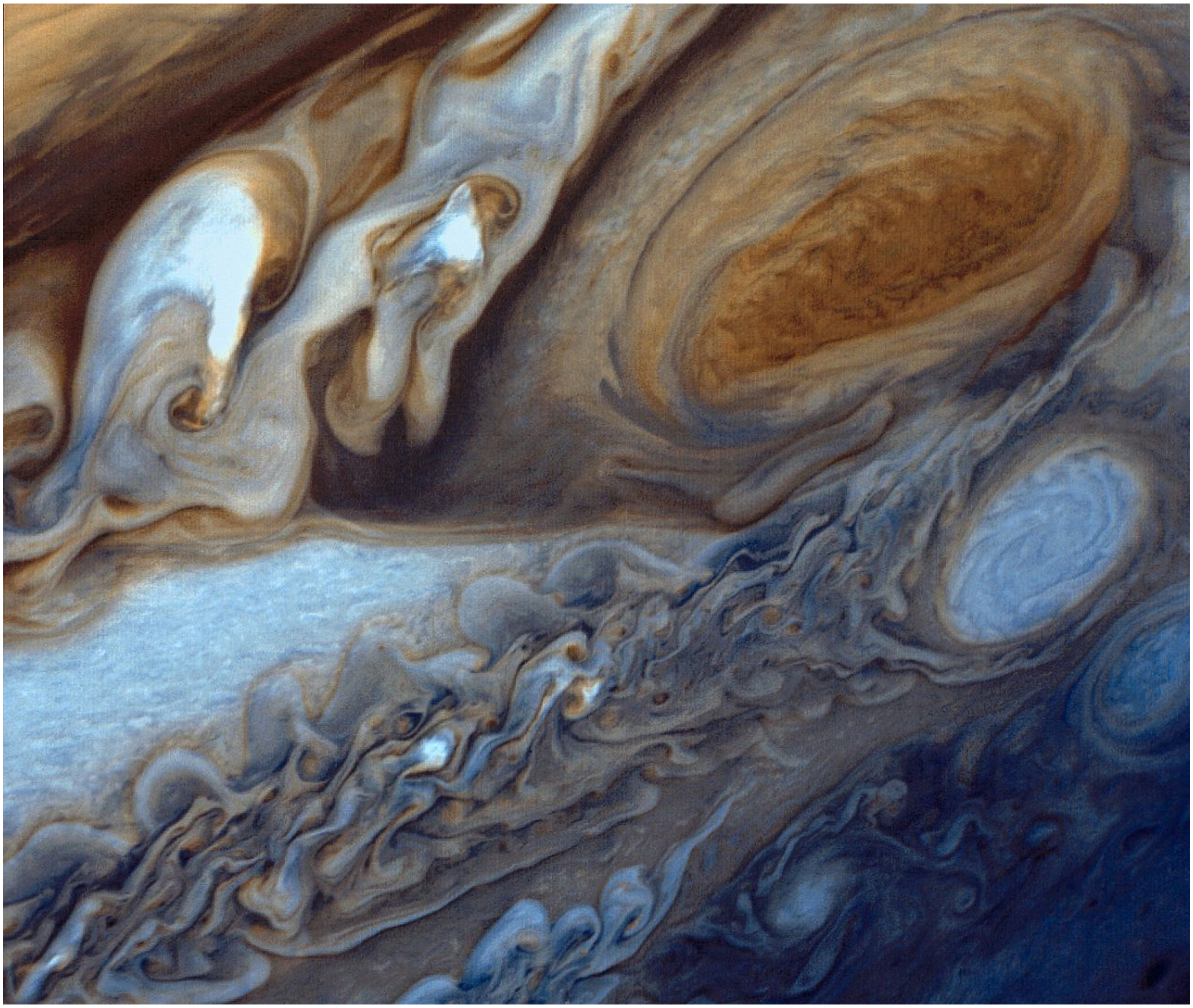
- A very strong magnetic field; 20,000 times that of Earth's



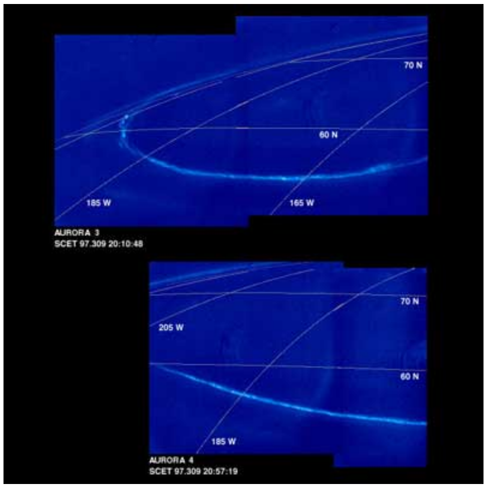
The planet Juptier via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.



Jupiter’s Great Red Spot via NASA Voyager 2Public Domain | Image courtesy of NASA.



Jupiter’s Great Red Spot with turbulent cloud tops via NASA Galileo SpacecraftPublic Domain | Image courtesy of NASA.



Lightning in Jupiter’s upper atmospherePublic Domain | Image courtesy of NASA.

8.6: Jupiter's Satellites

Jupiter currently has the largest known number of satellites in the solar system, with 67 known moons (as of August 2014). The four largest moons were discovered by Galileo Galilei and are called the Galilean Satellites or moons. They are Callisto, Europa, Ganymede, and Io, with Io having the closest orbit to Jupiter. And Ganymede is larger than planet Mercury.

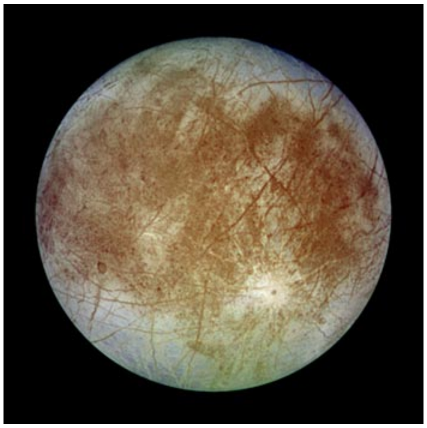
Jupiter's Galilean Satellites

Brief Descriptions

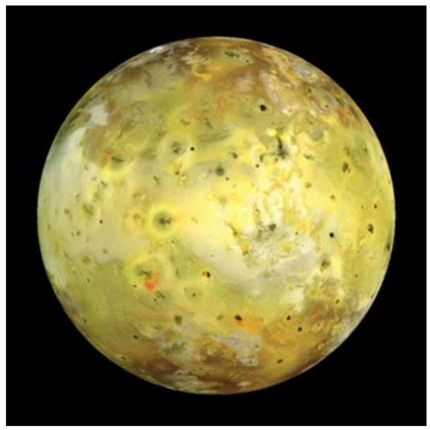
Callisto

- Europa
    - Ganymede
        - Io
            - Most active volcanoes in the solar system, Sulfur

Callisto via NASA Galileo SpacecraftPublic Domain | Image courtesy of NASA.



Europa via NASA Galileo SpacecraftPublic Domain | Image courtesy of NASA.


Ganymede via NASA Galileo SpacecraftPublic Domain | Image courtesy of NASA.

IoPublic Domain | Image courtesy of NASA.

8.7: Planet Saturn

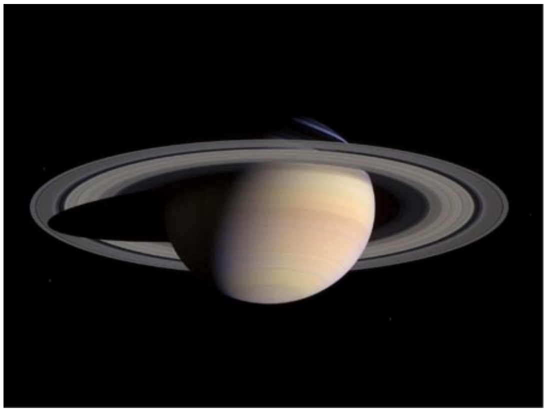
Saturn is "the ringed planet. " Although all four Gas Giant planets have rings, Saturn's are by far the most-spectacular and intricate. Saturn's upper atmosphere is not as turbulent when compared to Jupiter's upper atmosphere; it does not show as many markings and spots as Jupiter. The atmosphere shows an odd polar hexagon, due to Saturn's atmospheric jet stream. There are some other interesting Saturnian characteristics. First, the density of Saturn is so low that it would float in water – *if you could find a bathtub big enough to hold Saturn.* Much like Jupiter, Saturn probably has a very small rocky core surrounded by hydrogen and helium. And also like Jupiter, Saturn also experiences aurora and lightning.

Saturn at a Glance

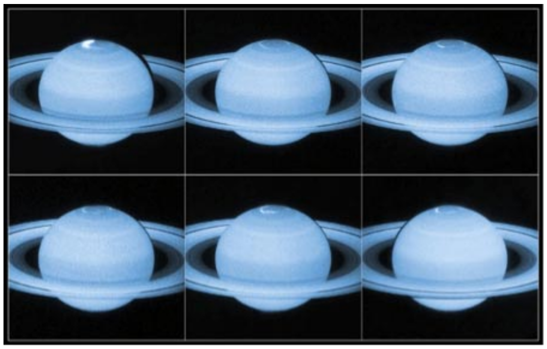
Characteristics to Compare

Atmosphere

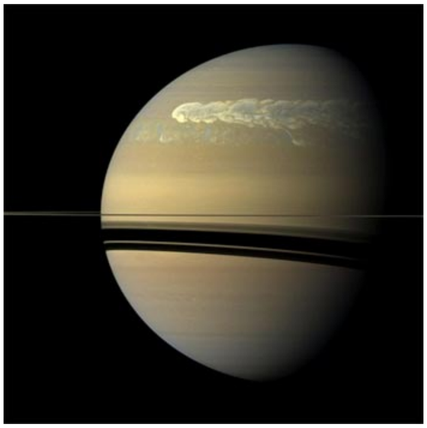
- Rotation
    - Revolution
        - Rings
            - Magnetic Field
                - Yes



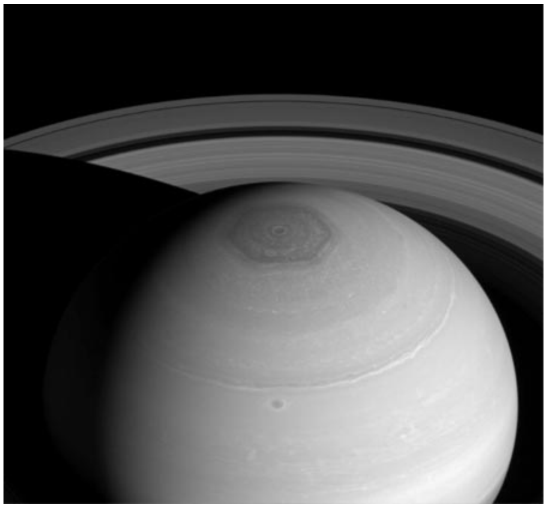
Images of the planet Saturn via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.



Saturn's aurora; white spots at the top via NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA.



Storm on Saturn’s cloud tops via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.

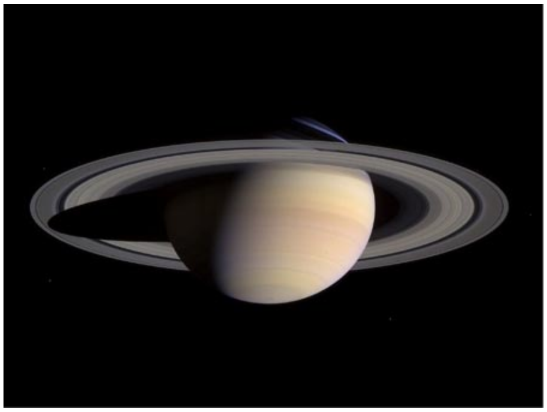


Saturn’s odd polar hexagon via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.

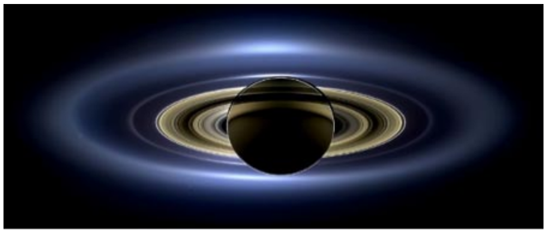
8.8: Saturn’s Rings

Saturn’s rings are made up of particles that range from dust-size to meters in diameter. The rings are mostly water and ice in composition, with some rocky silicate materials. Galileo Galilei first observed them in 1610; he could not discern them as rings and referred to them as the *ears of Saturn* . In 1655, astronomer Christian Huygens hypothesized that Saturn had a ring, based on his telescopic observations. Giovanni Cassini suggested in 1655 that Saturn’s ring was actually made up of numerous smaller rings with gaps or divisions between these smaller rings. Saturn exhibits seven major rings with multiple divisions and gaps in the rings. The outer F ring is twisted and knotted like a piece of taffy; this is due to interactions of the F ring with Saturn’s moon Prometheus. There are small moons, called **shepherd** or **sheepherder moons**, which orbit near the outer edges of a ring or within gaps in the rings.

These sheepherder moons maintain a sharply defined edge to the ring. Radial features in the B ring, called spokes, were suggested by Steve O’Meara (Earth observations) and confirmed by spacecraft. These **spokes**, seasonal in nature, appear to be caused by electrostatic forces. A quite-distant ring of dust was discovered in 2009, called the Phoebe ring, and the Saturnian moon Phoebe that is not visible in Earth-based telescopes.

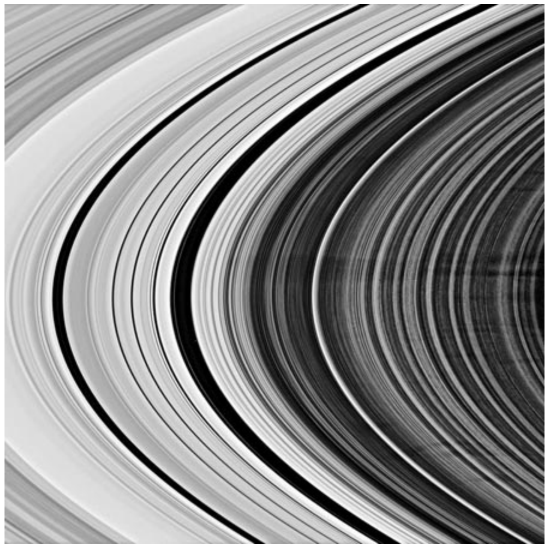


Saturn’s rings via NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA.



Saturn’s rings, with Saturn blocking the Sun via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.

Saturn’s F ring, with the moon Prometheus pulling material from the ring via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.


Spokes in Saturn’s B ring via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.

8.9: Saturn's Satellites

Saturn has 62 known moons (as of August 2014); a large number like Jupiter. Titan is the second largest moon in the solar system (to Jupiter's Ganymede) and is also larger than the planet Mercury. Christian Huygens discovered Titan in 1655. Most of Saturn's moons are very small; many are smaller than 50 kilometers (30 miles) across. As noted when discussing Saturn's ring, there are several Shepard moons and Gap moons.

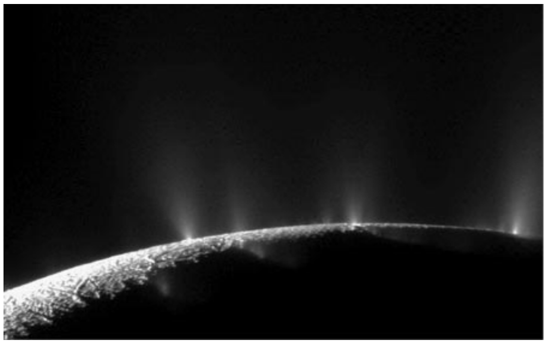
Saturn Satellites of Distinction

Brief Description

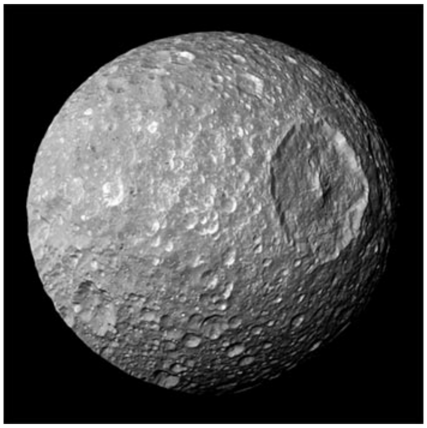
Enceladus

- Mimas
  - Prometheus
    - Titan
      - Thick atmosphere of mostly Nitrogen, liquid methane on the surface

Enceladus via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.

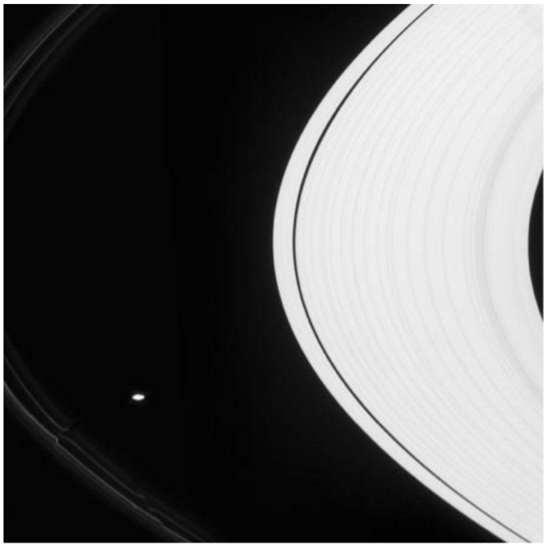


Geysers erupting from Enceladus, there are 101 geysers in what is called the Enceladus Geyser Basin via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.

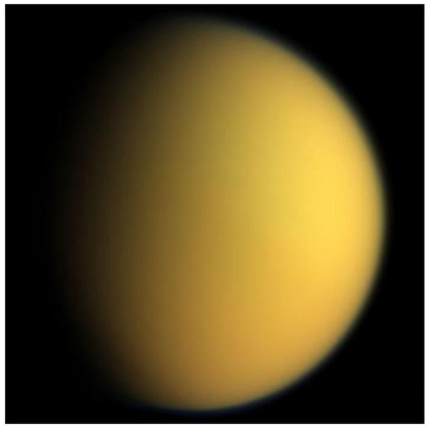


Mimas via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.

Prometheus via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.



F ring (left), Prometheus (center oblong), and Saturn’s rings to the right – note the F ring twists via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.



Titan and its thick atmosphere via NASA Cassini SpacecraftPublic Domain | Image courtesy of NASA.

Surface of Titan via NASA Huygens SpacecraftPublic Domain | Image courtesy of NASA.

8.10: Planet Uranus

Uranus was the first planet found with a telescope. Uranus was discovered by Sir William Herschel in 1781, even though others might have recorded Uranus prior to Herschel and not realized what they were seeing. Uranus is often referred to as Neptune's twin, because of similarities in their sizes, colors, and other characteristics.

Uranus rotates on its side. It is believed that this odd rotation is due to a collision with its moon Miranda. The planet shows little atmospheric activity, and actually looks like a green billiard ball. If Uranus has a core at all, it is a very small rocky core.

In its atmosphere, Uranus has more water, ammonia, and methane ices in its atmosphere than Jupiter and Saturn; so it is often referred to as an **Ice Giant**. It is the coldest planet in the solar system. Like Jupiter and Saturn, Uranus also exhibits aurora activity. The planet has 13 rings, composed of dark particles made of dust to less than a meter in diameter. Uranus has 27 known moons (as of August 2014); not as many as Jupiter or Saturn, but definitely its own system of worlds which orbit the planet.

Uranus at a Glance

Characteristics to Compare

Atmosphere

- Hydrogen (H_2), Helium (H_e), Methane (CH_4), Ammonia (NH_3), Water (H_2O)

Rotation

- Short rotation — 17. 3 hours retrograde (backwards)

Revolution

- Long revolution — 84. 01 years

Rings

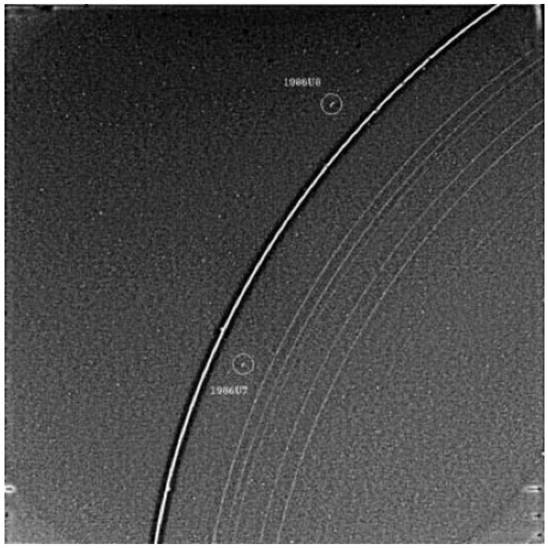
- An intricate system of rings:
  - 13 rings total; first 9 found via airborne telescope

Magnetic Field

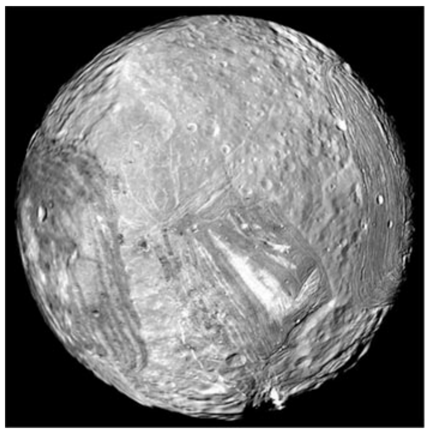
- Yes, tilted about 45 ^{o}. Reason for tilt unknown

Uranus Satellite of Distinction — *Chevron; is this possible tectonic activity? Probably collided with Uranus.*

Image of the planet UranusPublic Domain | Image courtesy of NASA.



Rings and Sheepherder moons (in circles)Public Domain | Image courtesy of NASA.


MirandaPublic Domain | Image courtesy of NASA.

8.11: Planet Neptune

Neptune was the first planet discovered through mathematical prediction. Urbain Le Verrier and John Couch Adams predicted the position in 1846. Neptune is smaller than Uranus, but denser. Like Uranus, Neptune is also referred to as an Ice Giant, as well as Uranus' twin. It too may have a very small rocky core. Neptune also exhibits more atmospheric activity than Uranus. Its Great Dark Spot is a storm similar to Jupiter's Great Red Spot, and about the same size as Earth. Neptune also has atmospheric scooters that are white cloud groups. It was so named because it moved faster than the Great Dark Spot. Its atmosphere sustains the highest winds in the solar system, in excess of 1,200 miles per hour. Like the other Gas Giant planets, Neptune also exhibits aurora activity.

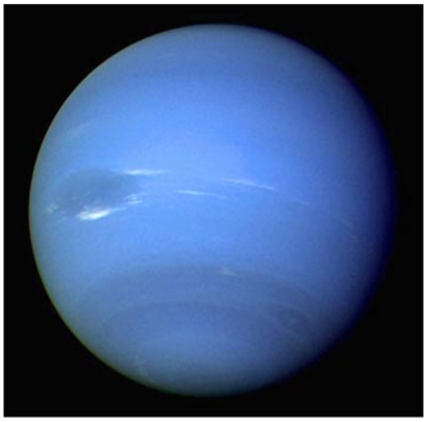
Neptune has five rings, which are composed of dark particles. The rings appear to be broken, more like arcs or ringlets. There are 14 known moons (as of August 2014).

Neptune at a Glance

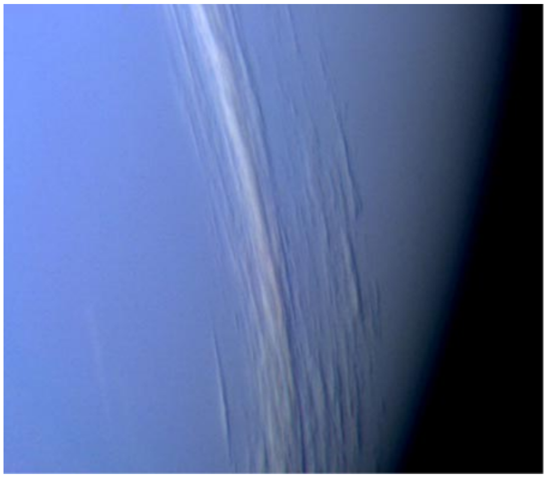
Characteristics to Compare

Atmosphere

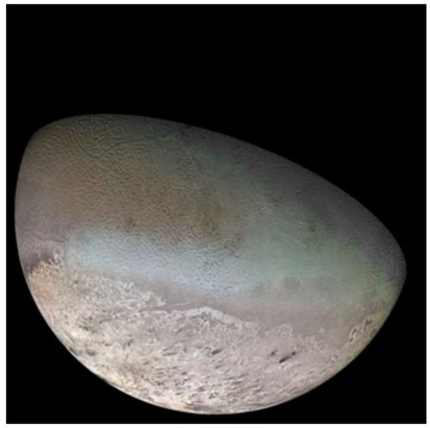
- Rotation
    - Revolution
        - Rings
            - Magnetic Field
                - **Neptune Satellite of Distinction** — *Triton (NOT to be confused with Saturn's moon of the same name); Retrograde (captured moon?), volcanism; polar caps.*



Neptune, showing the Great Dark Spot and ScootersPublic Domain | Image courtesy of NASA.



Clouds in the upper atmosphere of NeptunePublic Domain | Image courtesy of NASA.

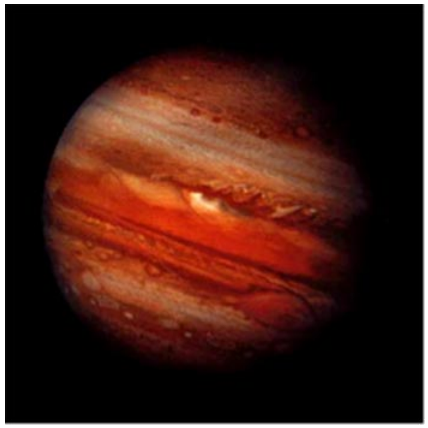


Neptune’s moon TritonPublic Domain | Image courtesy of NASA.

8.12: Gas Giant Planets and Select Satellites Overviews

Solar System's Gas Giant Planets at a Glance

Jupiter



Public Domain | Image courtesy of NASA.

Characteristics

Atmosphere

- Hydrogen (H_2), Helium (H_e), Methane (CH_4), Ammonia (NH_3), Water (H_2O)

Rotation

- Short rotation — 9. 8 hours

Revolution

- Long revolution — 11. 86 years

Rings

- One thin ring detected by the Voyager 2 spacecraft

Magnetic Field

- A very strong magnetic field; 20,000 times that of Earth's

Satellites

- 67

The Bottom Line…

- Largest solar system planet
- Great Red Spot
- Gives off more heat than receives
- Small, dense rocky core surrounded by H_2 and H_e
- Radio source
- Aurora
- Lightning and thunderstorms

Saturn

Public Domain | Image courtesy of NASA.

Characteristics

Atmosphere

- Hydrogen (H_2), Helium (H_e), Methane (CH_4), Ammonia (NH_3), Water (H_2O)

Rotation

- Short rotation — 10. 6 hours

Revolution

- Long revolution — 29. 46 years

Rings

- An intricate system of rings:
  - Spokes
  - Twisted F ring
  - Giant outer ring

Magnetic Field

- Yes

Satellites

- 62

The Bottom Line…

- Spectacular / intricate rings
- Would float in water
- Small, dense rocky core surrounded by H2 and He
- Polar hexagon
- Aurora
- Lightning

Uranus

Public Domain | Image courtesy of NASA.

Characteristics to Compare

Atmosphere

- Hydrogen (H_2), Helium (H_e), Methane (CH_4), Ammonia (NH_3), Water (H_2O)

Rotation

- Short rotation — 17. 3 hours retrograde (backwards)

Revolution

- Long revolution — 84. 01 years

Rings

- An intricate system of rings:
  - 13 rings total; first 9 found via airborne telescope

Magnetic Field

- Yes, tilted about 45 ^{o} . Reason for tilt unknown

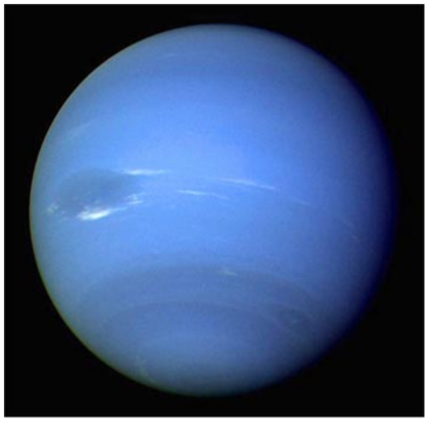
Satellites

- 27

The Bottom Line…

- 1st planet discovered with a telescope
- *Ice Giant*
- Very small rocky core
- Little atmospheric activity
- Looks like a billiard ball
- Aurora
- Neptune’s twin

Neptune



Public Domain | Image courtesy of NASA.

Characteristics to Compare

Atmosphere

- Hydrogen (H_2), Helium (H_e), Methane (CH_4), Ammonia (NH_3), Water (H_2O)

Rotation

- Short rotation — 16. 1 hours

Revolution

- Long revolution — 164. 8 years

Rings

- A partial, twisted series of 5 rings confirmed by the Voyager 2 spacecraft

Magnetic Field

- Yes, tilted about 45 ^{o}. Reason for tilt unknown

Satellites

- 14

The Bottom Line…

- 1st planet predicted position mathematically
- *Ice Giant*
- Very small rocky core
- Great Dark Spot, Scooters
- Looks like a billiard ball
- Aurora
- Uranus' twin

Consider this…

We consider the Gas Giant planets to be huge, especially Jupiter. But when compared to other stellar systems, they are small – even "king of the planets," Jupiter. Many of these hot Jupiters are much closer to their star than our Gas Giant planets and dwarf Jupiter in size. And it is theorized that some of these so-called "Super Jupiters" might be failed stars, that is, not quite enough mass for the nuclear fusion process. Nuclear fusion is where two particles collide at high speed and form a particle of a higher mass and a lot of energy.

Public Domain | Image courtesy of NASA.

CHAPTER OVERVIEW

9: Minor Bodies of the Solar System

9.1: Module Introduction

This module explores the minor bodies of the solar system: asteroids, comets, and dwarf planets, as well as meteors and meteorites.

Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

- Differentiate between the types of minor bodies found in our solar system
- List the characteristics of asteroids, including Near-Earth Asteroids (NEOs) and Potentially-Hazardous Asteroids (PHAs)
- Differentiate among meteoroids, meteors, and meteorites
- List the characteristics of three types of meteorites
- List the characteristics of comets
- List the characteristics of centaurs
- Explain the discoveries of Pluto and Eris
- List the characteristics of the Trans-Neptunian objects, Kuiper Belt and the Oort Cloud

9.2: Trans-Neptunian objects, the Kuiper Belt, and the Oort Cloud

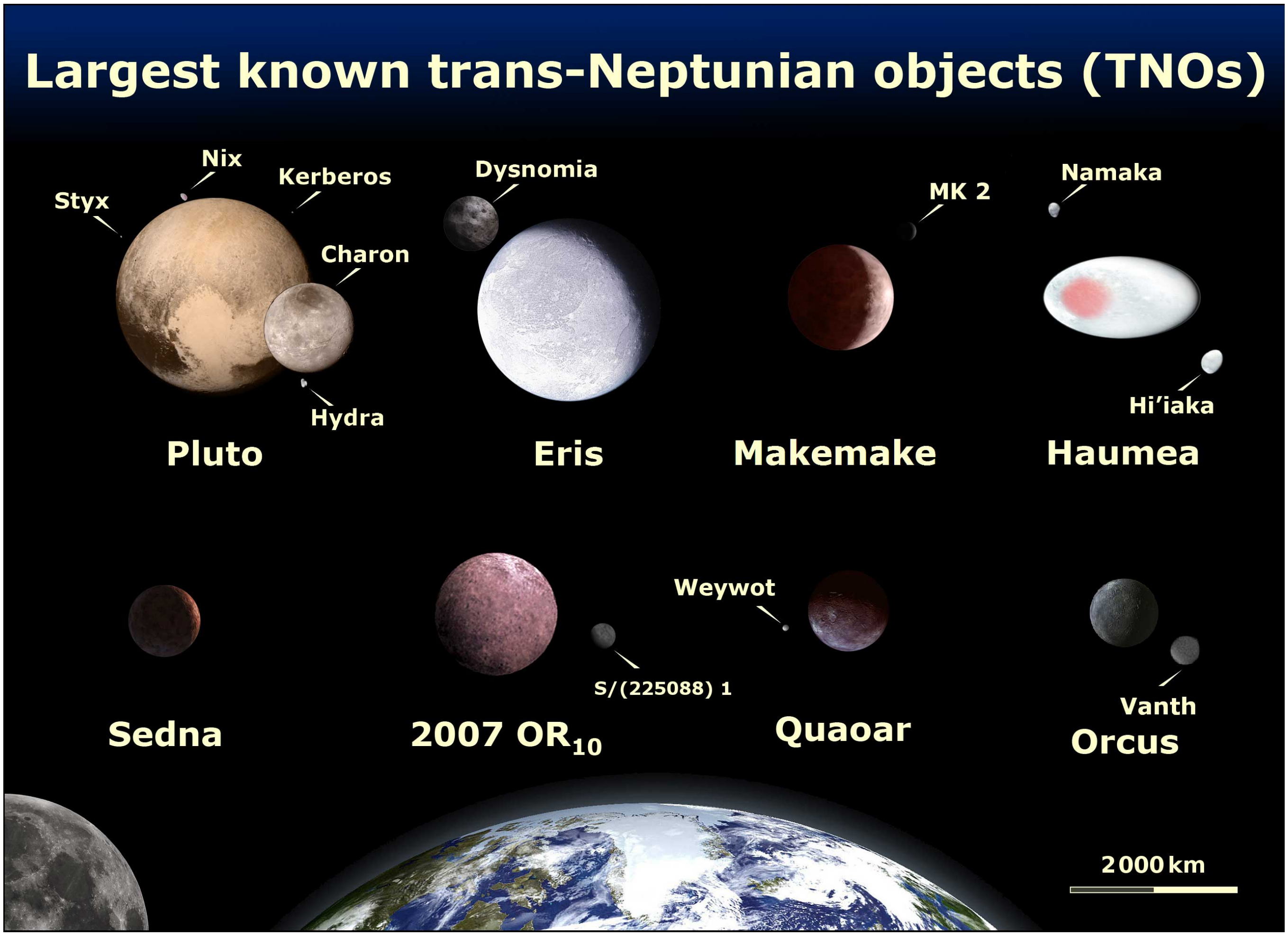
Trans-Neptunian objects (TNO) are any solar system minor planet that orbits the sun at a greater average distance than Neptune. Pluto is now considered a TNO, as is Eris. As of July 2014, over 1,500 trans-Neptunian objects have been cataloged and of these, some 200 have been designated as dwarf planets. From Earth, astronomers study TNO heat emissions, colors, and spectra. The **Kuiper Belt** is a region beyond the orbit of Neptune at 30 Astronomical Units (AU) to about 50 AU from the sun. It is sometimes called the **Edgeworth–Kuiper Belt**. The Kuiper Belt is much larger than the Asteroid Belt. It's about twenty times as wide and twenty to two hundred times as massive. Kuiper Belt objects, called **KBOs**, are composed of rock and metal, like the asteroids, but also frozen ices like ammonia, methane, and water. Trans-Neptunian objects are Kuiper Belt objects (KBOs), but KBOs are not TNOs because the distance range of KBOs from the sun is much farther out in the solar system.

At least two moons – Saturn's Phoebe and Neptune's Triton – are believed to be captured KBOs. To date, over 1,000 KBOs have been discovered and around 100,000 KBOs are suspected to exist.

KBOs are fragments from the original solar system's protoplanetary disc that did not combine to form the more-massive and larger bodies. Astronomers believe that belts of fragments like the solar system's Kuiper Belt are present around other stellar systems being studied.

9.3: The Oort Cloud and Kuiper Belt

The **Oort Cloud** is a hypothesized spherical cloud of icy objects up to 50,000 AU from the sun. This spherical cloud is the primary source of long-period comets. No Oort Cloud objects have been found, to date. Any object within the Oort Cloud would be called an **Oort Cloud Object, (OCO)**. The Oort Cloud would represent the physical boundary of the solar system.



CC BY-SA 3. 0 | Image courtesy of NASA and Wikimedia Author: Lexicon.

9.4: What do you think?

Ancient people feared comets. Knowing nothing about science or basic astronomy, can you imagine seeing this object—Comet Hale-Bopp, suddenly appear in the skies, larger and brighter than anything you have ever seen? How would the appearance of a bright comet have possibly affected you?

Image courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

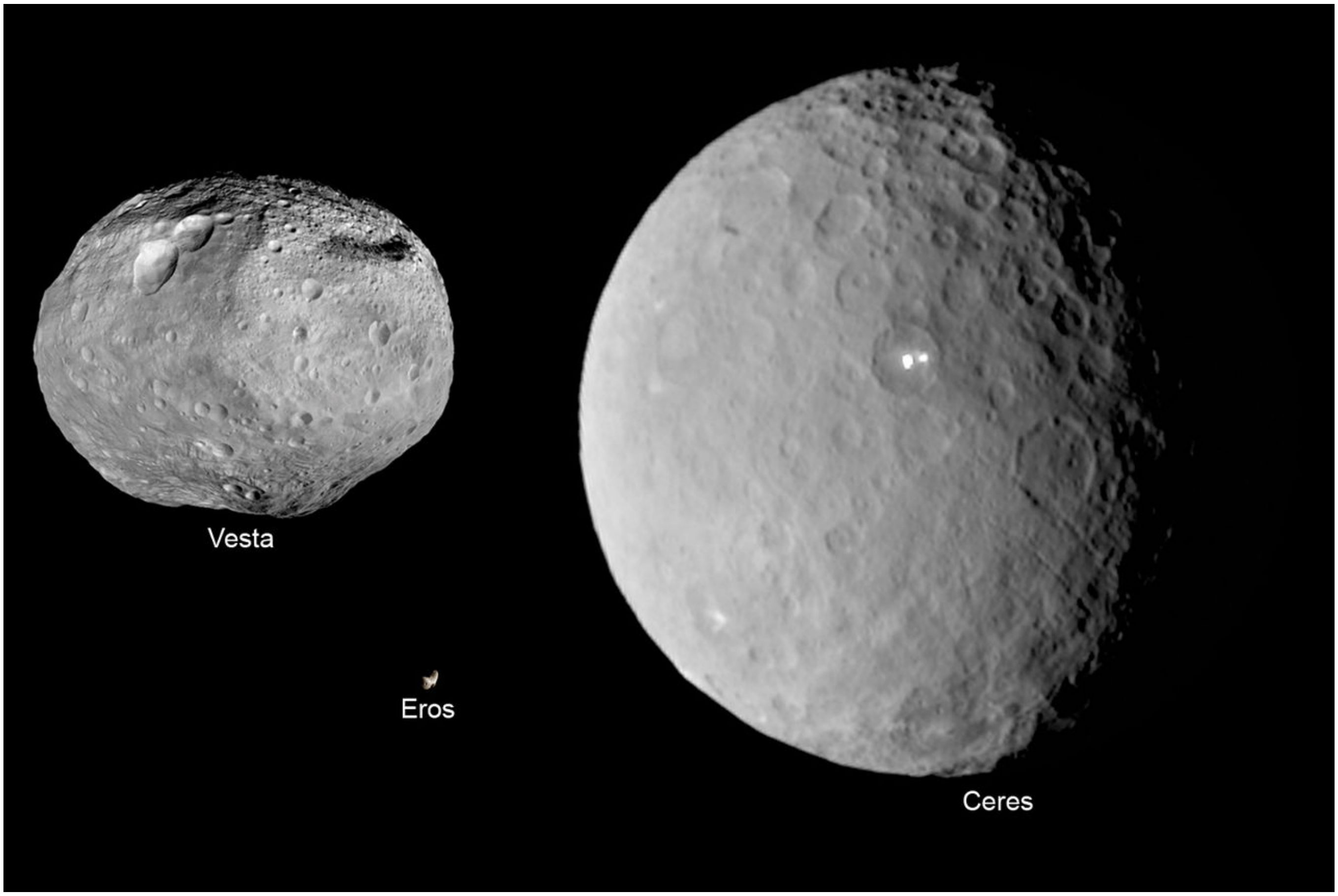
9.5: Minor Bodies

Minor Bodies are the smaller, often non-spherical objects found in the solar system. The minor bodies include the asteroids, comets, meteoroids, the groups of objects referred to as the Kuiper Belt Objects, Trans-Neptunian Objects, and Oort Cloud Objects, and other space junk and dust. Minor bodies are significantly smaller in size when compared to the sun and planets. Each of these objects usually has its own orbit, is mostly irregular in shape, and was formed from leftover solar nebula material.

Minor Planets specifically refer to the dwarf planets, asteroids, centaurs, Kuiper belt objects, and other trans-Neptunian objects.

9.6: Asteroids

The **asteroids** are a group of the solar system's minor bodies that are much like the Rocky Planets in composition: carbon-rich, silicate materials (rock), and/or metal. The word Aster-oid means star-like. Asteroids are also called **minor planets** (not to be confused with dwarf planets). The larger asteroids are called **planetoids**. Italian astronomer Giuseppe Piazzi discovered the first asteroid, Ceres, in 1801. Ceres, which orbits between Mars and Jupiter, was first thought to be a planet. Later that same year, Pallas was discovered in basically the same orbit as Ceres. And by 1807 two additional asteroids had been discovered: Pallas and Vesta. At this time, some 625,000 asteroids have been identified, and astronomers are finding new asteroids all of the time. Most of the asteroids orbit between Mars and Jupiter, an area called the **asteroid belt**.



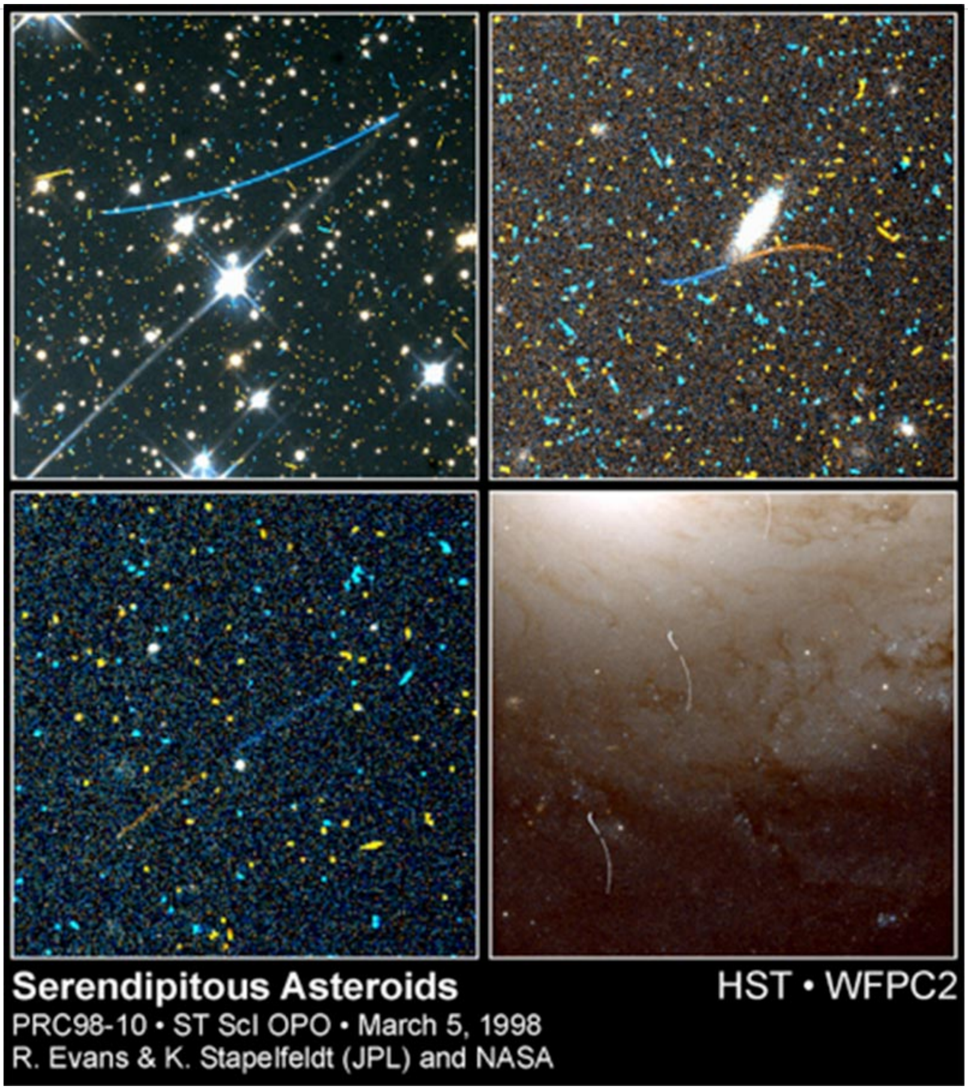
Public Domain

Ceres is the largest asteroid found to date, and was reclassified as a Dwarf Planet in 2006. Ceres appears to be fairly spherical in shape, which is unusual for asteroids in general. Ceres is 950 kilometers or 590 miles in diameter, and makes up a third of the mass of the asteroid belt.

There are a number of interesting **asteroid characteristics**. Asteroids are most-likely leftover material from the formation of the solar system. Most asteroids are quite irregular in shape, with sizes ranging from around 0. 6 mile to 590 miles (Ceres). Asteroids can have satellites. Ida, with its moon Dactyl, was the first discovered pair. Currently more than 150 asteroids are known to have a small companion satellite; some have two moons.

The asteroids are the parent body sources for most meteorite impacts on Earth and on other solar system bodies. Ninety-five percent of the original asteroids are no longer around; most were impactors. An **impactor** is an object that strikes, or impacts, another object. Asteroid impacts cause **catastrophism** : the sudden shaping of a planet's or satellite's surface due to an asteroid impact.

9.7: Brightest Asteroids Visible from Earth



Public Domain | Image courtesy of NASA.

(4) Vesta

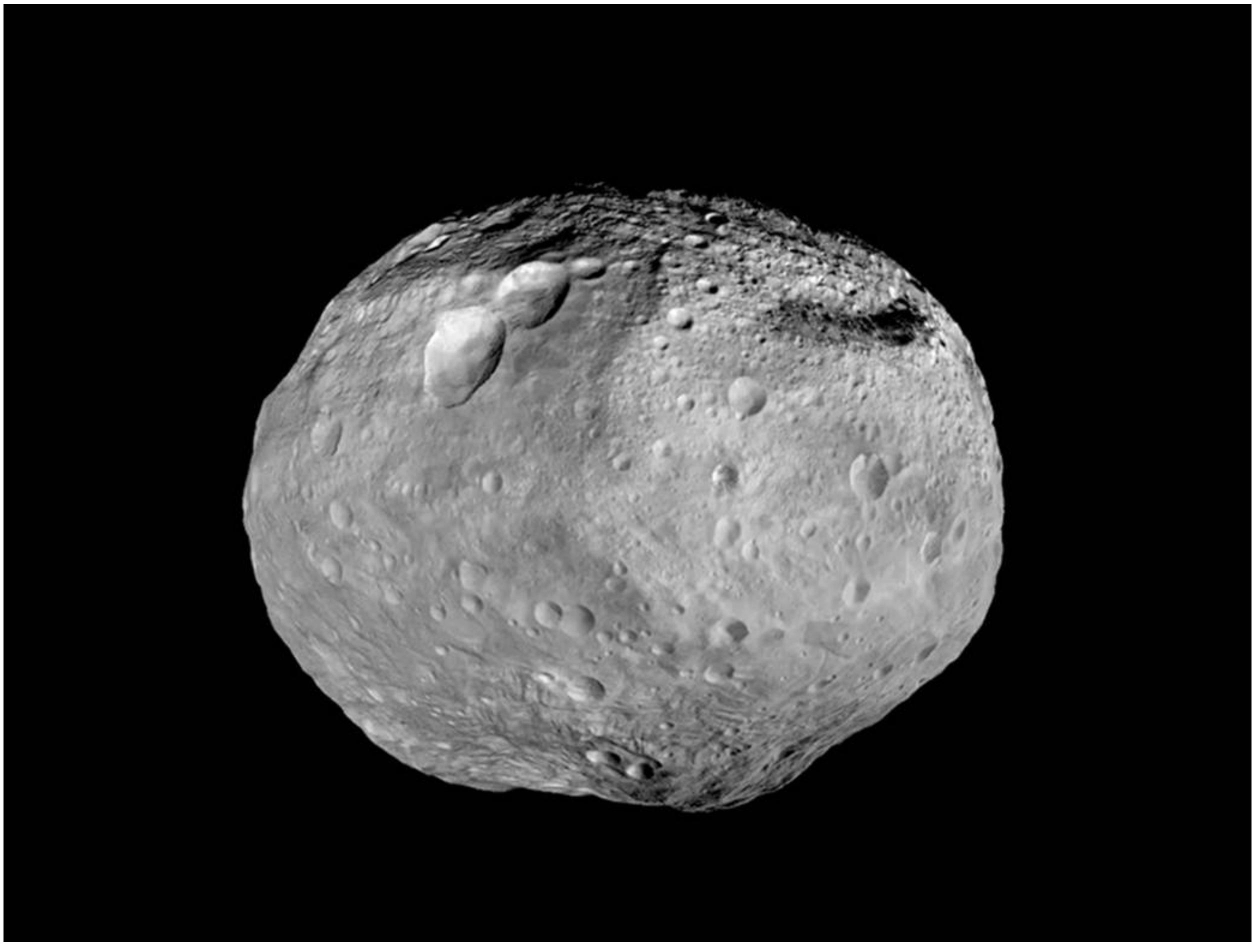


Image of the asteroid (4) VestaPublic Domain | Image courtesy of NASA/JPL-Caltech/UCAL/MPS/DLR/IDA.

Maximum Visual Magnitude

- 5. 1

Diameter in Miles

- 326

(2) Pallas

Maximum Visual Magnitude

- 6. 4

Diameter in Miles

- 338

(1) Ceres [Dwarf Planet]

Maximum Visual Magnitude

- 6. 7

Diameter in Miles

- 590

(7) Iris

Maximum Visual Magnitude

- 6. 7

Diameter in Miles

- 149 x 124 x 124

(433) Eros

Image of the asteroid (433) ErosPublic Domain | Image courtesy of NASA.

Maximum Visual Magnitude

- 6. 8

Diameter in Miles

- 21 x 7 x 7

9.8: Asteroid Classification

There are three major groups of asteroids, based on where they orbit in the solar system.

Main Asteroid Belt

Asteroids orbiting between Mars and Jupiter. This contains the majority of known asteroids and is estimated to have 1 to 2 million asteroids and a significantly higher number of smaller pieces (meteoroids and dust). These were most likely formed due to the gravitational attraction of Jupiter and experienced many collisions.

Trojan Asteroids

Asteroids share an orbit with a larger planet. The Trojan Asteroids do not collide with the planet because of where the Trojan asteroids orbit the sun in relation to the parent planet. Jupiter has the largest number of Trojan asteroids discovered to date.

Near-Earth Asteroids (NEAs)

Finally, there are the **Near-Earth Asteroids or NEAs** ; these asteroids pass close to Earth. About 10,000 NEAs have been discovered to date. And over 1,400 have been classified as **Potentially Hazardous Asteroids or PHAs** ; those asteroids that could pose a threat to Earth. PHAs come closer to Earth than about 5 million miles.

PHAs are being discovered all of the time, so the number of known PHAs continue to grow. None of the known potentially hazardous asteroids are on a collision course with Earth… **with one possible exception**. Astronomers employ the **Torino Scale** for categorizing the impact hazard associated with PHAs; the scale ranges from 0 to 10, with 0 being no chance and 10 being 100% chance of collision.

Asteroid 99942 Apophis was discovered in 2004, originally it was called 2004 MN4. The diameter of Apophis is approximately 325 meters or 1,066 feet. Apophis will pass dangerously close to Earth in 2029 and 2036. Observations and orbital calculations show there is no chance of impact during either of these close passages.

9.9: Meteoroids, Meteors, and Meteorites

Three terms that are often mistakenly used interchangeably are meteoroids, meteors, and meteorites. **Meteoroids** are materials orbiting in space and are smaller than asteroids.

Meteors are the streaks we see in the sky, commonly called *shooting* or *falling stars* ; also can be **fireballs** and/or **bolides**. Most **meteor showers** are comet "dust" left behind as a comet orbits the sun that Earth runs into this trail of dust as we orbit the sun.

Meteorites are materials that makes it to the surface of a planet, satellite, etc.

"I would more easily believe that (a) Yankee professor would lie than that stones would fall from heaven. "

—Thomas Jefferson (1808)

9.10: Meteorites

Meteorites are representatives of the early solar system. There are three types of meteorites. **Stones or Stony meteorites.** These are composed of silicates and other materials. Most stony meteorites contain metal in the form of iron and nickel. And stone meteorites are by far the most common type; some 94% of recovered meteorites are stony. Stone meteorites also include very rare types of meteorites, including lunar, Martian, and possibly even comets.

Iron meteorites, or Irons. These are composed of iron (Fe) and nickel (Ni), with some cobalt (Co) and other trace elements and minerals. Iron is the predominant metal, and the type of Iron meteorite depends on the ratio of iron to nickel. No Earth rock has iron and nickel in combination. Thus a ‘rock’ recovered with iron and nickel together is a meteorite. Irons are very dense meteorites, in comparison to stony meteorites.

Stony Irons. As the name indicates, they are a combination of iron and stony meteorite properties and the rarest type or class of meteorite. The **Pallasites**, a class within the Stony Irons, are simply spectacular. When sliced and polished, you can see a metal matrix of iron-nickel that surrounds crystals of olivine – peridot in gem terms.

9.11: The Impact of Meteorites

Meteorites can cause damage upon impact, from minor to significant. Examples of three major impacts causing significant damage in the last 100 years are included below.

Tunguska

Place

- Tunguska, Krasnoyarsk | Krai, Russia

Date

- June 30, 1908

The Impact

- An air burst comet or asteroid impact damaging over some 2,150 square kilometers or 830 square miles of forested area. No meteorites were ever recovered.

Sikote-Alin

Place

- Sikhote-Alin, Primorye | Russia

Date

- February 12, 1947

The Impact

- A brighter-than-the-sun fireball announced the arrival of an air burst impactor, showering some 28 tons of meteoritic iron shrapnel on the Sikhote-Alin Mountains.

Chelyabinsk Oblast

Place

- Chelyabinsk Oblast | Russia

Date

- February 15, 2013

The Impact

- 1,491 people were injured and over 7,200 buildings damaged by the air burst from this impactor, estimated to weigh 10,000 tons; numerous stone meteorites were found.

9.12: Comets

Often called dirty snowballs, **comets** are really more like snowy dirtballs. Presently, there are around 5,000 known comets; with new comets being discovered all of the time. The number of known comets is much smaller in number than the known number of asteroids. Many comets orbit in the **Kuiper Belt** and the **Oort Cloud**. Comet orbits are often highly elliptical, so much so that these orbits are sometimes described as cigar-shaped. Comet orbits around the sun can be a short period (<200 years) or a long period (>200 years).

Comets are named after their discoverers, which is a tradition that spans centuries. And hundreds of years ago some European astronomers made their living discovering comets.

We have seen a comet impact a planet; Comet Shoemaker-Levy 9 impacted Jupiter with 21 cometary fragments in July 1994. Gene and Carolyn Shoemaker and David Levy discovered the comet.

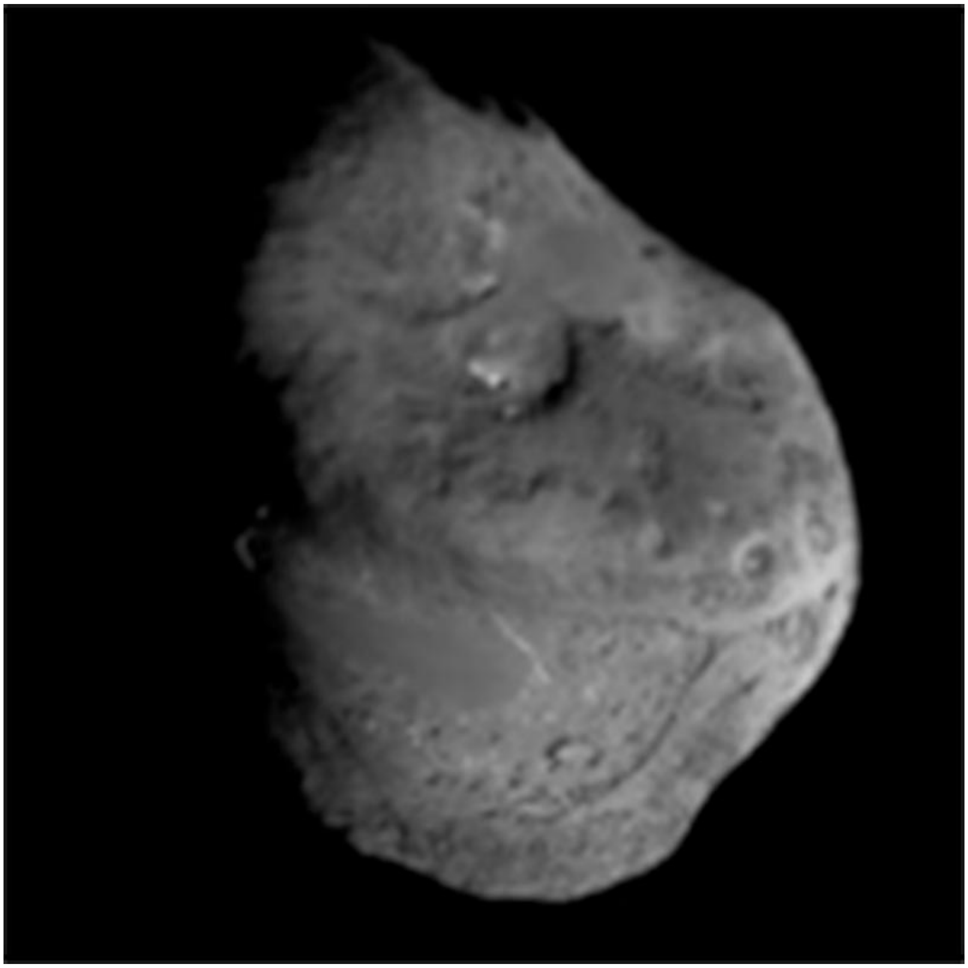
"Comets are like cats. They both have a tail and they both have a mind of their own…"

—David Levy (1994)

9.13: Comet Characteristics

Comets are composed of Carbon dioxide (CO2), water ices, silicates, and organic material. The materials at the surface of the comet are of a talc-like fineness, as seen up close on Comet Tempel-1. Comets are the sources for the majority of our meteor shower "material;" the fine dust comets leave behind like bread crumbs as they orbit the sun.

The comet's **nucleus** is the solid, core structure of a comet. The **coma** or **head** is the fuzzy haze that surrounds the comet's nucleus. The **tail** may be made of gas, dust, or both. The **coma** and **tail**are what we see from Earth. The sizes of comet nucleus have been observed up to around 30 kilometers or 20 miles in diameter. When a comet gets close to the sun, they begin to heat up and outgas, making for the coma and sometimes a tail.



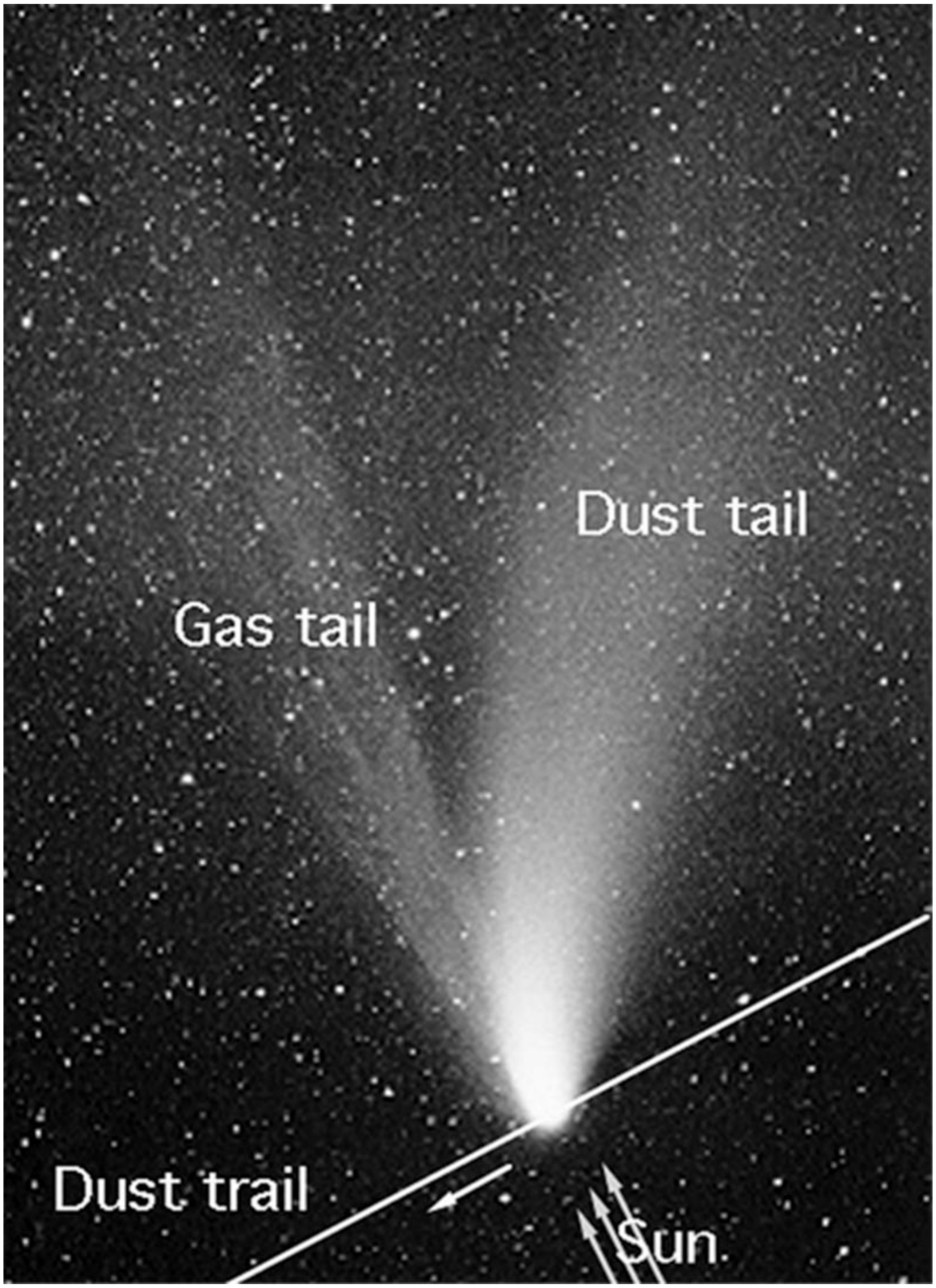
Tempel-1 cometPublic Domain | Image courtesy of NASA.

The behavior of comets is often unpredictable, due to their interactions with the sun, and other solar system dynamics. Comets, which have made numerous passages around the sun, appear to produce less dust and gas, thus less-impressive tails. Often first-time inner solar system comets can break up when passing near the sun, which was the unfortunate fate of Comet ISON in 2013.

The **true nucleus** of a comet has been seen six times: Halley (1986), Borrelly (2001), Wild-2 (2004), Tempel-1 (2004 and 2005), Hartley-2 (2010), and Churyumov-Gerasimenko (2014). If all goes according to plan, the European Space Agency's Rosetta spacecraft will release a lander, called Philae, in November 2014. Philae will land on Comet Churyumov-Gerasimenko, providing us with a wealth of data.

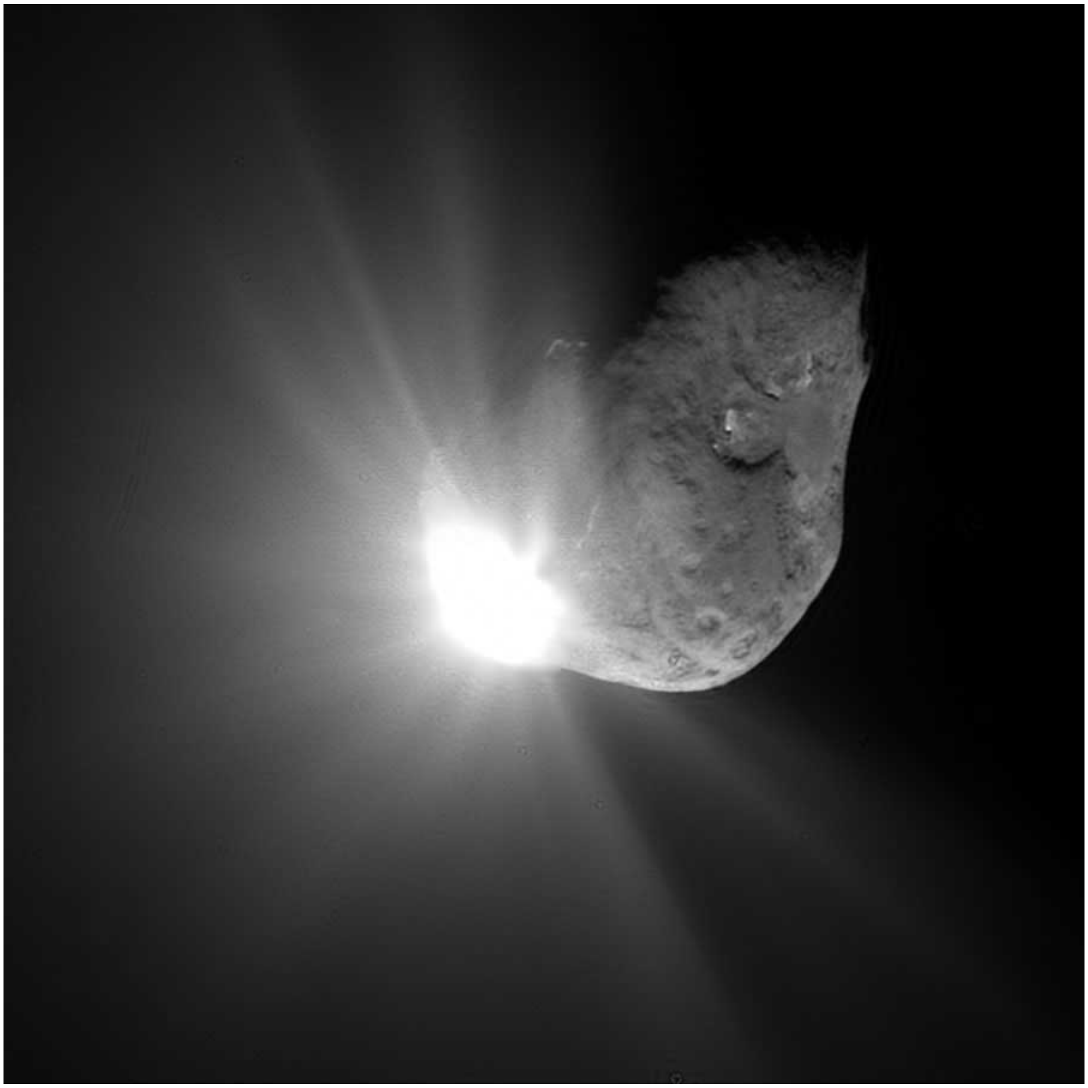
9.14: Images of Comets

Public Domain | Image courtesy of NASA.



Public Domain | Image courtesy of NASA.

CC SY-SA 3. 0 | Image courtesy of Wikimedia Author: Soerfm.



Public Domain | Image courtesy of NASA.

9.15: Comets in History

Comets have often been written about and portrayed in history. Some of the earliest comet observations were recorded by the Chinese on oracle bones. Oracle bones were pieces of turtle shells and bones used for a form of divination. Aristotle thought and proposed that comets were an atmospheric phenomena, in other words, not in our solar system or in space.

Comets were considered bad omens until the 16th century. These omens would include crop failures, diseases, deaths of royalty, or other such catastrophic events. Pliny the Elder (23-79 AD), a Roman natural philosopher, thought comets were the cause of political issues and death. Halley's Comet made a passage at the same time during the Battle of Hastings in 1066.

9.16: Scientific Advances

In the more-advanced and scientific approaches to comets, Tycho Brahe measured the parallax of a comet in 1577, which showed it was outside the atmosphere of the Earth. Isaac Newton derived his Law of Universal Gravitation, for which he showed the occasional parabolic orbits of objects. He was able to correlate a parabolic orbit to a comet in 1680. Edmund Halley applied Newton's Law of Universal Gravitation to a series of comet appearances over some 350 years. Three of these comet appearances had similar orbits; Halley hypothesized it was the same comet. Based on this, Halley predicted the comet would return in 1758 or 1759; the comet did appear as Halley predicted and was named Halley's Comet.

9.17: Halley's Comet

Perhaps the best-known comet, Halley's Comet, has been a regular visitor through the solar system for thousands of years. Halley is pronounced like Valley … hæli. The comet has been observed and recorded since at least 240 BC. Records of Halley's passages were made by the Chinese, Babylonians, and medieval Europeans. Recall, Edmund Halley was the first astronomer to determine that Halley's comet was the same comet that passed by Earth every 75-76 years. The 1910 Earth passage of Halley's Comet brought much scientific revelation, and much fear. Cyanogen gas was discovered by astronomers during the 1910 passage, leading to mass panic among the public. People were selling comet pills, comet umbrellas, and gas masks.

Halley's Comet was the first comet to be visited by spacecraft, in 1986; Vega 1 (USSR) and Giotto (European Space Agency). And, interestingly, it turns out that in the last 2,000 years the least-visible or poorest passage of Halley's Comet to Earth was in 1986. The next close passage of Halley's Comet will be July 2061; so mark your calendars!

Halley's Comet in *1910*Public Domain

9.18: A Comet Impacts a Planet

Except for seeing meteors enter our atmosphere, no contemporary astronomer had ever observed an impact on another world until 1994. **Comet Shoemaker–Levy 9, S-L 9,** was discovered in March 1993 by astronomers Eugene and Carolyn Shoemaker and David Levy. Carolyn's first impression of the discovery photo was it "looked like a squashed comet. " This description was due to the fact that the comet had been broken apart by the gravitational pull of Jupiter. The largest cometary fragment was 2 kilometers or 1. 2 miles across.

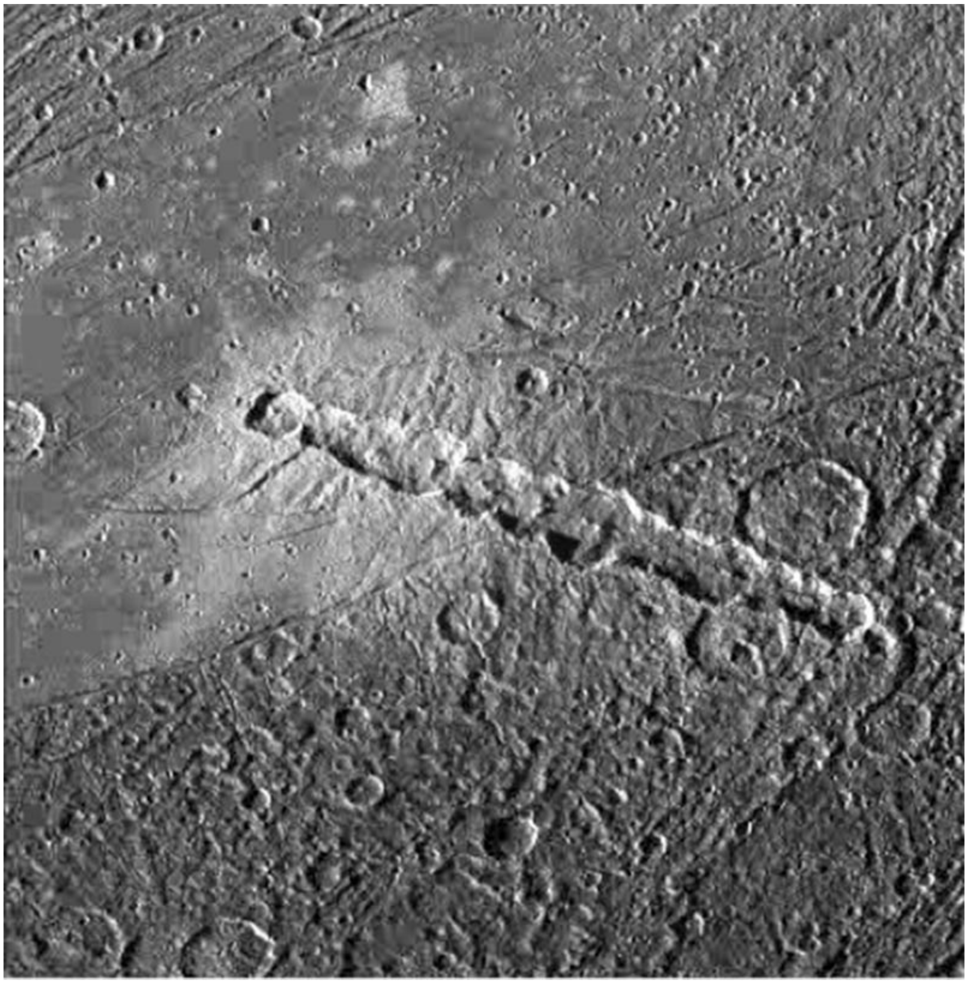
Public Domain | Image courtesy of NASA.

After determining the comet's orbit, it was found that Shoemaker–Levy 9 fragments would impact Jupiter over several days, 22-26 July 1994. The question became if the impacts would be visible to astronomers and orbiting satellites, like the Hubble Space Telescope.

Over the five-day period, twenty-one (21) distinct impacts were observed by satellites like the Hubble Space Telescope, as well as Earth-based telescopes. Fireballs resembling an atomic bomb mushroom cloud were seen at Jupiter's horizon. Dark spots were seen in the upper atmosphere of Jupiter after impact; these were visible even in small amateur telescopes. Some of these spots were as big as Earth. The black impact features were visible on Jupiter for months; some likened them to a black eye. Due to the S-L 9 series of impacts, astronomers were better able to explain rows or chains of craters found on the Moon and other objects, like Jupiter's moon Ganymede.

NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA.

NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA.



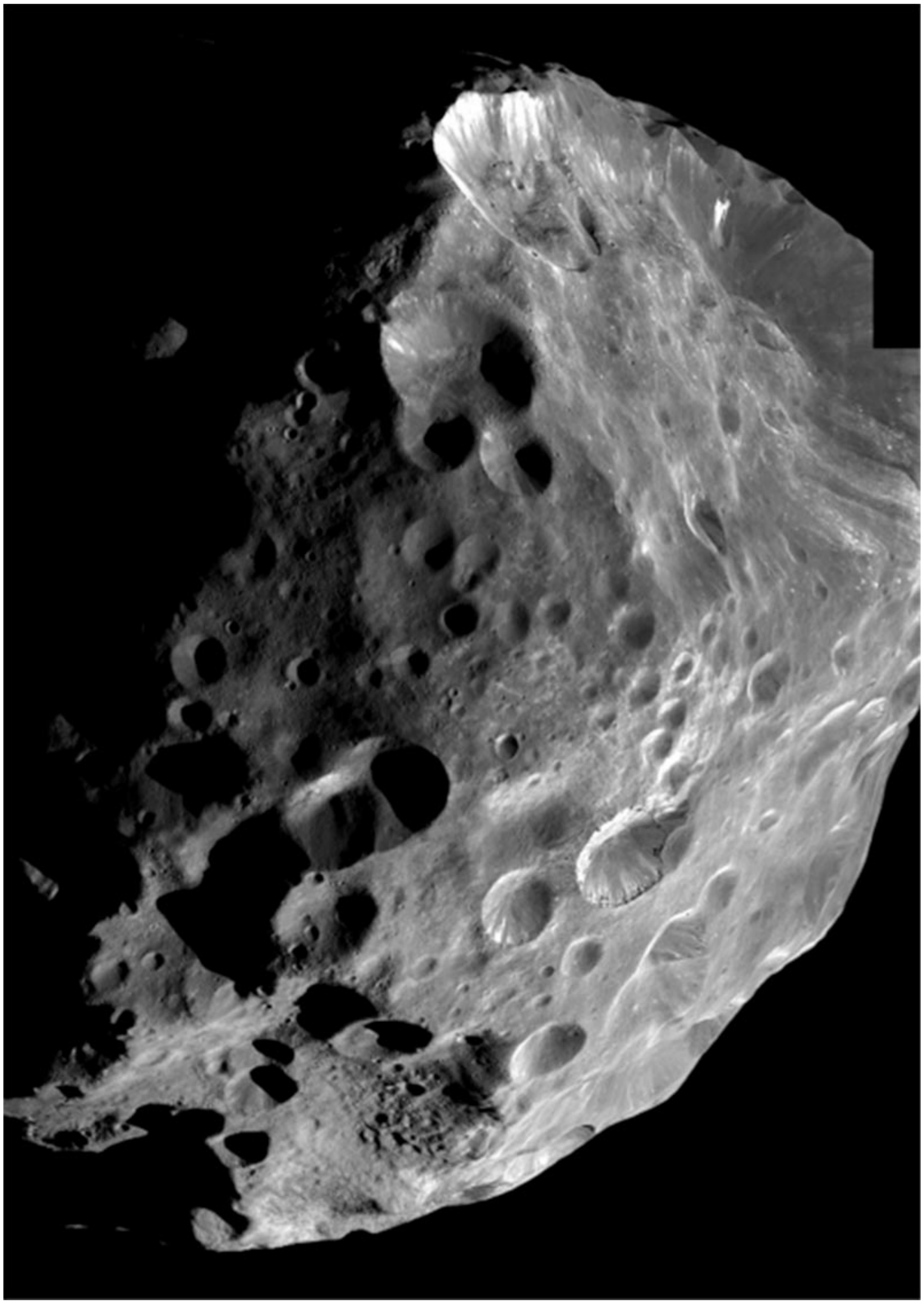
NASA Galileo SpacecraftPublic Domain | Image courtesy of NASA.

9.19: The Centaurs- Are they Asteroids or Comets?

In the past few years, astronomers were closely observing asteroids that had characteristics of comets, and comets, which seemed more like asteroids. Astronomers determined they had found a new group of objects: the Centaurs. These objects are named after the mythological beings that were a mixture of human and horse. **Centaurs** behave with characteristics of both asteroids and comets; the formerly clean line between comets and asteroids was gone.

It is thought that perhaps 44,000 centaurs exist. Most centaurs have been found between Jupiter and Neptune, crossing the orbit or orbits of one of the Gas Giants. Several varying characteristics have been observed with identified centaurs being studied. What has been found so far is water ice on their surfaces, exhibiting comet-like tails, and the fundamental make-up of asteroids and not comets. There may be some relation between the centaurs and the Kuiper Belt Objects.

Probable the most notable centaur is **Chiron** ; an approximately 110-kilometer-wide object that displays characteristics of both an asteroid and the nucleus of Halley's Comet. Saturn's moon Phoebe might be a captured centaur. No confirmed centaur has been photographed up close.



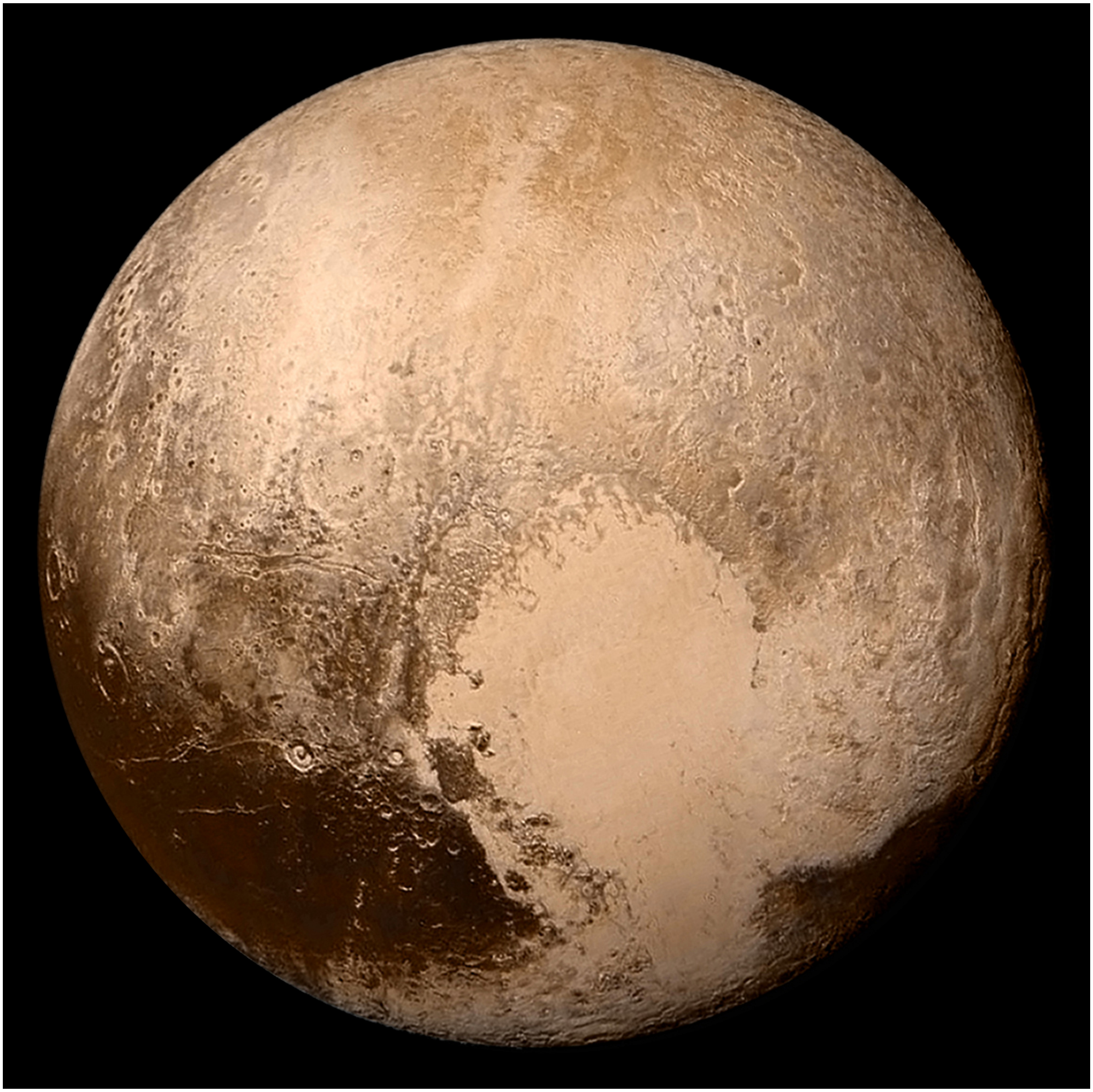
Public Domain | Image courtesy of NASA.

9.20: Pluto

Pluto enters the solar system's stage. The then 9th planet was discovered in 1930 by Clyde Tombaugh at Lowell Observatory. The first two letters of **PL** uto are also for **P** ercival **L** owell, who mathematically predicted the location. In Roman mythology, Pluto (Greek: Hades) is the god of the underworld. This seemed like a fitting name for a planet so distant from the sun. Pluto has been controversial in recent years. Is Pluto a planet? Is it a comet or a centaur? Pluto appears to outgas like a comet and it appears to have more of a carbon monoxide, CO, atmosphere. Why does it have a moon, **Charon**, which is nearly the same size as Pluto, and also has four smaller moons, making five moons total? Pluto and Charon orbit around each other; a true double-dwarf planet system.

Pluto has a highly-elliptical orbit, more like a comet or asteroid than a planet. It is so elliptical that Pluto's orbit crosses inside the orbit of Neptune for a short period. And the orbit of Pluto is highly tilted against the plane of the solar system's planets.

Many of these questions will be answered in 2015 as the NASA spacecraft **New Horizons** arrives at Pluto after a nearly-decade long trip from Earth.

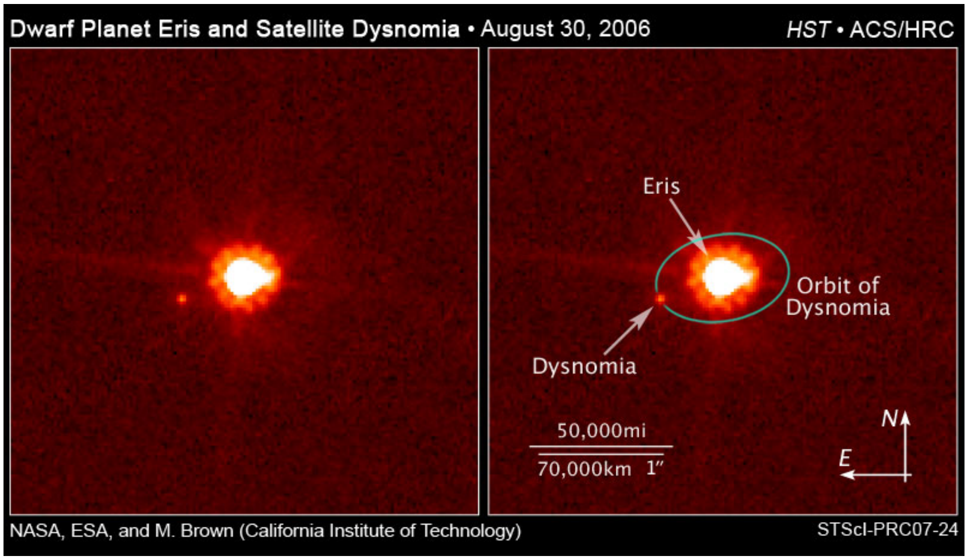


Public Domain | Image courtesy of NASA.

9.21: Eris

Planet X: 2003 UB313, Eris was discovered by Dr. Mike Brown on October 21, 2003. After multiple observations in July 2005, the discovery of Eris was confirmed and formally announced. Eris is about 14. 5 billion kilometers from the sun and is in a very highly tilted orbit compared to the other planets. Eris is about 2,326 kilometers in diameter, whereas Pluto is 2,338 kilometers. Like Pluto, Eris is probably a very large comet or ice ball with a moon. Eris is named after the Greek Goddess of chaos and strife. A moon has been discovered orbiting Eris, named Dysnomia (Eris' daughter who was the spirit of lawlessness). Dysnomia is about 250 kilometers in diameter.

When first discovered, Brown gave Eris the name Xena, and its moon Dysnomia the name Gabrielle. Later the International Astronomical Union adopted the names Eris and Dysnomia.



Public Domain | Image courtesy of NASA.

CHAPTER OVERVIEW

10: The Sun

10.1: Module Introduction

"Here Comes the Sun
Here comes the sun
Here comes the sun,
and I say, It's all right
Little darling
It's been a long, cold lonely winter
Little darling
It feels like years since it's been here"
…
Sun, sun, sun, here it comes

George Harrison
The Beatles
Abbey Road, 1969

This module overviews our star, the Sun, how light and energy are produced, the various solar regions and features, and how we observe the Sun.

Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

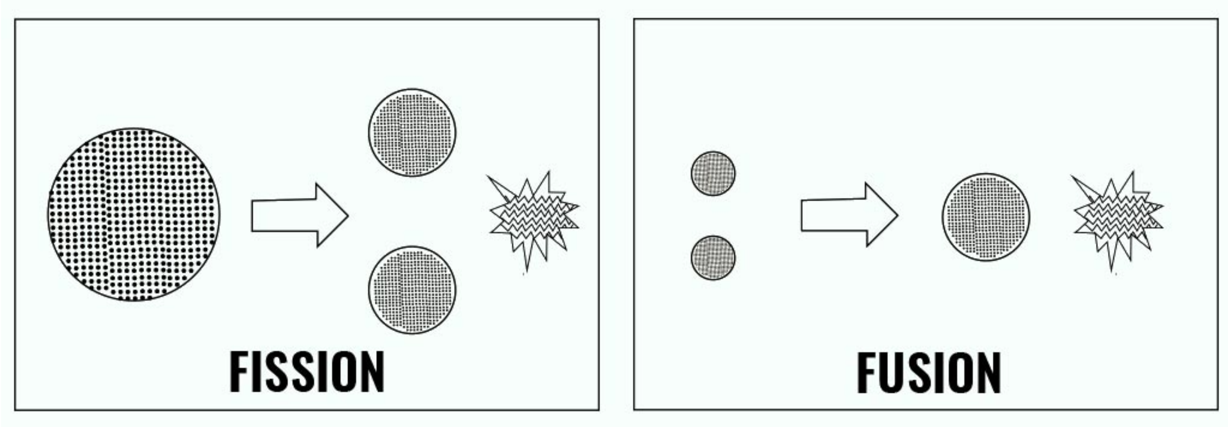
- Describe the production of energy and light through the proton-proton cycle
- Be able to identify the Sun's regions
- Be able to identify the Sun's solar features
- Overview how we study the Sun
- Identify the potential dangers it can pose to Earth

10.2: What do you think?

What would life be like if Earth was in the orbit of Venus or Mars? Would life be possible? Would life as we know it be possible? How much do we depend on the sun?

10.3: Fission and Fusion

Fission is the splitting of large nuclei of certain isotopes into smaller nuclei along with the release of energy with several free neutrons. Almost all of the fission fragments or products are radioactive. Neutrons released during the fission process can strike other nuclei and cause them to split, called a **Chain Reaction**. **Fusion** is the combining of particles to produce a new isotope and energy; **think of nuclear fusion as being the opposite of nuclear fission**. Fusion is the combining of particles into larger particles, whereas fission is the splitting of particles into smaller particles. The fusion process involves smaller nuclei than the fission process. When fusion occurs at a very high temperature — 50 million degrees Celsius, this is referred to as **thermonuclear fusion**.



The Fission versus Fusion processCC BY-SA 3. 0 | Image courtesy of Wikimedia Author: Kelvinsong.

10.4: Our Star, the Sun

The sun, our central star in the solar system, plays a major role in life on Earth. The sun is about 300,000 times closer than the next closest star, Proxima Centauri. It takes light about 8. 3 minutes to travel from the sun to Earth; whereas light from Proxima Centauri takes over four years. Size and temperature-wise, the sun is an “average” star, at best. The sun goes through constant changes: energy output, brightness, size; all of which affect Earth.

Studying the sun and how it works allows astronomers to understand other stars. This study of how stars work is called **Astrophysics**. We specifically study the sun’s **fusion** process.

The sun’s **photosphere** vibrates like ripples on a pond. This is due to the sun producing sound waves through the gases. Sound waves and ripples emanate from within the Sun at very low frequencies deep within the Sun and higher frequencies close to the Sun’s surface. Studying these ripples and sound waves allows astronomers to examine the sun’s interior.

The sun in white light is visible through a small telescope. Note the sunspots; the large group is near the center. CC BY-SA 3. 0 | Image courtesy of Wikimedia Author: SiriusB.

10.5: How the Sun Works

The sun does not burn. The belief that the sun does burn is a misconception. In stars the size of the sun or smaller, the fusion process is referred to as the **proton-proton cycle** or **proton-proton chain reaction**. The general steps to the Proton-proton cycle include:

1. It takes about 100,000 years for that energy to get from the sun's core to the photosphere.

10.6: A “Quick Guide” to Solar Fusion—The Proton-Proton Cycle

Two protons fuse to yield deuterium, which fuses with a proton to form He-3. This fuses with another He-3 to form He-4, two protons, and a lot of energy is produced and released during this process. The Proton-Proton Cycle is for *less-massive* stars, like the sun.

Eighty-five percent of the sun’s energy comes from this type of reaction; other reactions include:

1. A He-3 atom and a He-4 atom combine to form a beryllium-7 ($4p^+ + 3n^0$) and a γ
2. A Be-7 atom captures an e- to become lithium-7 atom ($3p^+ + 4n^0$) and a neutrino
3. A Li-7 combines with a p+ to form two He-4 atoms

It appears that the sun has used about 50% of its Deuterium. So, what happens when the sun uses 100% of its Hydrogen? *The Proton-Proton Cycle will continue until the sun runs out of Hydrogen.* This is much like a car running out of gas – unless you can syphon fuel from another car (or another star).

How do we know that Solar Fusion happens? We look for the neutrinos from the fusion process by counting the actual number of neutrinos received versus the calculated number of neutrinos expected.

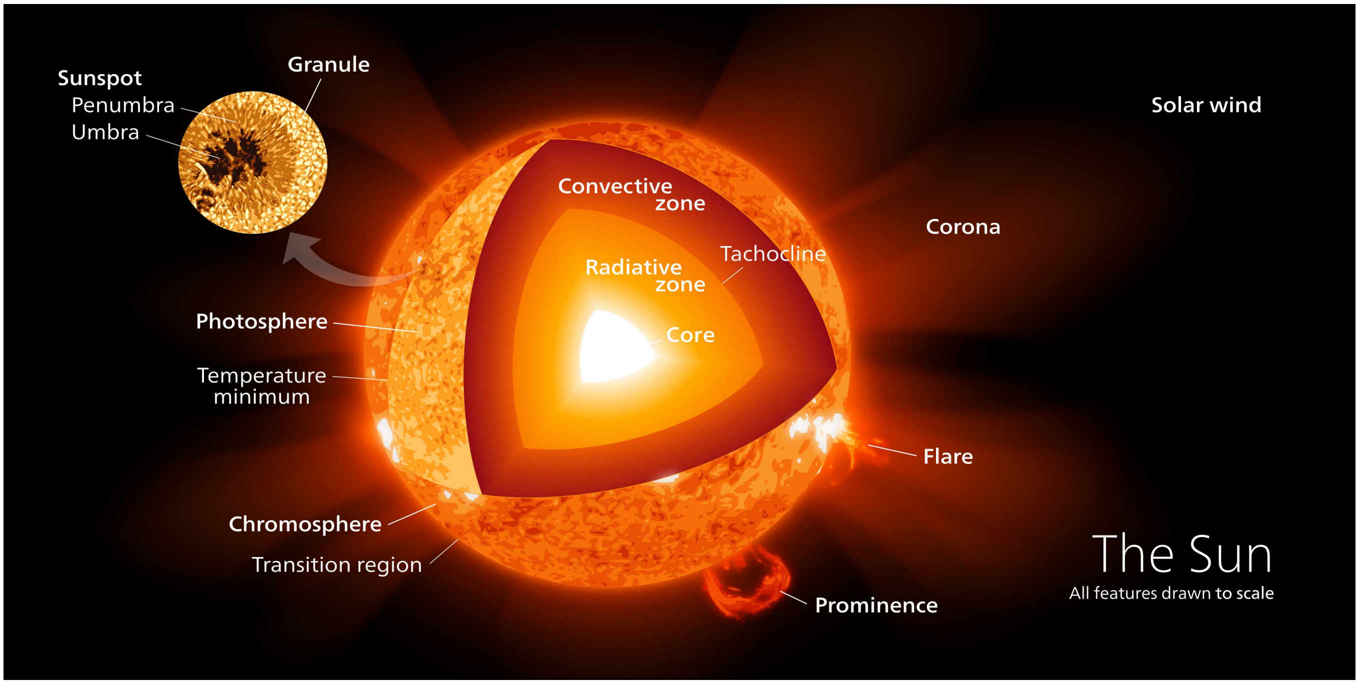
More-Massive Stars

For stars more massive than the sun, the Proton-Proton cycle can still occur, but another reaction sequence becomes more favorable for converting hydrogen to helium. It is called the **CNO cycle** ;**C** arbon- **N** itrogen- **O** xygen. These stars are ~1. 33 solar masses or larger with the final fusion end product being the element iron, Fe. The process goes no further because iron cannot be fused due to its binding energy.

10.7: Solar Regions

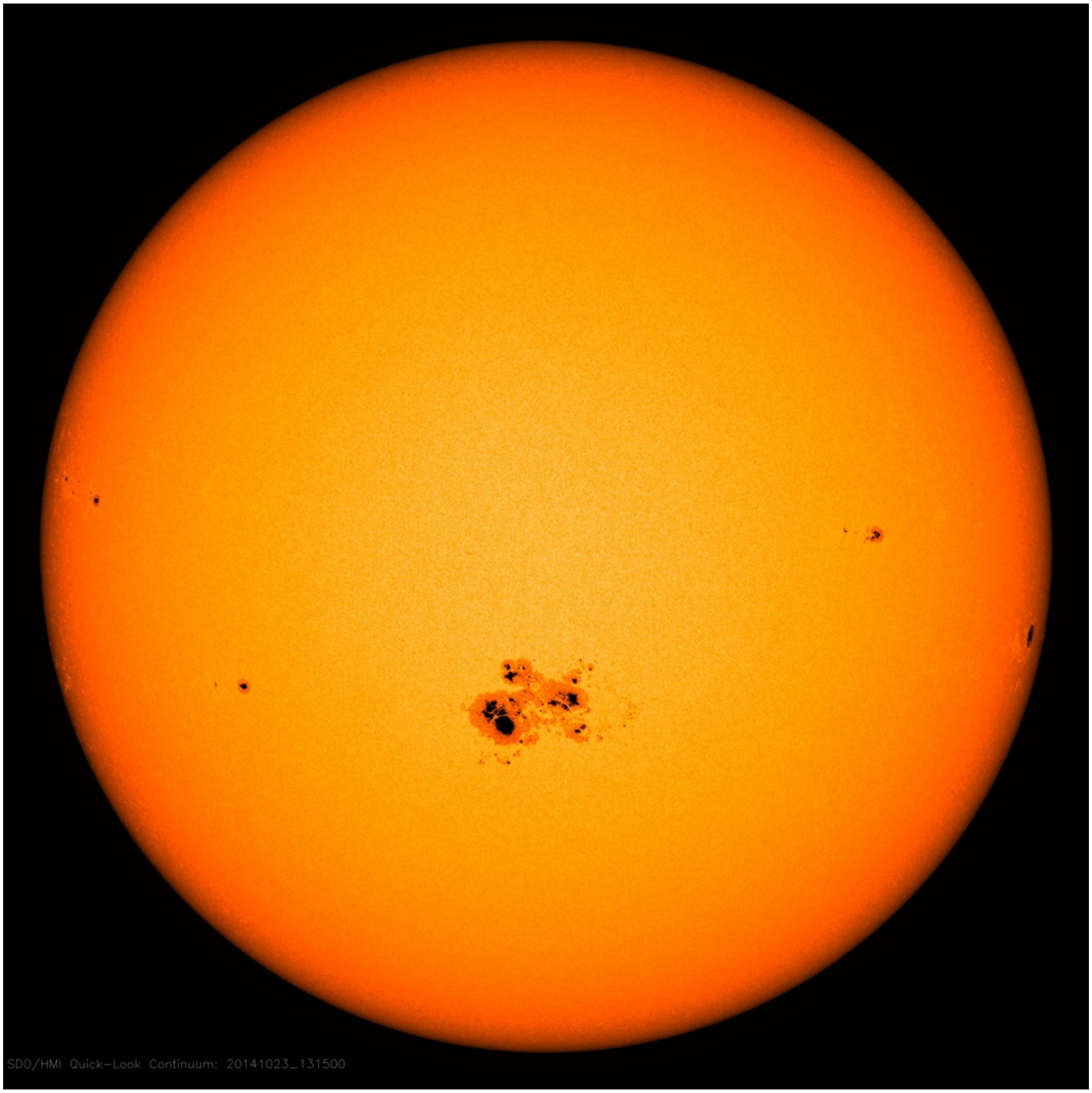
Astronomers identify four major regions within the sun.

1. First there is the sun’s **Core**, the central region where nuclear fusion occurs. This is a very high temperature gaseous soup of charged particles called plasma at 15 million degrees.
2. Next is the **Radiative Zone**, where energy generated in the core is carried by light that bounces from particle to particle through the Radiative Zone.
3. Above the radiative zone is the **Interface Layer**, where it is thought the sun’s magnetic field is generated. This layer or zone lies between the Radiative and Convective Zones.
4. The **Convective Zone** is the region in which energy is transported outward by convection; 70% of the sun’s radius. Convection occurs because heated fluids rise and cooler fluids fall. Convection is the area of the sun which shows rising heat – recall that heat rises and cold falls.



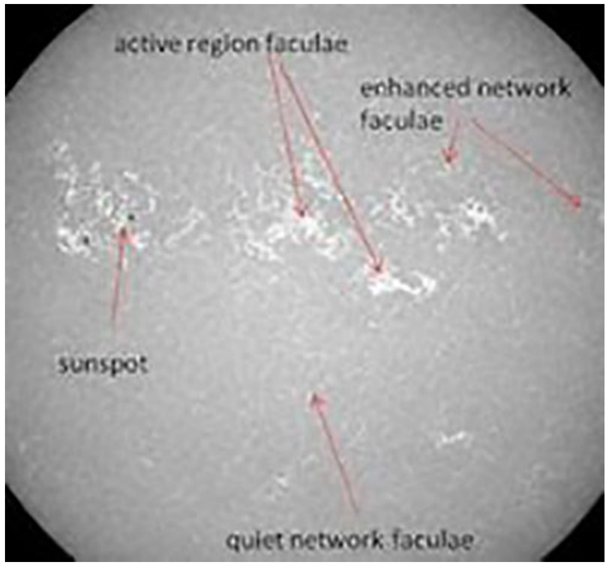
Regions of the SunPublic Domain | Image courtesy of NASA.

10.8: Major Solar Features



Photosphere, with SunspotsPublic Domain | Image courtesy of NASA.

The **Photosphere** is the visible portion of the sun. It consists of the area in which gaseous layers change from completely opaque to being transparent. The photosphere is also the lowest observable layer of the solar atmosphere.



Solar *Faculae*Image courtesy of courtesy of P. Foukal, Heliophysics, Inc.

Faculae are bright areas visible on the Photosphere. The term faculae is Latin for “little torch. ”

Image courtesy of Hinode JAXA/NASA/PPARC.

Granulation is vast gas bubbles, with rising centers and sinking edges. This bubbling pattern is due to solar convection, as noted in the sun’s regions. Each granulation cell is about 1,000 miles across; compare that to the diameter of Earth at a little under 8,000 miles. Granulation is also a photosphere feature.

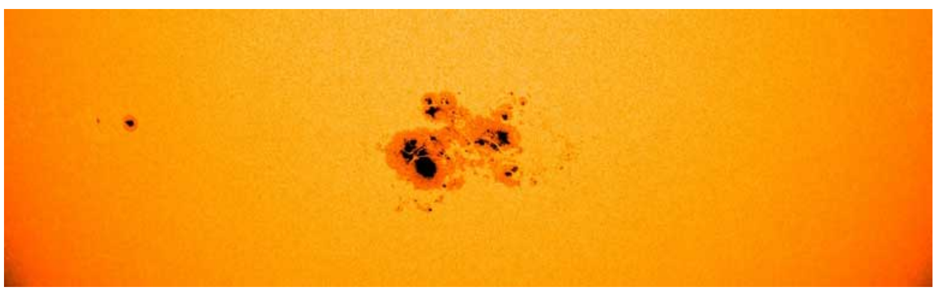


Image courtesy of Nasa/SDO.

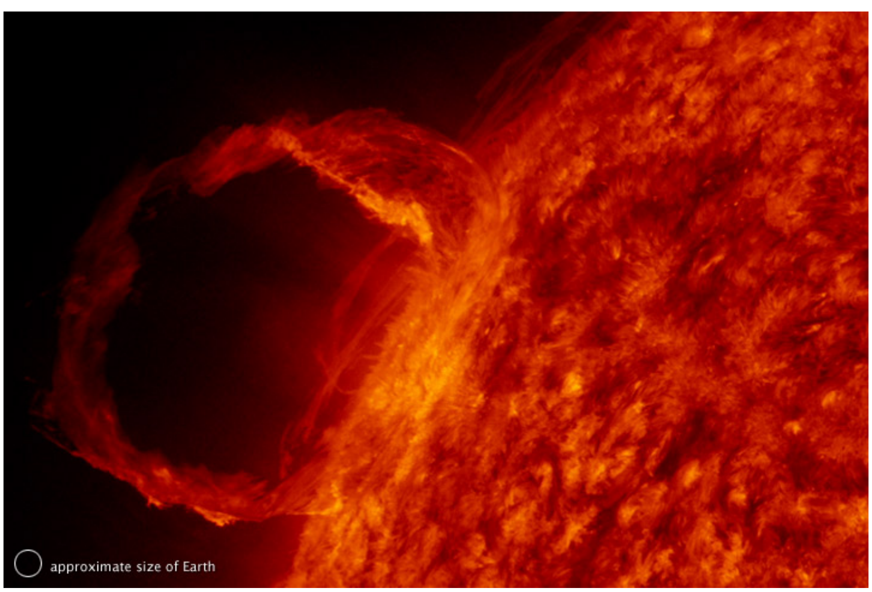
We observe **limb darkening** because the sun is a sphere, near what is seen as the edge of the solar disk, the light must travel farther through the solar atmosphere. This causes the limb to be dimmer than the rest of the disk.

Sunspots are temporary disturbed magnetic areas in the Photosphere. Sunspots come in many shapes and sizes, according to the status of the sun’s magnetic field. This magnetic field traps gas, slowing its motion, and making it cooler than the surrounding area. Sunspots look dark because it is cooler than the surrounding area. Usually, sunspots have two parts: a darker central region called the **umbra** surrounded by a lighter region called the **penumbra**. Astronomers have noted a sunspot cycle. This cycle averages in duration of slightly more than 11 years, in which **sunspot**frequencies varies from a maximum to a minimum and back to a maximum again.

Image courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

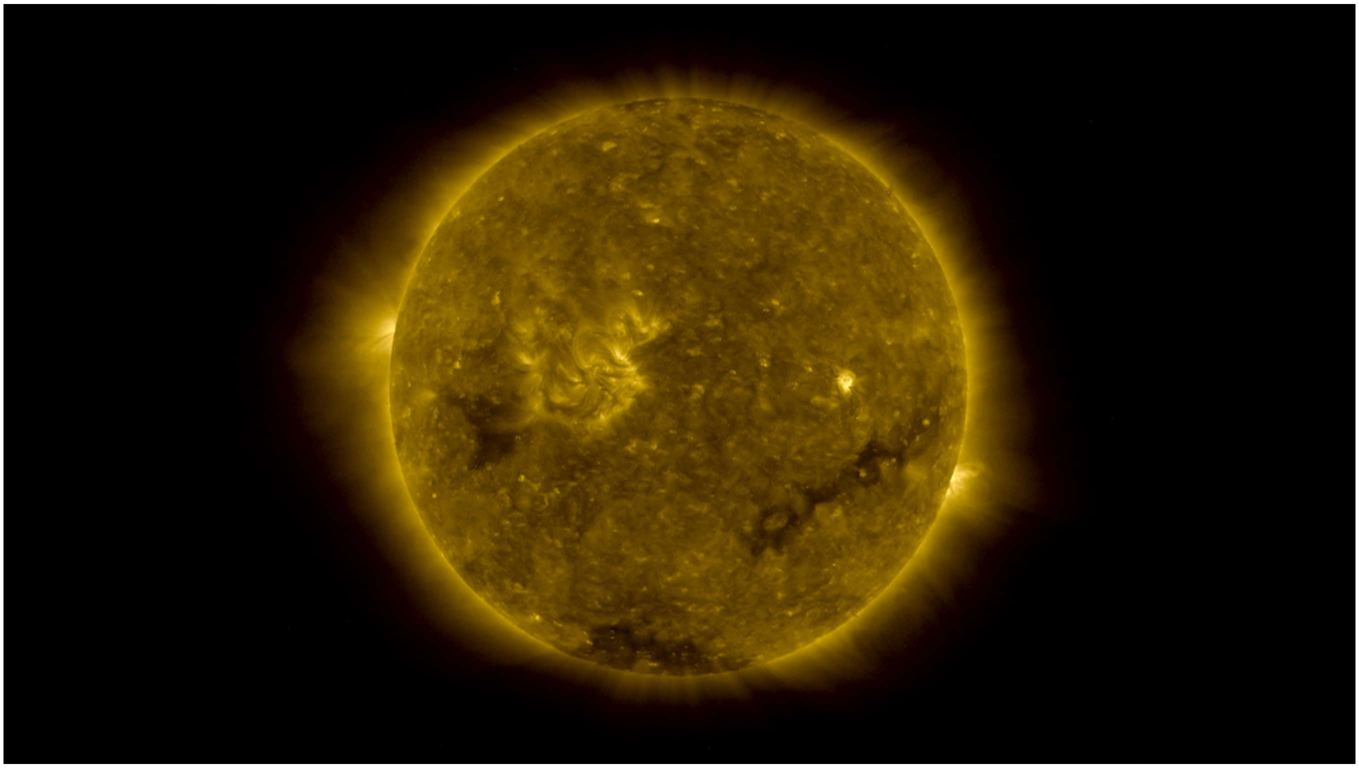
The **Chromosphere** layer of the sun's atmosphere located above the Photosphere / beneath the Corona. The term 'chromosphere' means the sphere of color. This is due to the fact that hydrogen atoms emit energy called hydrogen-alpha (H-α) radiation. The chromosphere is reddish in appearance, therefore it is hard to see.

Prominences are bright gas clouds ejected from the sun and shaped by the sun's magnetic field. They appear as spikes, loops, "trees," detached regions, and more when they occur at the sun's edge as seen from Earth. When seen straight on, however, prominences look like dark lines, known as **filaments**, silhouetted against the solar disk because they are slightly cooler than the surface beneath.



Solar Dynamics Observatory *Spacecraft*Image courtesy of NASA, image and animation from the Goddard Space Flight Center Scientific Visualization Studio and the Solar Dynamics Observatory.

Flares occur when the sun's atmosphere suddenly releases built-up magnetic energy. These emit radiation storms and are by far the Solar System's largest explosions.

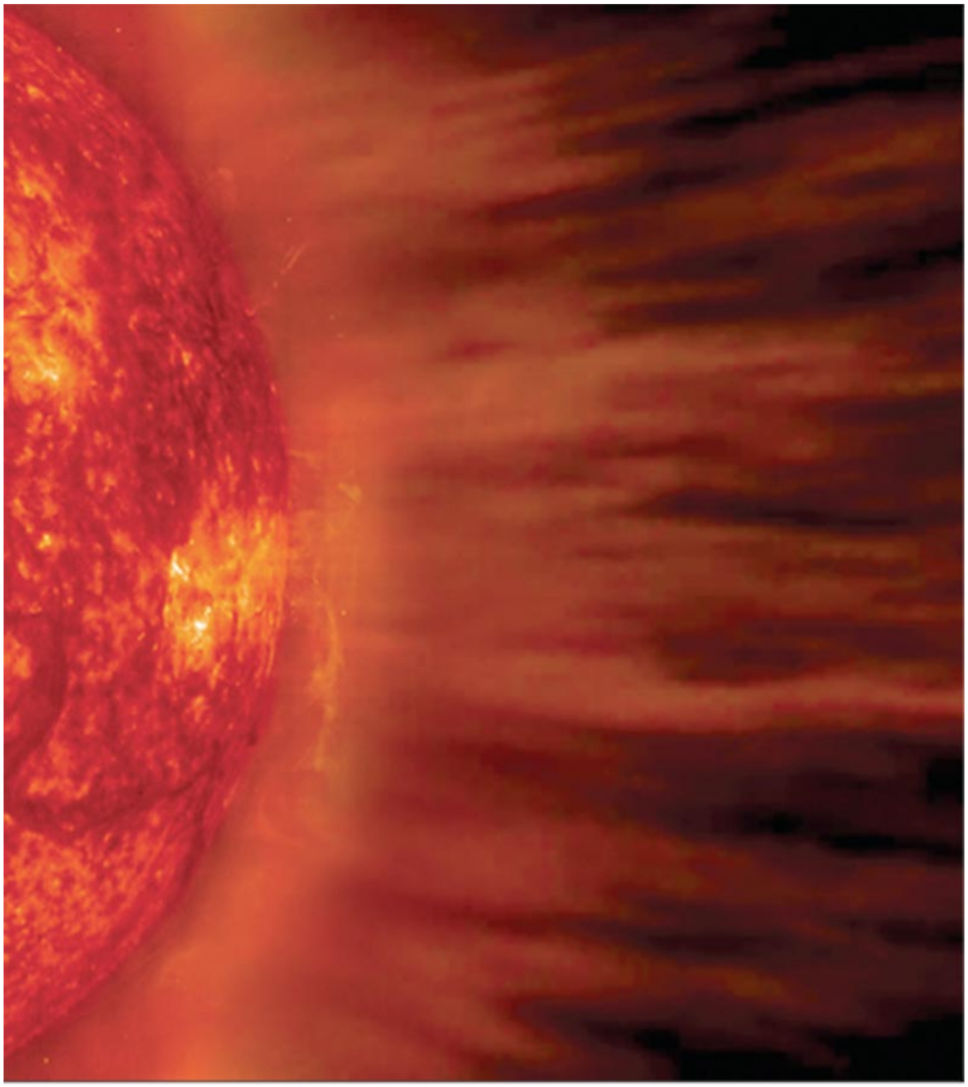


NASA SDO, Solar Dynamics Observatory SpacecraftPublic Domain | Image courtesy of NASA.

The **Corona** is the sun's outer atmosphere; charged particles and dust at low density and very high temperature (10 million K).

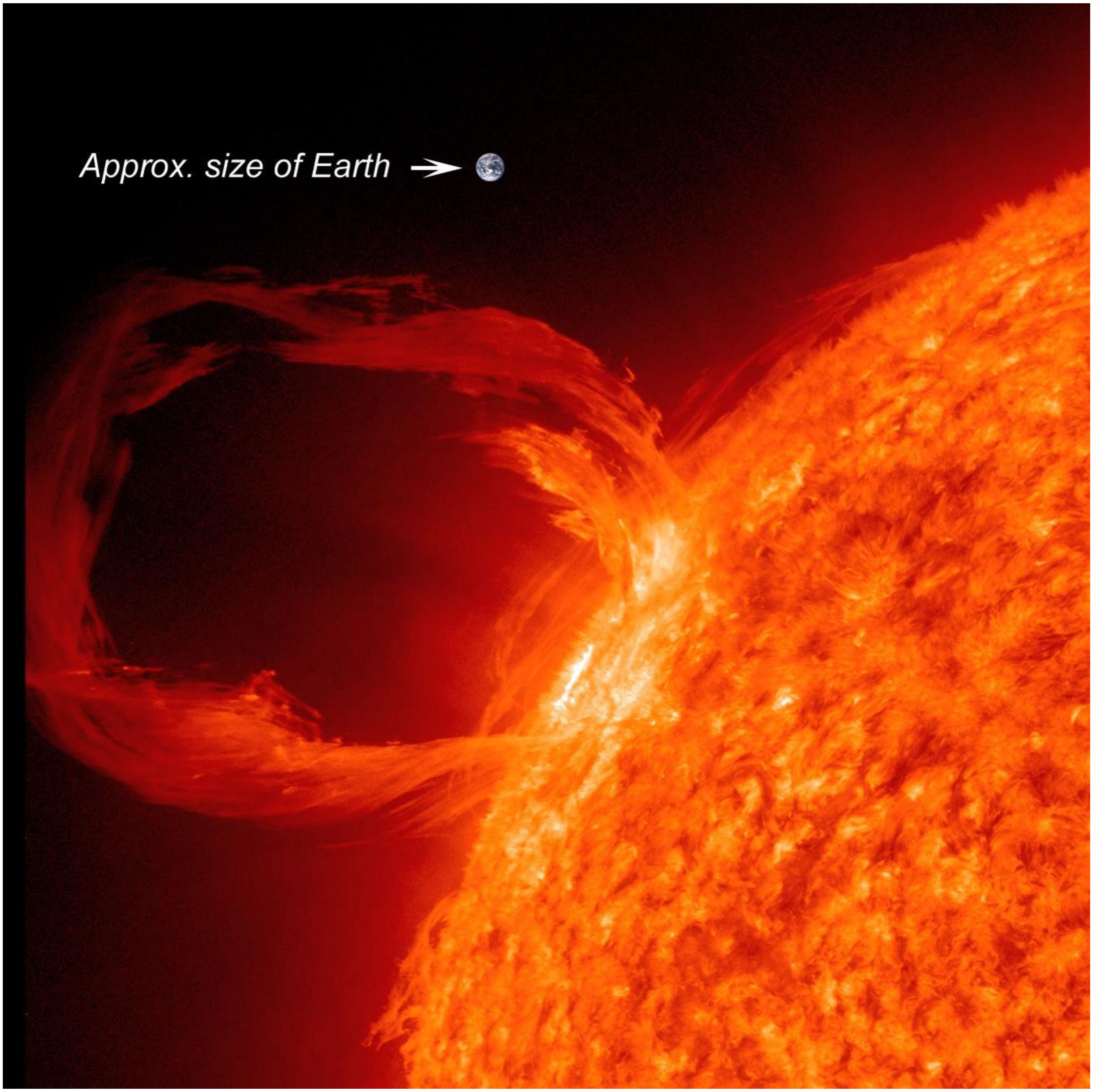
Solar *Corona*Image courtesy of Mike Reynolds, Ph. D. of FLorida State College at Jacksonville.

Solar Wind streams off of the sun in all directions at speeds of about 1 million miles/hour); the source of the solar wind is the sun’s Corona.



Public Domain | Image courtesy of NASA / SOHO.

A **Coronal Mass Ejection** or **CME** occurs when huge gas bubbles threaded with magnetic field lines are ejected from the sun over several hours. If a CME directly hits Earth, the results can be catastrophic; from disruption of orbiting satellites to destroying electrical power stations. It takes 3 to 72 hours for a CME to strike Earth.



Public Domain | Image courtesy of NASA.

10.9: Studying the Sun

We can clearly see the sun's surface features, examine its characteristics in a variety of wavelengths, and glean insight into the nuclear mechanisms of not only the sun, but also of other stars. When observing the sun in **Visible light**, you MUST use a proper solar filter — in front of your eyes, the telescope or binoculars to view the sun safely. A proper solar filter is safe because it does not transmit ultraviolet or infrared radiation, both of which are much more harmful to your eyes than light. It also drops the sun's brightness to a comfortable level. And a pinhole viewer can also be constructed to safely – and indirectly – view the sun and sunspots.

You might have heard that you should never look at an eclipse. First of all, all lunar eclipse phases are safe to view. The partial phase of a solar eclipse, or an annular solar eclipse requires a proper solar filer. It is NOT the eclipse that causes eye damage, it is the sun. During solar eclipse totality, no filter whatsoever is required.

In 1814, optician and physicist Joseph Frauenhofer (1787-1826) invented the first spectroscope. Frauenhofer was comparing the spectra of fire to that of the Sun when he noted dark lines in the sun's continuous spectrum. Named the **Frauenhofer lines**, these absorption lines are a function of the sun's photosphere.

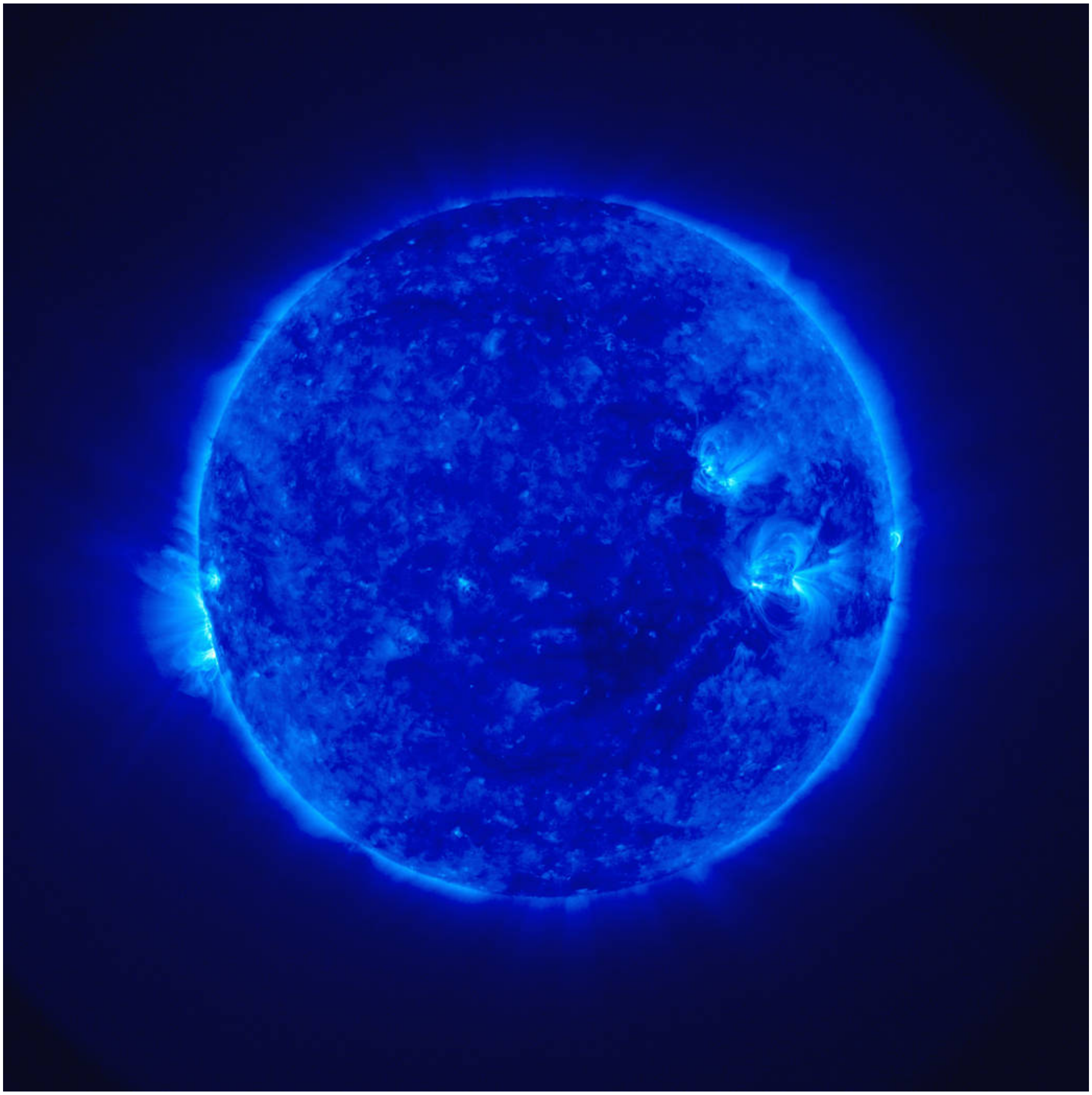
Such a spectrum is created when light passes through a gas or a liquid, or strikes a solid surface. You see the spectrum of the absorption; the wavelengths of light absorbed by the material are absent in the spectrum, leaving blank spaces behind

Perhaps the most-impressive is **Hydrogen-Alpha, H-a**. H-a filters center on a wavelength of 6562. 8 Å and allow through only a tiny part of the red light the sun produces, blocking all other colors. Solar flares and prominences are best seen through an H-a filter.

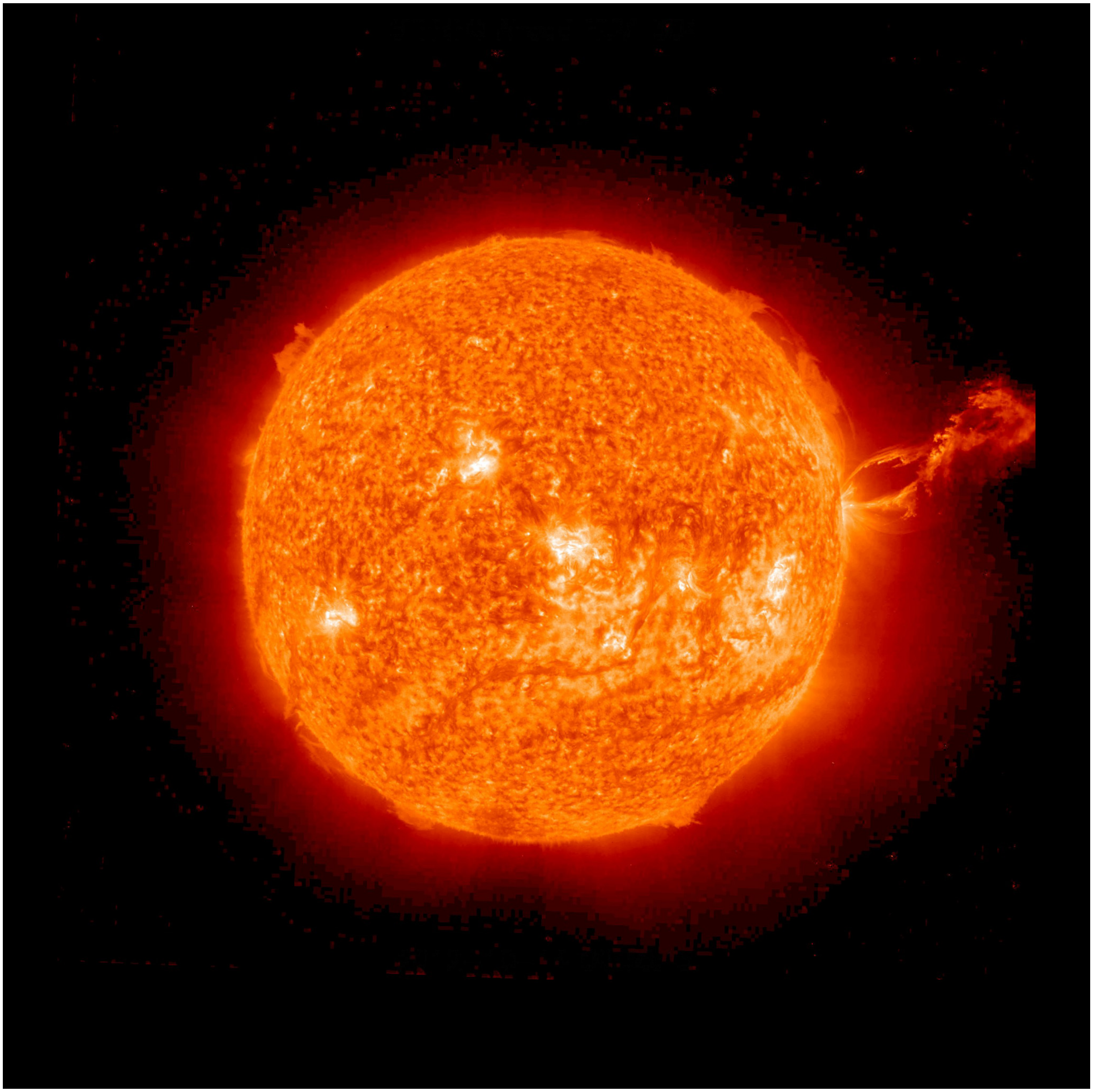
Studies of the element calcium, Ca, on the sun are done at **Calcium H** (3969Å) and **Calcium K-lines** (3933. 7Å). This is instrumental in determining the solar atmosphere's depth.

Other specific features are visible at narrow bandwidths. High granulation and supergranulation detail, and impulsive-phase flare eruption kernels are visible at the **Sodium Na-D line** (5895. 9Å). Flare and magnetic lines research is conducted at the **Helium D3 line** (5875. 61Å); this is one of the most impressive visually.

Light emitted by highly charged iron (Fe) ions at high temperatures is best studied in the **Ultraviolet, UV. And X-Rays** are released from the sun's upper atmosphere and corona.



Public Domain | Image courtesy of NASA / GSFC.



Public Domain | Image courtesy of NASA / GSFC.

Our Sun is important – *critical* – to life on Earth, yet is it not the calm star, which we all might presume…

Watch on YouTube these NASA solar videos:

“Fiery Looping Rain on the Sun,” Video Link *Note the Earth to scale from 1:06 to 1:22.*

“Eruptive events on the sun can be wildly different. Some come just with a solar flare, some with an additional ejection of solar material called a Coronal Mass Ejection (CME), and some with complex moving structures in association with changes in magnetic field lines that loop up into the sun’s atmosphere, the corona” (NASA, retrieved, March 29, 2015).

On July 19, 2012, an eruption occurred on the sun that produced all three events:

- The Solar Dynamics Observatory’s AIA Instrument collected the footage in this video. SDO collected one frame every 12 seconds, and the movie plays at 30 frames per second, so each second in this video corresponds to 6 minutes of real time. The video covers 12:30 a. m. EDT to 10:00 p. m. EDT on July 19, 2012.

“Magnificent Eruption,” Video Link

Consider the following questions based on the YouTube videos:

1. What was your first reaction to seeing/hearing these videos?
2. How would you describe the Earth when compared to the Sun in size in the first video, *“Fiery Looping Rain on the Sun? ”*
3. As we ‘look’ at our Sun in the sky, it seems fairly quiet. Yet what do these videos show us?
4. Why would we want to monitor the Sun’s activity? What can this teach us about other stars?
5. Your speculation: if one of these Coronal Mass Ejection outbursts were to strike Earth directly, could it cause any problems?

10.10: The Dark Side of the Sun

The sun – and every star – is not a consistent, even-running object. The sun is a variable star; not as much variation or changes as most stars classified as variable. But the sun does go through sunspot cycles and sunspot activity extremes.

Both long- and short-term differences in solar activity are believed to affect the global climate, yet it has shown to be challenging to link the variation of the sun to Earth's climate. One school of thought is that these solar variations are due to sunspot cycle extreme minimums, which can make for a colder climate period. One hypothesis is that the Little Ice Age, which occurred between 1550 and 1850, was due to low solar activity. During the 1607-1608 winter, extreme frost was reported in Jamestown, Virginia. New York Harbor froze in the winter of 1780; very cold periods were well-documented throughout Europe and worldwide.

The release and outbursts of energy through solar flares and Coronal Mass Ejections can cause devastating effects on Earth. Solar flare X-Rays travel at the speed of light, 186,000 miles per second or 3 x 108 meters/second. Electrically charged particles, released from a CME, travel at around 1 to 2 million miles an hour; think of this as a cosmic tsunami. These are capable of taking down Earth's electric power grid and knocking out orbiting satellites, with catastrophic results. One such event ooccurred in Quebec, Canada due to a CME, March 1989. In 1859, enormous solar storms struck Earth. The Aurora were so bright at night people thought it was daylight. And these CMEs literally burned out that day's only electronic system: the telegraph.

10.11: The National Solar Observatory

The National Solar Observatory Telescope *Tower*Image courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

The main telescope at NSO Sacramento Peak is the Richard B. Dunn Solar Telescope. This imposing solar tower, 136 feet high, produces 0. 2 arc-second resolution and over many years has produced some of the finest solar images and data. Another 220 feet of the Dunn Solar Telescope lies below ground, making the total length of this imposing instrument 356 feet. The instrument was upgraded to include adaptive optics; another advantage to reduce seeing effects while observing the sun.

10.12: NASA’s Heliophysics Science Division

Nasa’s Heliophysics Science Division conducts research on the sun, its extended solar-system environment (the heliosphere), and interactions of Earth, other planets, small bodies, and interstellar gas with the heliosphere. Division research also encompasses geospace — Earth’s uppermost atmosphere, the ionosphere, and the magnetosphere — and the changing environmental conditions throughout the coupled heliosphere (Solar System weather). National Aeronautics and Space Administration, Goddard Space Flight Center

CHAPTER OVERVIEW

11: Stellar Properties

11.1: Module Introduction

Children's lullabies were quite popular in decades past. Many of us learned a number of these lullabies as children, though they do not seem to be as popular today. In Rhymes for the Nursery, published by sisters Jane and Ann Taylor in 1806 in London was a simple rhyme about a star. Many of us have heard and even sung the first verse of what we call Twinkle, twinkle little star. And some of these questions in this children's lullaby are still the same astronomers and astrophysicists are asking today.

The Star

Twinkle, twinkle little star,
How I wonder what you are,
Up above the world so high,
Like a diamond in the sky.
When the blazing sun is gone,
When he nothing shines upon,
Then you show your little light,
Twinkle, twinkle, all the night.
Then the traveller in the dark,
Thanks you for your tiny spark,
He could not see which way to go,
If you did not twinkle so.
In the dark blue sky you keep,
And often through my curtains peep,
For you never shut your eye,
'Till the sun is in the sky.
As your bright and tiny spark,
Lights the traveller in the dark.
Though I know not what you are,
Twinkle, twinkle, little star.
Twinkle, twinkle, little star.
How I wonder what you are.
Up above the world so high,
Like a diamond in the sky.
Twinkle, twinkle, little star.
How I wonder what you are.
How I wonder what you are.

Jane Taylor
The Star, *Rhymes for the Nursery*, 1806

This module looks at the characteristics of stars, the terminology astronomers use to describe the stars, and the types and classifications of stars.

Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

- Identify the basic stellar characteristics
- Describe how astronomers use parallax
- Identify terms, such as light-year, parsec, stellar luminosity, and magnitude system
- Detail Stellar Types and those responsible for the development of the stellar types
- Describe how the H-R Diagram works and what it shows
- Identify the different types of binary stars and variable stars
- Differentiate between globular and open clusters

11.2: Variable Stars

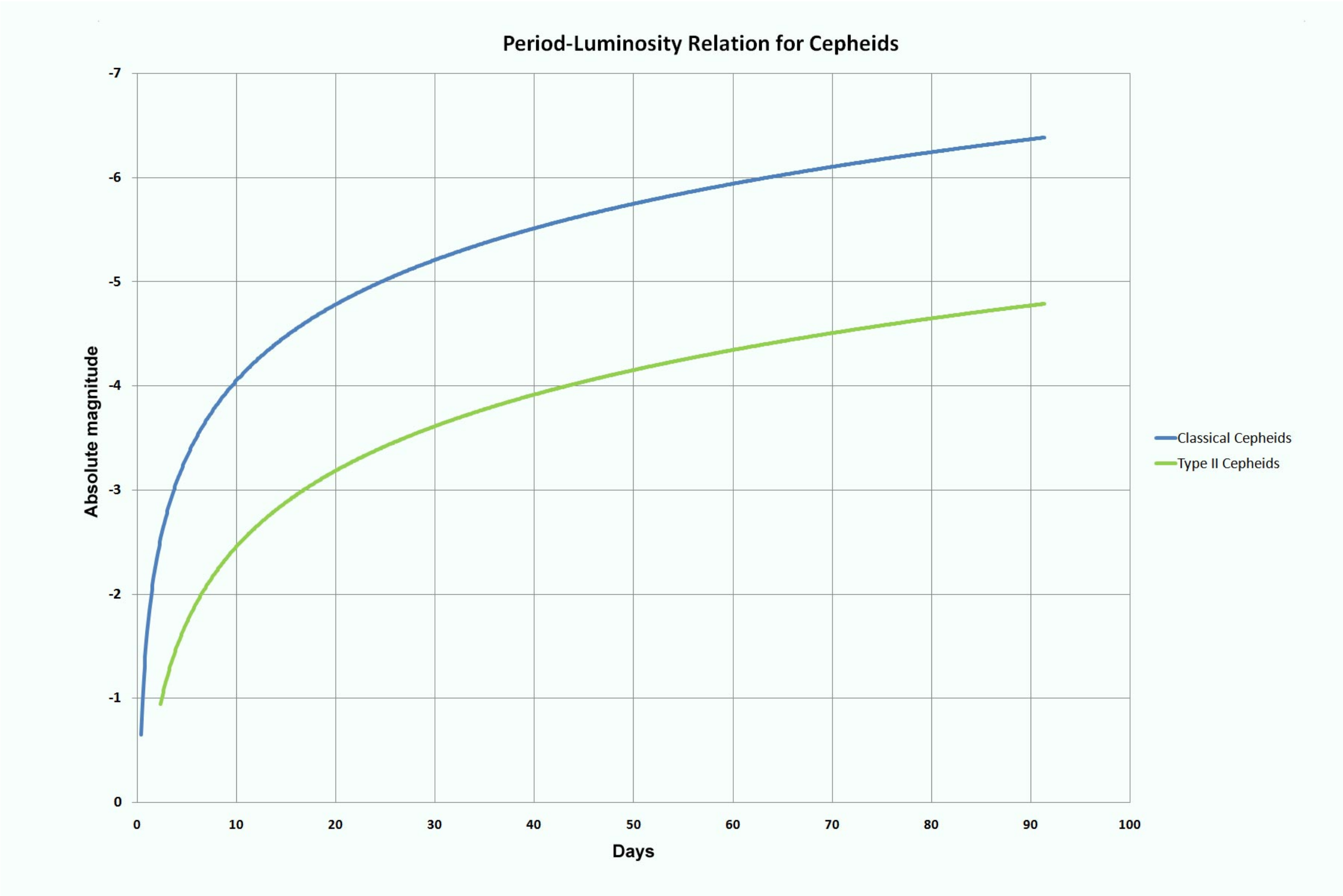
Sometimes a star will change luminosity not due to an eclipse, but due to some sort of physical characteristic. These are called **variable stars** or **variables**. These changes in brightness can range from 1/1000 of a magnitude to 20 magnitudes over a period of a fraction of a second to many years. Over 150,000 variables are known, and many others are suspected to be variables.

There are two major classes of variable stars: **Pulsating Variables** and **Cataclysmic Variables**. **Pulsating variable stars** swell and shrink, which affects the star's brightness. One important class of pulsating variable stars is the **Cepheid Variables**.

Public Domain | Image courtesy of NASA.

11.3: Cepheids

Often simply called **Cepheids**, these variables are massive, high-luminosity stars with short periods of one to 70 days and light variations of 0. 1 to 2 magnitudes. Astronomers use Cepheids as a “standard” for distances because of the direct relationship between a Cepheid’s luminosity and variable pulsation period. Once you determine a specific Cepheid’s luminosity and variable pulsation period, you can determine how distant it is because of the inverse square law. This makes Cepheids a major galactic distance indicator.

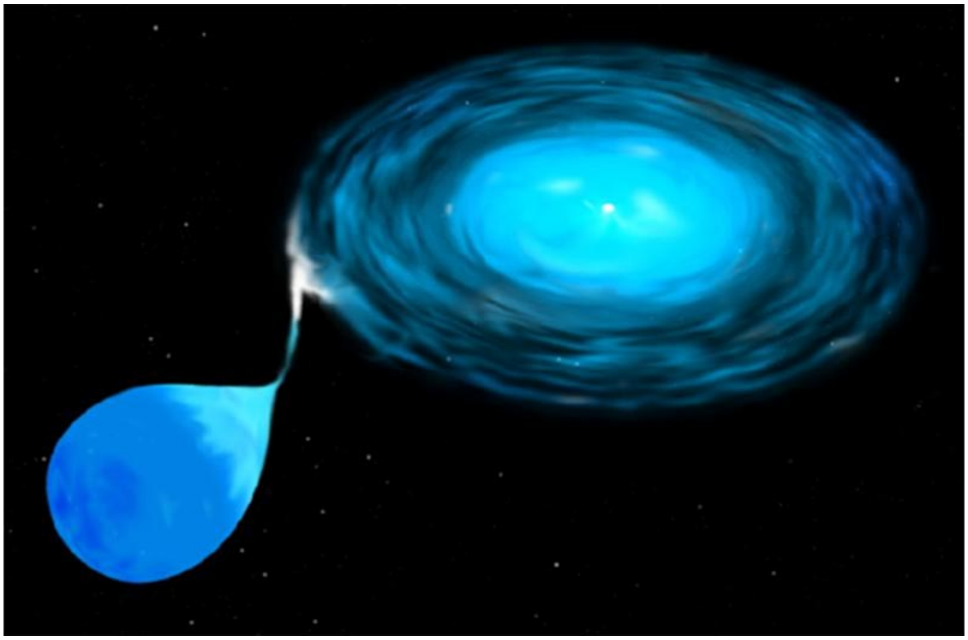


Public Domain

11.4: Cataclysmic Variables

Cataclysmic variables are binary stars, which consist of a white dwarf primary and an orbiting secondary star. The secondary star is transferring matter to the primary star. This causes the primary star to irregularly outburst a significant increase in brightness. Cataclysmic variables were originally called **novae** (singular: nova) from the Latin term *new* , since the star seemingly appeared out of nowhere. After the outburst, the cataclysmic variable will eventually dim back down significantly until more stellar fuel is transferred from the secondary star to the primary star. This process will go on until there is no more stellar fuel to transfer.

The primary star (upper right) is pulling stellar material off the secondary star (lower left). Once a significant amount of mass builds up on the primary star, it will outburst and brighten significantly. Then the star will dim back down, repeating the process as long as fuel is available from its secondary star.



Public Domain | Image courtesy of NASA.

11.5: Star Clusters

Stars are often seen to group into what astronomers term as **star clusters**. Star clusters are gravitationally bound groups of stars. There are two major types of star clusters. **Open Clusters (OC)** are groups of young, hot stars that are physically related by being held together by gravity; less than 50 to 100 or more stars. **Globular Clusters (GC)**, or **globulars**, are tight groupings of very old stars; 10,000 to one million or more stars. Open clusters are irregular in shape or pattern, whereas globular clusters are spherical in shape. Open cluster stars can somewhat disassociate with other open cluster star members, since the gravitational attraction thus association with each other is loose and can be affected by other astronomical bodies passing near the OC.

Photographically, the two types of star clusters are easy to tell apart. Open clusters have fewer stars and appear to be not-well organized or symmetrical in shape. Globulars have many, many more stars than open clusters and are symmetrical and spherical in shape.

Open Clusters

Images courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

Globular Clusters

Images courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

11.6: Consider this…

Tyson at the 40th Anniversary Apollo 11 celebration, July 20, 2009Public Domain | Image courtesy of NASA.

“So strong was that imprint [of the night sky] that I’m certain that I had no choice in the matter, that in fact, the universe called me.
”

—Dr. Neil deGrasse Tyson Astrophysicist and host of *Cosmos From an interview with Stephen Colbert, January 29, 2010*

11.7: The Unknown in Astronomy

One of the best techniques astronomers employ is in understanding what is normal. For example, if we consider our Sun a normal star, how do other stars compare? When is a star atypical when compared to the Sun? And atypical in what way?

It is usually the abnormal or weird objects that are the most interesting. One example is stars that vary significantly in brightness and energy output on a regular basis. Why do these stars go through these variations? Or consider stars that also vary significantly in brightness and energy output, yet on an irregular basis. What makes them so much different than regular variable stars, or steady stars like our Sun?

11.8: Star and Celestial Object Characteristics

Star characteristics consider physical characteristics such as **stellar mass, size, surface temperature, and luminosity**. These basic characteristics assist in detailing specifics about a star; not all stars are the same and these variations in characteristics can be significant. The distance from the Sun and Earth to a specific star is also important as astronomers detail the star's characteristics. Of these characteristics, **stellar mass** is the most important characteristic. The mass of a star determines things, such as how quickly a star will consume its stellar fuel through the fusion process to the star's final ending when it has used all of its fuel. Yet how does one measure a star's mass? How do you weigh a star?

It turns out that Isaac Newton studied this question. He turned to Kepler's Third Law, where one measures the **period** and **average distance** of the object's orbit about a star. Yet, you need two objects – a star and an object orbiting a star – to use this solution. It turns out that over 50% of all stars have a companion star. So, astronomers use this adaptation on Kepler's Third Law developed by Newton to measure the mass of the two binary stars.

Kepler's 3rd Law — $a^3 = kP^2$

Where **a** is the orbiting object's semi major axis, **P** is the orbiting object's period to orbit, and **k** is a constant, referred to as Kepler's constant.

By examining the color of each of the stars in the binary system, you can compare two single stars with the same colors.

Stellar mass is usually related to the mass of the Sun, where the Sun equals 1 m_{sun}, 1 $m_{\odot}$, or 1 solar mass. The bright star Sirius, the Dog Star in the constellation Canis Major, is about 2. 02 m_{sun}. One of the most massive stars is Eta Carinae, with a mass somewhere between 100 to 150 times the mass of the Sun, 100-150 $m_{\odot}$.

Stellar mass units — m_{sun} :: $m_{\odot}$ :: solar mass

A star's mass will vary over its lifetime, depending if it adds, or accretes, mass from another star, loses mass to another star, or simply loses mass through the normal processes, such as through its stellar wind or pulsating outputs.

Stars are occasionally classed by their stellar masses based upon their evolutionary behavior as stars approach the end of their nuclear fusion. In the next module, we will introduce the classes of stars, based on their solar masses.

Stellar size refers to a star's diameter or radius. Stars range in diameter, from neutron stars with diameters of about 40 kilometers or 25 miles, to supergiants with diameters of approximately 900,000,000 kilometers or 540,000,000 miles — about 650 times the Sun's diameter.

A star's **surface temperature**, measured in Kelvin, K, is dependent on the star's diameter and the rate of energy production at the stellar core, and is measured at the star's photosphere. An estimate of the surface temperature is the star's **color**, often called the **color index**. Annie Jump Cannon was the first to sort spectral data and designed the stellar spectral classes.

The hotter the star, the whiter it will appear, whereas the cooler the star, the redder it will appear. Think of heating a piece of metal; the hotter it is, the whiter the metal will appear. As the metal cools, it will appear orange and then red in color. The reddish-colored metal is still hot, yet cooler than when the metal was white blue-white in color.

Stellar luminosity is the amount of light and other radiant energy released by a star. A star's luminosity is dependent on its diameter (sometimes noted as the star's radius, d = 2r) and its surface temperature.

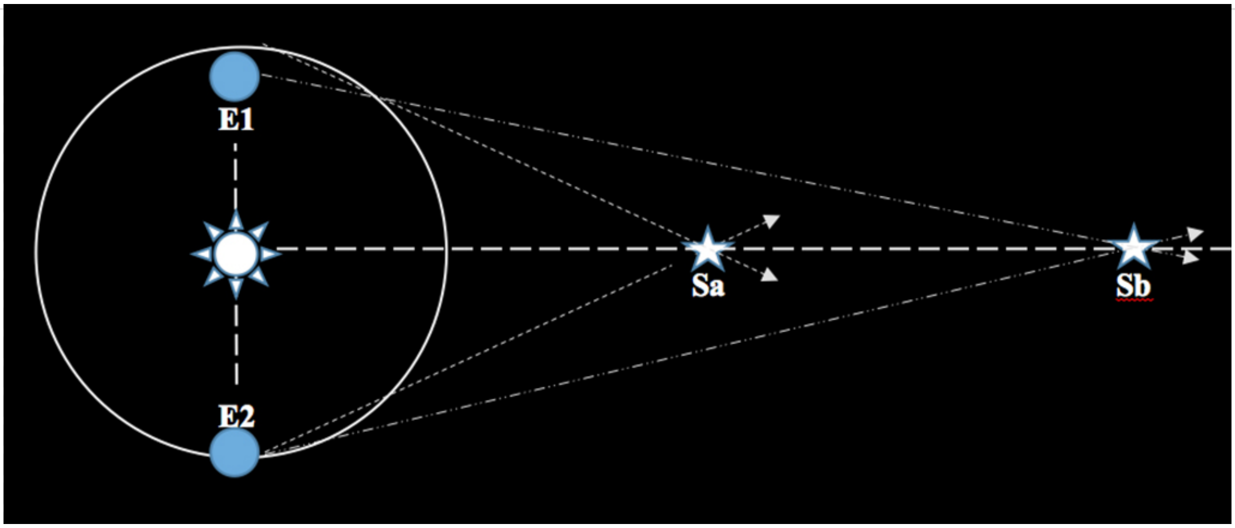
11.9: Distances to the Stars and other Celestial Objects

When discussing stars, astronomers consider other factors, such as the **star's distance** and **brightness**. These quantities might seem easy to determine at first, yet they are challenging. And to fully understand each star's physical characteristics, we need to determine these most basic of quantities.

The distance to a specific star – beyond our Sun – is not an easy thing to determine. There is no way to use a measuring tape; the tool we are used to using in our own personal universes. As with measuring distances from object to object here on Earth, radar works well for many Solar System objects, but not beyond. The radar beam spreads out too much and loses energy. And it would take over eight years for that beam to travel to the closest star beyond the Sun – Proxima Centauri – and back. By the time the radar beam returned, there would be nothing to receive here on Earth because the beam would have lost all of its energy.

So to measure the distance to nearby stars, astronomers observe an object's **stellar parallax**. This is the apparent shift of an object relative to some distant background as the observer's point of view changes. As Earth and observer orbits the Sun, the specific star being observed will appear to move relative to the background stars. **Parallax is the only method for directly measuring stellar distances.** You may try this by holding a finger up at arm's length. Open one eye and close the other. Now blink; reverse the open-closed eyes. Notice the objects in the distance appear to shift back and forth compared to your closer finger.

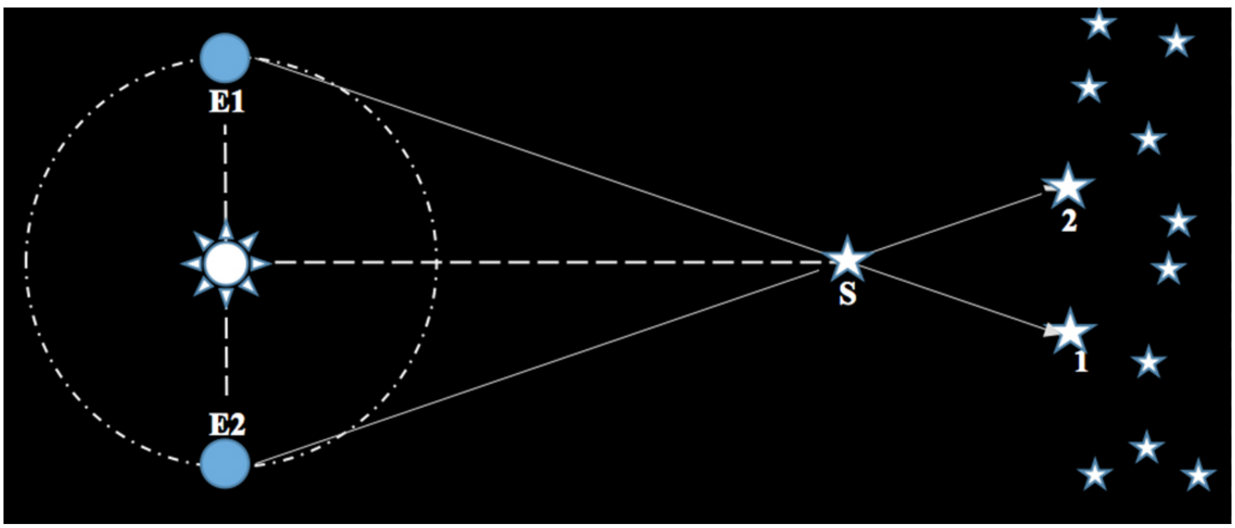
11.10: Stellar Distances



Images courtesy Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

This diagram *(not to scale)* shows Earth's orbit about the Sun. Recall that one orbit is 1 year, 12 months, or 365. 24 days. Earth is shown twice, at the 12 o'clock position, or **E1**, and at the 6 o'clock position, or **E2**. These two positions are six months apart on Earth's orbit about the Sun. The star being observed is the larger star, indicated by the **S**. The star **S** appears to shift against the background of stars from position **S1** to position **S2** over the six months. This is the parallax motion. By looking at this as a triangle and using trigonometric relationships and the angles, you can determine the distance to the star **S**.

There are issues with determining stellar parallax, and how useful it is in determining stellar distances. First, note that parallax only works with fairly close stars. Examine this diagram to see what happens when one star is at a greater distance.

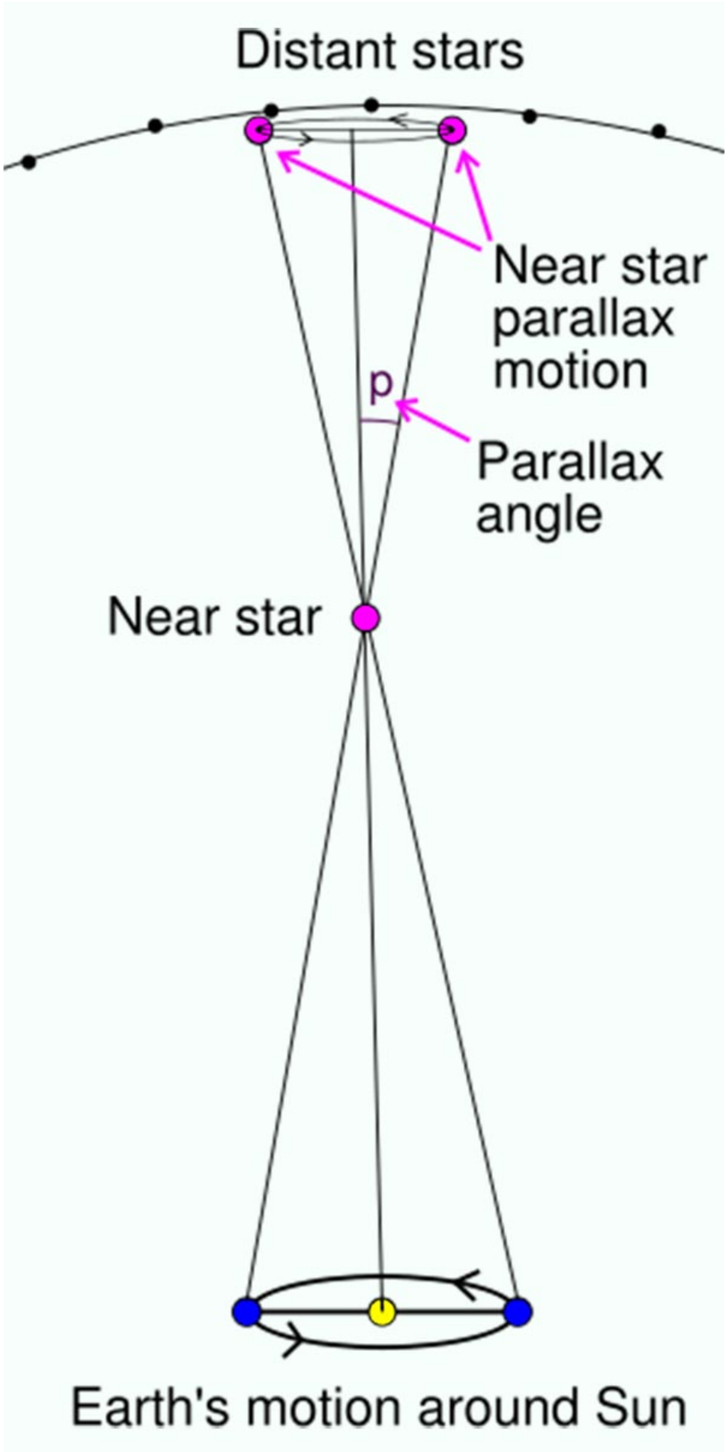


Images courtesy Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

As with the first diagram, Earth is at two positions, **E1** and **E2**. In this diagram and case, there are two stars, **Sa** and **Sb**. The background stars in the first diagram have been removed to see the angles and two stars better. Note that star **Sb** is about two times as far from the Sun and Earth as star **S1**. Look at the angles; the **E1-Sa-E2** angle is much larger than the **E1-Sb-E2** angle. Think of the angles they create as pieces of pizza.

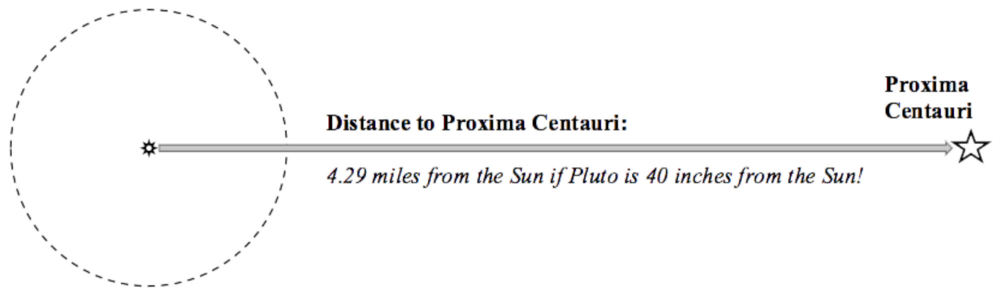
11.11: Everything is Moving

Another challenge is the fact that the star's position you are measuring, the Sun and Solar System, and these background stars are also moving. The way to overcome this issue is to make more than two measurements and to take into account all of the motions – the Solar System and background reference stars.



Public Domain | Image courtesy of Wikimedia Author: Booyabazooka

11.12: How Close are the Close-by Stars?



Images courtesy Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

The closest star? **The Sun**. After the Sun is **Proxima Centauri**, part of the three-star Alpha Centauri (α Cen) star system. Proxima Centauri is about 25,219,301,250,000 miles or 40,586,533,727,000 kilometers away. So let's look at this in other ways. *A 50-mile high stack of toilet paper stretched out on 1 sheet = 1 million miles scale.* **Alpha Centauri** is often listed as the second closest star to Earth, *this is incorrect* . Proxima Centauri is the second-closest star and orbits Alpha Centauri.

11.13: Light-Years

Yet trillions of miles to the nearest star beyond the Sun is not a measurement or system that is user-friendly. So astronomers use light-years instead. A **light-year (ly)** is a unit of length or distance; the distance light travels in one year. It is also written as light year or lightyear. So how does light travel in one year, or what is the length of a light-year? This sounds like a time calculation, and is often misused as such in movies, television shows, and books. The light-year is a distance measurement, and is calculated by knowing the speed of light.

Using light-years instead of miles, meters, or kilometers provides one a friendly number. For example, instead of stating the Sun is 93,000,000 miles away, one can note it is 8. 33 light minutes distance. What of Proxima Centauri, 25,219,301,250,000 miles or 40,586,533,727,000 kilometers away? Using light-years, Proxima Centauri is 4. 29 ly in distance.

To give you a sense of the size of our galaxy and even the Universe, there are about 30 stars, which lie within 16. 5 ly of Earth. Only 30 stars out of the billions of stars in just our own Milky Way galaxy.

Light Years: Calculations

Light-Years calculated in miles — the English System: 186,000 miles/second x 365. 25 days/year x 24 hours/day x 60 minutes/hour x 60 seconds/minute = 5,869,713,600,000 miles or 5. 8697136 x 10^{12} miles

Light-Years calculated in meters and kilometers — the Metric System: 299,792,458 meters/second x 365. 25 days/year x 24 hours/day x 60 minutes/hour x 60 seconds/minute = 9,460,730,472,580,800 meters or 9. 4607304725808 x 10^{15} meters = 9,460,730,472,580. 8 kilometers 9. 4607304725808 x 10^{12} kilometers

Astronomical Units in 1 ly; distance from the Sun to Earth (93,000,000 miles = 1 AU): 1 ly = 63,241. 077 AU or 63241077 x 10^{4} AU * *The distance light travels in one year is 63,241. 077 times the distance from Earth to Sun.

11.14: Parsec Vs. Light-Year Measurement

Astronomers also employ other types of measurements, specifically the **parsec (pc)**. The parsec is defined as the distance to an object with a parallax angle of 1 arcsecond. This takes us back to our measurements using parallax. When determining the relationship between the *pc* and *ly* , one finds that:**1 pc = 3. 261 light years (ly) = 1. 9174 x 1012 mi = 3. 0857 x 1013 km. M**

The parsec was named from the abbreviations of a **par** allax of one arc **sec** ond. The idea of the parsec was to provide astronomers a method to calculate stellar and other astronomical distances quickly and with ease from their data. The parsec is preferred by astronomers, whereas the light-year is more popular in science texts and everyday use.

11.15: Stellar and Celestial Object Brightness

There are a number of other stellar characteristics astronomers and astrophysicists consider. **Luminosity** is a star's total amount of power radiated into space, measured in watts. Think about a light bulb in your home. The output is measured in watts. Most of us use 60 watts tungsten light bulbs or the new LED bulbs with an output of around 60 watts, yet using about 10 watts of power.

How does a light bulb with a luminosity of 60 watts compare to the Sun's output? The accepted luminosity of the Sun is 3.846×10^{26} watts. With such large numbers, the Sun's luminosity is often stated as $1\ L_{\odot}$. The number $1\ L_{\odot}$ is easier to work with than 3.846×10^{26} watts, yet they mean the same quantity.

Apparent Brightness is the amount of light reaching us per unit area, measured in flux. This incoming light varies by the **Inverse Square Law**. Mathematically this is given as:

Apparent Brightness is proportional to $1/d^2$

Let's look at an example many have experienced. You see a light one mile away, and note its brightness. You move away from the light, and you again look at the light. You might think the light should be half as bright. Actually it is ¼ as bright, as given by the Inverse Square Law.

Apparent brightness at 1 mile: $1/1^2 = 1$ Apparent brightness at 2 miles: $1/2^2 = ¼$

We all experience the Inverse Square Law in real life, from driving a car at night to looking at lights on and in buildings and streetlights as we approach a light or move away from the light.

11.16: Magnitude System

The **magnitude system** is a scale to show how bright stars appear. The initial magnitude system was developed by the Greek astronomer, geographer, and mathematician Hipparchus (190 BC to 120 BC). He ranked stars by their apparent brightness, with 1 being the brightest and 6 being barely visible, without the telescope or other optical aid.

He also designed his original magnitude scale, such that the star Polaris, the northern hemisphere's pole star, would have a magnitude of 2. Hipparchus' initial magnitude scale was revised by Norman Pogson in 1856. Pogson specified a 1st magnitude star is 100 times brighter than a 6th magnitude star. Based on Pogson's system, a 1st magnitude star is 2. 512 times as bright as a 2nd magnitude star. With this revision also came inclusion of brighter objects, such as the Sun and Moon, and fainter objects then visible through the telescope. What we see in our sky is called an object's **Apparent Magnitude, M_v**.

Example Apparent Magnitudes, M_v

Object

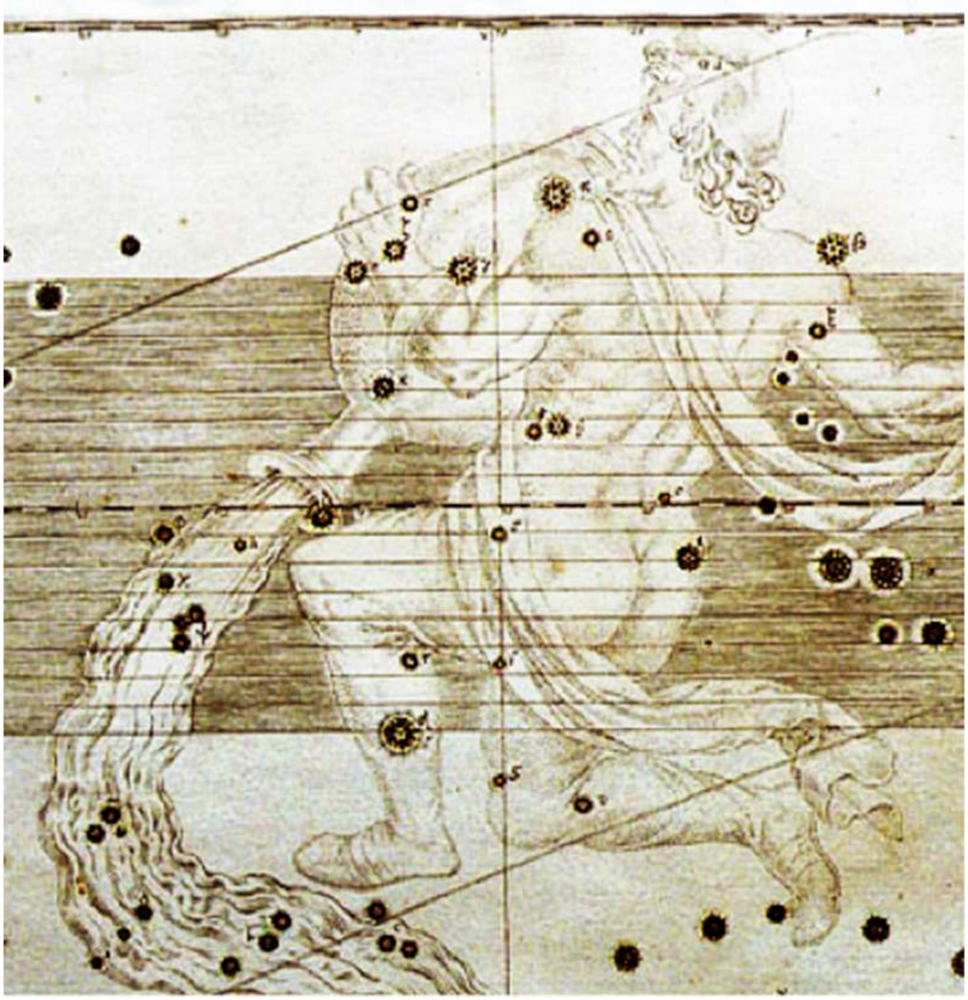
- Sun
- Moon
- Sirius (brightest star in the sky beyond the Sun)
- Polaris, the northern hemisphere's pole star
- Andromeda Galaxy, M31
- Maximum brightness of dwarf planet Ceres
- Faintest objects visible using 7×50 binocular
- Pluto at maximum brightness
- Faintest objects observable in visible light with 8m Earth telescopes
- Faintest objects observable in visible light with the Hubble Space Telescope

Apparent Magnitude – as seen from Earth

- -26. 74
- -12. 74
- -1. 4
- 1. 98
- 3. 44
- 6. 64
- 9. 50
- 13. 65
- 27. 00
- 31. 50

11.17: Celestial cartography

Celestial cartography, also known as **uranography** or **star cartography**, is the area of astronomy that produces star maps. Most are aware of cartographers who made early and more recent maps of Earth. Both types of cartography were difficult in early history; we were not certain of the exact sizes and shapes of land masses, and there are many, many stars to chart correctly. Many early Earth and star maps were very artistic in nature and truly took not only a scientific mind, but the skills of an amazing artist.



Public Domain

CC BY-SA 3. 0 | Image courtesy of Wikimedia Author: Rursus / kstars.

11.18: Planispheres

Celestial objects are shown on planispheres, star charts and maps, and star atlases, as well as computer and tablet applications and programs. The printed planispheres and charts use different size "dots" to represent the object's brightness. Many of the new star chart computer and tablet applications and programs are able to show star brightness without using a larger or smaller dot.

The charts, maps, and applications show the object's apparent magnitude. The apparent magnitude scale is based on what we see, and does not truly compare a star's true brightness to other stars. So astronomers devised a second scale: **Absolute Magnitude, M**. This scale defines brightness as if we moved all the stars to the same distance; 10 parsecs. These measurements, albeit hypothetical since we cannot move objects to a distance of 10 pc, are the measure of a celestial object's intrinsic brightness. This allows astronomers and astrophysicists to directly compare star brightness'; *comparing apples to apples* .

Note:

Take our Sun, for example. It is so close, relative to the other stars and celestial objects, that it appears to be very bright, with an apparent magnitude -26. 74 Mv. Yet move the Sun to the hypothetical distance of 10 pc, and the Sun becomes a relatively faint 4. 83 M absolute magnitude object.

Comparing Some Apparent versus Absolute Magnitudes

Object

- Rigel
- Polaris (double star)
- Betelgeuse
- Vega
- Sirius
- Alpha Centauri (triple star)
- Sun
- Andromeda Galaxy, M31
- Black Eye Galaxy, M64

Apparent Magnitude, M_v

- 0. 12
- 1. 98
- 0. 42 (variable, 0. 3 to 1. 2)
- 0. 03
- -1. 4
- -0. 01
- -26. 74
- 3. 44
- 9. 36

Apparent Magnitude, Mv

- -7. 02
- -3. 6
- -2. 99
- 0. 6
- 1. 4
- 4. 3
- 4. 83
- -21. 5
- -21. 7

11.19: Star Colors

As you look up at the sky at night, you might notice stars are not all white in color. If you happen to look up at a winter sky, you will be greeted by the blue-white Dog Star Sirius in the constellation Canis Major. And nearby is the reddish star Betelgeuse in Orion the Hunter. Contrast these colors to that of our yellow Sun.

Yet star color is an important indicator for astronomers; the color is an indication of a **star's surface temperature** at its **photosphere**. A star's **photosphere temperature** dictates its **color**. It turns out that the hotter stars are **whiter** and **cooler** stars are redder. This is exactly what we observe around us. If you heat a piece of metal, you will note that the hotter metal glows what we call "a white hot. " As the metal cools, it becomes orange and then red. It is still hot if it is red, it is just not as hot as the white-hot metal. Stars are the same.

We classify stars by their colors and thus their **photosphere temperatures**. This is called a star's **Spectral Type**. Stars are categorized by their spectral types. This categorization was first done by**Father Angelo Secchi** in the 1860s and 1870s. In the 1880s at Harvard University, **Edward Pickering** observed and recorded stellar spectra and **Williamina Fleming** classified Pickering's spectra with a system of letters.

In 1901, Harvard astronomer **Annie Jump Cannon** revised the various classifications to give us our more-modern Spectral Types interpretation. One of the final notes in this all-important classification system was **Cecilia Payne Gaposchkin's** 1925 doctoral dissertation, where she showed that spectral types were a sequence in stellar photosphere temperatures.

Harvard astronomer **Henry Norris Russell** was concerned about Payne Gaposchkin's dissertation conclusion that the Sun was primarily composed of hydrogen. This contradicted the theory at the time of the publication of her doctoral dissertation — that Earth could be so different than the Sun. Later, Russell came to the same conclusion, published his own paper, and barely mentioned Payne Gaposchkin's work. Russell is often given credit for this discovery, even though it was not originally his work for which to receive credit.

11.20: Spectral Type

As noted, from numbers to a series of numbers and letters came the spectral type classification of Annie Jump Cannon. The basic Spectral Types are **O – B – A – F – G – K – M**. Cannon decided to drop several letters and numbers, thus the seemingly unorganized system we employ today. As can be seen in the graphic, the Spectral Type is indicative of the star's color, thus the star's photosphere temperature.

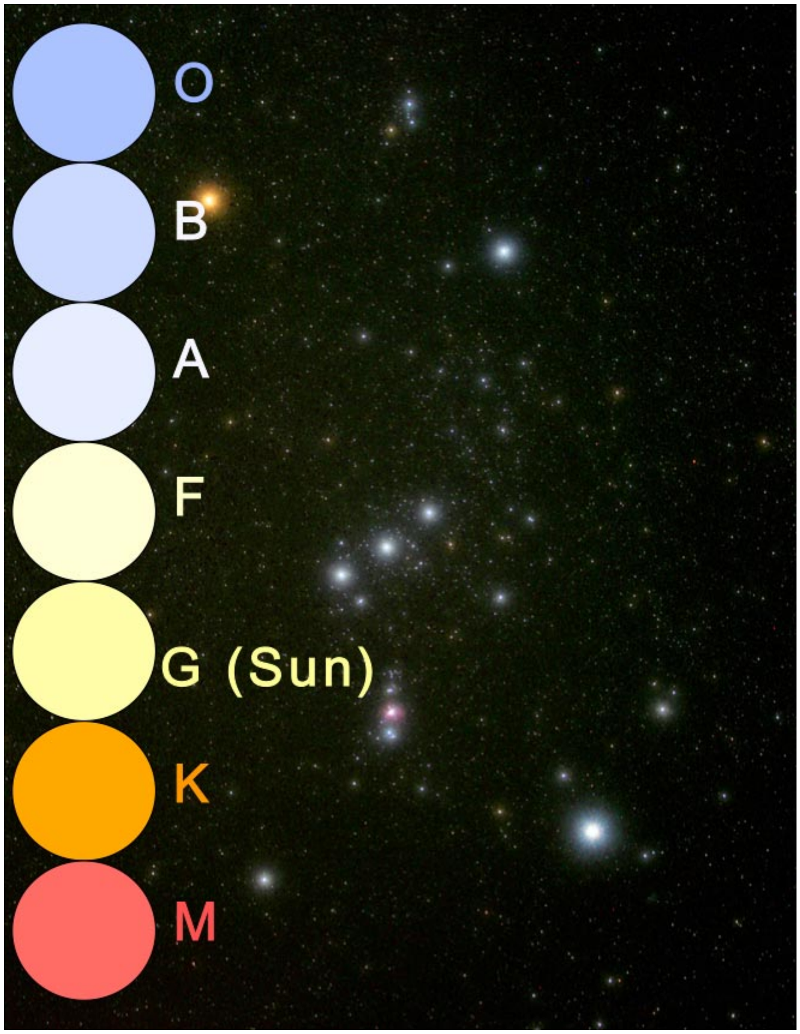


Image courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

11.21: Sample Spectral Types

Trying to remember the Spectral Types in order? A couple of excellent – and time-proven mnemonics to assist you:

O h **B** e **A** **F** ine **G** irl/ **G** uy, **K** iss **M** e **O** h **B** oy, **A** n **F** **G** rade **K** ills **M** e

There are several other Spectral Types, like the carbon RNS stars (additional mnemonic is **R** ight **N** ow **S** weetheart) or the very low temperature L, T, and Y stars (additional mnemonic is **L** ove **T**o **Y** ou).

O

Temperature Range

- >30,000 K

Color

- Blue-blue-white

Stellar Examples

- *Orion Belt Stars (3 stars)*

B

Temperature Range

- 10,000-30,000 K

Color

- Blue-white

Stellar Examples

- *Rigel, Orion's shoulder star*

A

Temperature Range

- 7,500-10,000 K

Color

- White

Stellar Examples

- *Sirius, the Dog Star in CMa*

F

Temperature Range

- 6,000-7,500 K

Color

- Yellow

Stellar Examples

- *Polaris, North Pole Star*

G

Temperature Range

- 5,000-6,000 K

Color

>

- Deep Yellow

Stellar Examples

- *Sun*

K

Temperature Range

- 3,500-5,000 K

Color

>

- Orange

Stellar Examples

>

- *Arcturus, bright star in Boötes*

M

Temperature Range

- …3,500 K

Color

- Red

Stellar Examples

- *Betelgeuse, Orion’s armpit*

11.22: The Hertzsprung-Russell Diagram

The Hertzsprung-Russell diagram, also referred to as the H-R Diagram, is a graph of stellar absolute magnitude or luminosity versus their spectral type or photosphere temperature. The H-R Diagram was created circa 1910 by Danish astronomer **Ejnar Hertzsprung** and American astronomer **Henry Norris Russell**. Plotting stellar luminosity versus color (temperature) allowed Hertzsprung Russell to see patterns in stars, from groupings of stars to how stars change over time, what is called stellar evolution. Looking at the H-R Diagram, you will first note that numerous stars are plotted. Imagine millions of stars, that is what makes up the diagram itself.

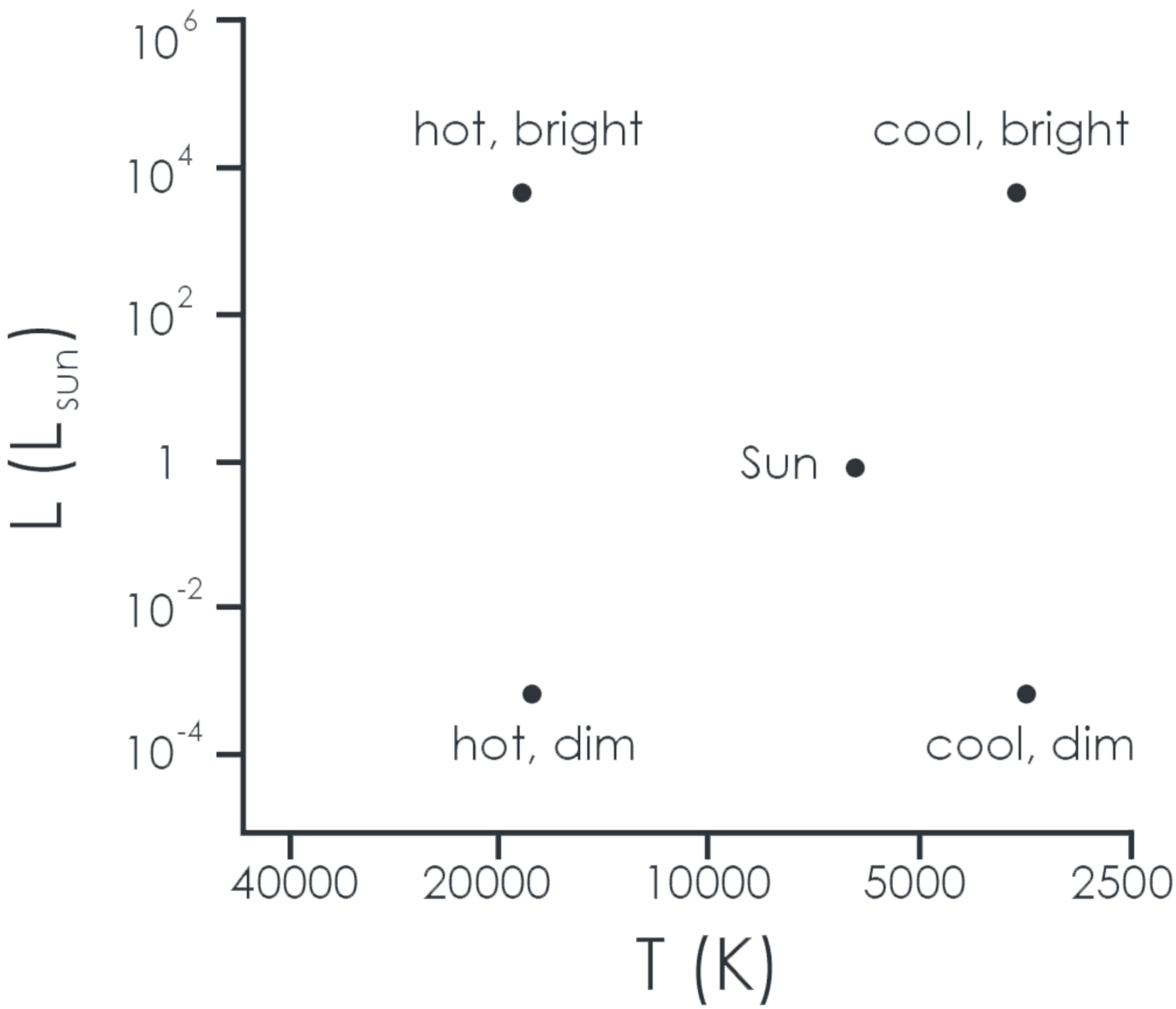
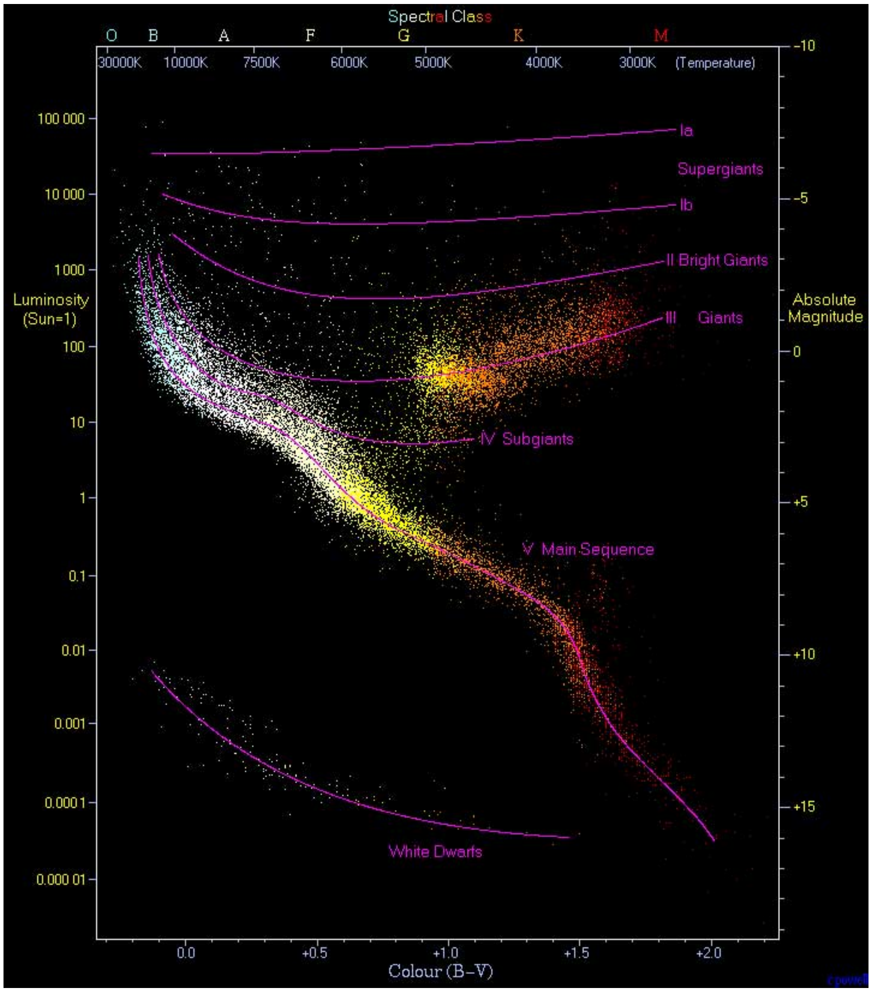


Image courtesy of Florida State College at Jacksonville.



CC BY-SA 2. 5 | Image courtesy of Richard Powell.

The graph also shows the colors of the plotted stars — note the stars on the left of the graph are more blue-white, towards the center yellowish, and on the right red to almost a purple color. That indicates the stellar temperature.

As you go higher on the graph, up the Y-axis, the stars are brighter — the stellar luminosity. This can be plotted as the L_{sun} with the $L_{sun} = 1$. It can also be plotted as Absolute Magnitude, M.

11.23: The Four Hertzsprung-Russell Diagram Stellar Groups

The H-R Diagram plots stars such that there are four major groups.

The **Supergiants** are cool stars, which are very large and very bright. They are located towards the top right of the graph.

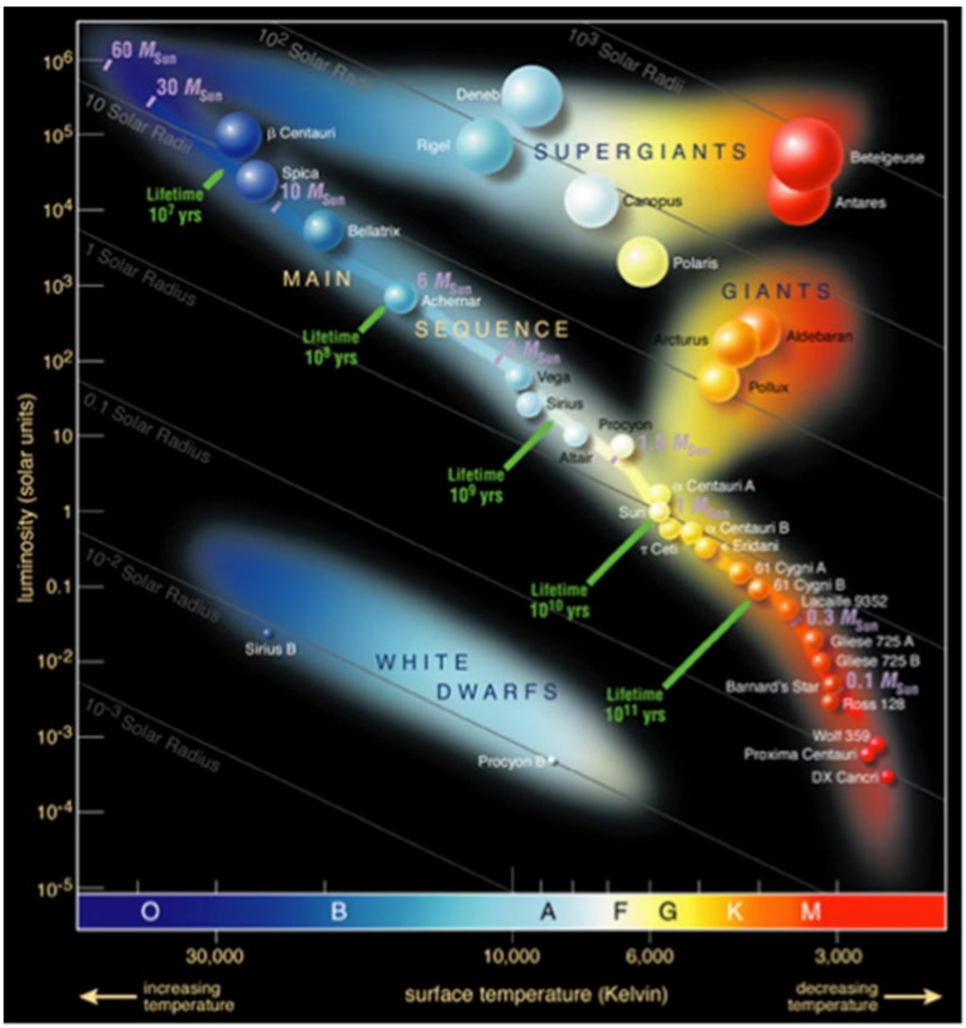
The **Giants** are cool stars, which are a little smaller and dimmer than the Supergiants.

The **White Dwarfs** are very hot stars, which are small in size and relatively dim. They are found in the lower left of the H-R Diagram.

The **Main Sequence** is a band of stars, which includes most of the stars, like our Sun. These are usually smaller stars, often dwarf stars.

The H-R Diagram can also show a star's life, referred to as Stellar Evolution. During the 1930s, it was found for stars with uniform chemical composition, there is a relationship between stellar mass and the star's luminosity and diameter.

Other important derivations of the Hertzsprung-Russell diagram can be used to show different data, for example classes of stars, protostars, brown dwarf objects, or graphs known as color index and color magnitude diagram.



CC BY 4. 0 | Image courtesy of European Southern Observatory (ESO).

11.24: Types of Star Systems and Stars

There are numerous types of stars and star systems throughout the Universe. We will touch on a few of these; some of the more common stars and star systems and some of the strangest of the stars.

Occasionally, astronomers will look through their telescopes and see two or more stars which happen to line up so that we see what appears to be a double star system, yet these stars are not physically related to each other. These are called **Optical Doubles** and simply happen by chance. Such occurrences are more infrequent than one would think. Systems in which physically associated star systems are made up of two stars are **Binary Stars**. And a **Visual Binary** is a pair of stars that we can see orbiting each other.

An **Eclipsing Binary Star**, or EBS, is a star system in which the star's orbital plane is such that it lies in the line of sight of telescopes on Earth so that the stars eclipse each other. Also called**eclipsing variables**, as one star orbits the more massive central star, the observers on Earth see eclipses occur.

First, the orbiting star will eclipse the more massive central star, eclipsing or blocking some of the light from the more massive and larger central star. Then, the smaller orbiting star will pass behind the more massive central star, usually eclipsing or blocking all of the light from the orbiting star. These eclipses can occur often if the orbiting star is close enough to the more massive central star. Or it may take weeks or months, perhaps even years, between eclipses depending on the EBS.

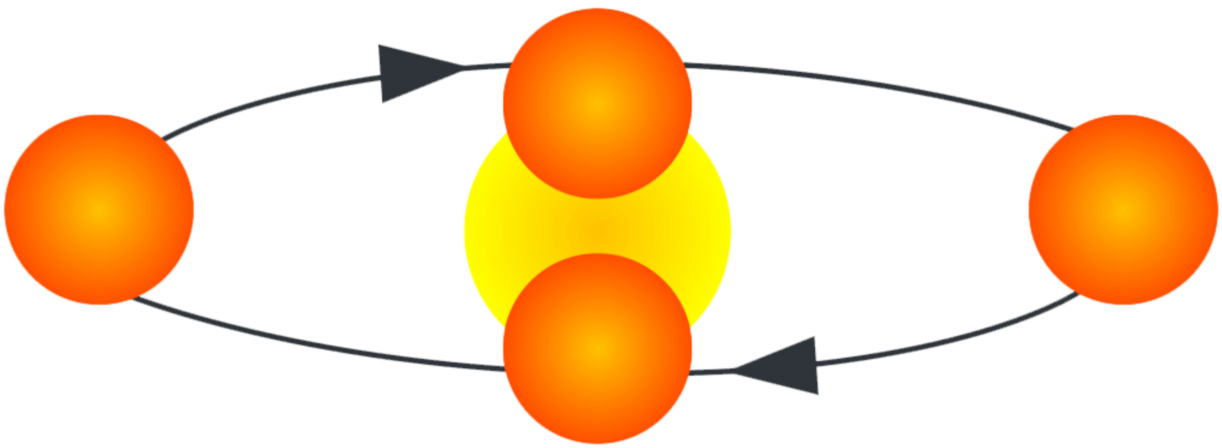


Image courtesy of Florida State College at Jacksonville.

CHAPTER OVERVIEW

12: Stellar Evolution

12.1: Module Introduction

I like the night. Without the dark, we'd never see the stars.

Stephenie Meyer
Twilight

"I think that we sare like stars. Something happens to burst us open; but when we burst open and think we are dying; we're actually turning into a supernova. And then when we look at ourselves again, we see that we're suddenly more beautiful than we ever were before!"

C. JoyBell C.

This module looks at how stars form and develop over time, including the less-massive stars, like the Sun, and more-massive stars.

Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

- Define the biology-like terms astronomers use when describing stars.
- Identify the characteristics of low-mass stars.
- Describe how white dwarfs, novae, and Type 1a supernovae are formed in low-mass stars.
- Identify the characteristics of high-mass stars.
- Describe how neutron stars, supernovae, and black holes are formed in high-mass stars.
- Define GRBs.
- Describe GRB characteristics

12.2: Star Life

There are specific terms in biology, which deal with life: birth, growing up, getting old, death, and even evolution. For the sake of convenience and familiarity, astronomers use similar terminology when dealing with stars. This module will focus on astronomical concepts, such as stars being born or stellar birth, stellar nurseries, stellar life, stars growing old, star death, and stellar evolution. **Note that stars are not alive!** These are simply terms of familiarity. Stars are formed in **interstellar medium**, which is filled with hydrogen, helium, and dust. This interstellar medium is cold and dense. These areas in space are also called **Molecular Clouds, Interstellar Clouds, or Stellar Nurseries** (more than one star).

One debate that transpired in the 1800s into the early 1900s was the question of what composed the stars. A doctoral student at Harvard, **Cecelia Payne-Gaposhkin**, noted in her 1925 doctoral dissertation that stars were made of hydrogen. Not all agreed with Payne-Gaposhkin's findings, yet as more data was collected and researched, her theory was proven correct a few short years after she first proposed the theory.

So how are stars 'born'? That is, what are the steps to a stellar birth? First, hydrogen, helium, and dust – the interstellar medium – has to accumulate. The interstellar medium starts to collapse due to gravity; these various atoms and dust particles attract each other, forming larger and larger clumps, attracting more gas and dust. As the interstellar medium collapses, the density, pressure, and temperature within the interstellar medium increases. Think of it like this: as the density increases, more particles are striking each other, generating more energy and heat.

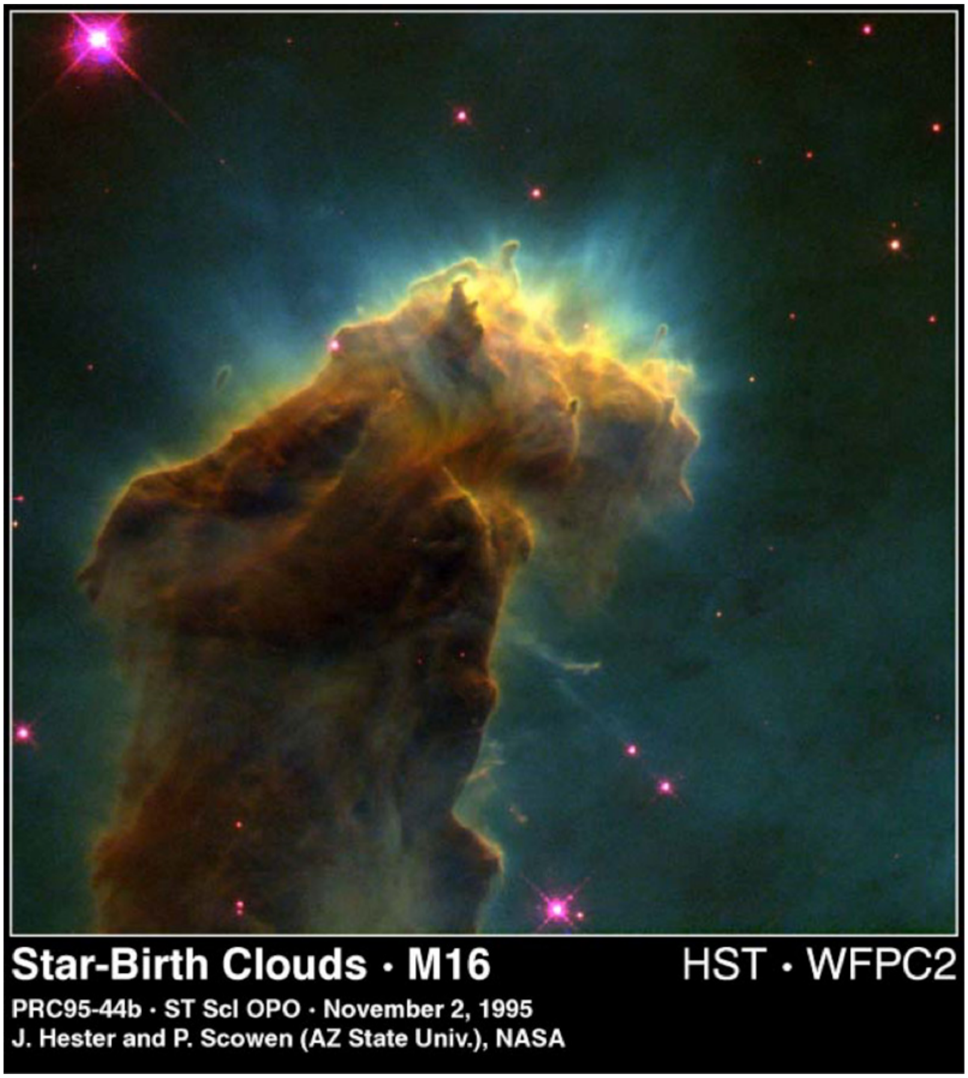
12.3: Stellar Birth

There are relationships between pressure, temperature, and volume in a gas like interstellar medium:

Where:

- This relationship shows that as the pressure (P) increases, the temperature (T) increases and the volume decreases (V).

  As the pressure, density, and temperature increases, no thermal (heat) energy can easily escape. The rising pressure and density leads to the formation of a Protostar, where the core is not yet undergoing fusion. The star 'turns on' – *a star is born* – when the protostar's core temperature reaches 10,000,000 K; fusion begins as the proton-proton cycle.



Public Domain | Image courtesy of NASA.

12.4: Stellar Mass

The type and life of the new star depends on the initial amount of material present: its stellar birth weight. Astronomers group stars as **Low-mass**, $<1.33\ m_{\odot}$; **Intermediate-mass**, $1.33\ m_{\odot}$ to $4\ m_{\odot}$; and **High-mass** $:>4\ m_{\odot}$. (Recall $\mathbf{m}_{\odot}$ refers to the mass of the Sun, the Sun = $1\ m_{\odot}$) Each of these star groups has different lives and deaths. In this module, we will examine low- and high-mass stars.

Stellar Mass versus Star Life range, Spectral Class

Mass; $m_{\odot}$

$60\ m_{\odot}$

$30\ m_{\odot}$

$10\ m_{\odot}$

$3\ m_{\odot}$

$1.5\ m_{\odot}$

1 $m_{\odot}$

$0.1\ m_{\odot}$

Time; Year

3 million years

11 million years

32 million years

370 million years

3 billion years

10 billion years

1000’s of billion years

Spectral Type

03

07

B4

A5

F5

G2 (Sun)

M7

12.5: Stellar Evolution

CC BY 4. 0 | Image courtesy of European Southern Observatory (ESO).

Stellar evolution is the process by which a star experiences a sequence of drastic variations during its stellar life. Depending on the initial stellar mass, this lifetime ranges from a few million years for the most massive to trillions of years for the least massive, which is considerably longer than the age of the Universe at 13. 7 billion years.

12.6: Low-Mass Stars

Low-Mass Stars fuse hydrogen into helium, the proton-proton cycle. The classic low-mass star is the Sun. Low-mass stars have large convection zones when compared to intermediate- and high-mass stars. In **very low-mass stars**, the Convection Zone goes all the way to the star's core!Over time, a low-mass star consumes all of the hydrogen in its core – *what happens now?* Think about a car that runs out of gas. Unless you put more gas in the tank, the car will not run. The same is true with stars; no more fuel in the stellar core will end the stellar fusion process.

When the core hydrogen is used up and no more nuclear fusion occurs, the star's outer stellar layers expand and the core shrinks. At this point, the star becomes a **Subgiant Star**. The star's outer layers continue to expand and the star brightens. The star then becomes a **Red Giant Star**. In about one billion years, the Sun will begin its Red Giant phase.

So how does the star expand and get brighter if it has ceased to fuse hydrogen in its collapsing core? Helium is left in the star's core and gravity continues to shrink the core and the surrounding layers. These surrounding layers contain hydrogen; the surrounding shell of hydrogen begins to fuse, called **Hydrogen Shell Burning**. The now red giant star is now larger than out to the orbit of Mars.

Next, helium fusion begins, for which very high temperatures are required.

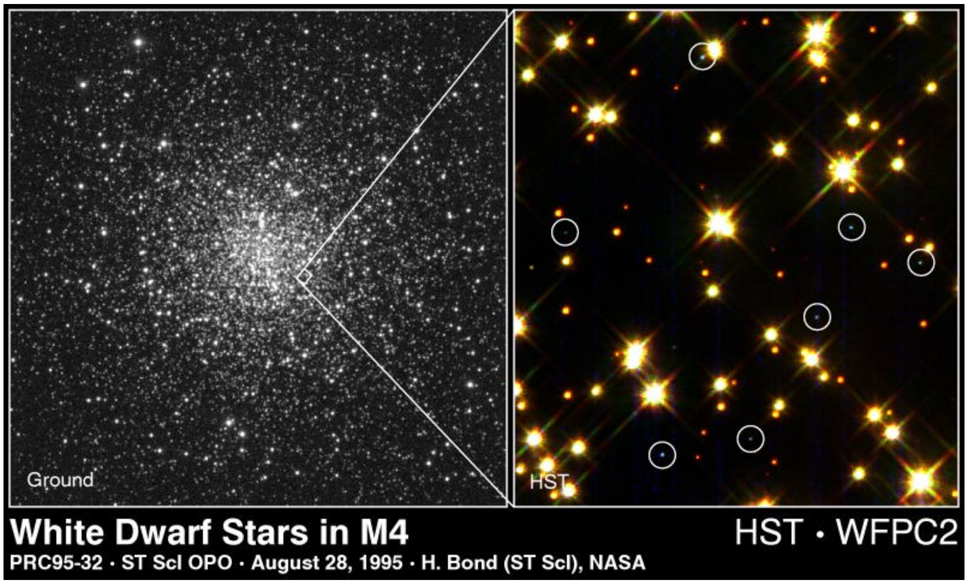
$^{3}\mathbf{He} \rightarrow {}^{12}\mathbf{C}$

This occurs when three helium nuclei are fused into one carbon.

The star begins to dim and shrink in size. Now the cycle *reverses* ; hydrogen and helium are fused at a tremendous rate. This process takes a few million years. Now the star's outer layers flow outward from the star, with the star's core is mostly composed of carbon (from the fusion of the remaining helium into carbon).

12.7: White Dwarf

The star can form a White Dwarf, then a planetary nebula. A **White Dwarf** is the inert stellar core that remains after a star has ended all core nuclear fusion. All nuclear fusion is over, that is, all available hydrogen in the star's core has been fused into helium and the helium into carbon. This White Dwarf stellar core is incredibly dense; in fact if you were to weigh a White Dwarf, it would weigh about 5 tons per teaspoon. It is extremely dense due to the collapse of the star's core; gravity has created an incredible density.

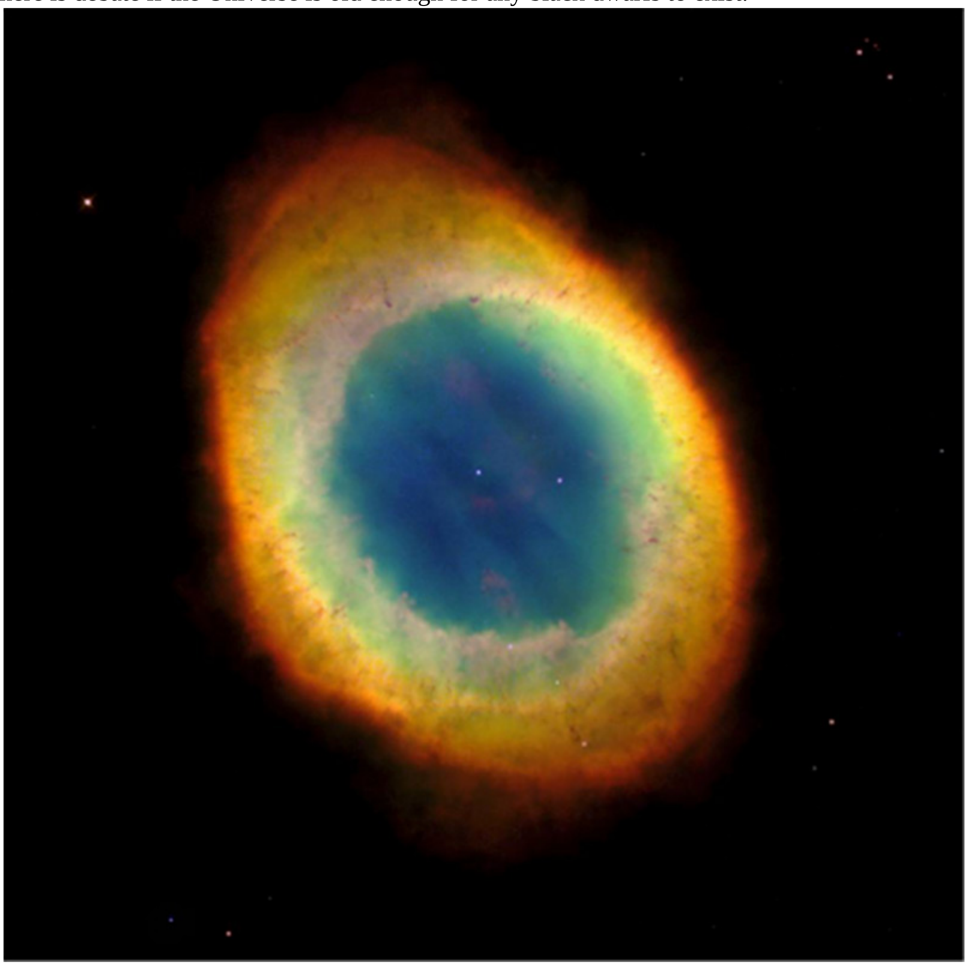


Public Domain | Image courtesy of NASA.

12.8: Planetary Nebula

The star's **planetary nebula** is created when a shell of gas is ejected by the star and illuminated by its central, White Dwarf. The term planetary nebula was coined by astronomer William Herschel in the 1780s as he was observing these objects. He brought attention to their round shapes, which reminded Herschel of planets. Planetary nebula are only visible tens of thousands of years, a short period in the life of a low-mass star. We see them due to the ultraviolet energy released by the White Dwarf. Once the White Dwarf cools and fades, neither the planetary nebula nor White Dwarf is visible. What remains is an expanding cloud of gas and dust and a carbon sphere.

Note: In the end, all that remains is a cold, dark mass composed mainly of carbon. These are occasionally referred to as **black dwarfs**, although there is debate if the Universe is old enough for any black dwarfs to exist.

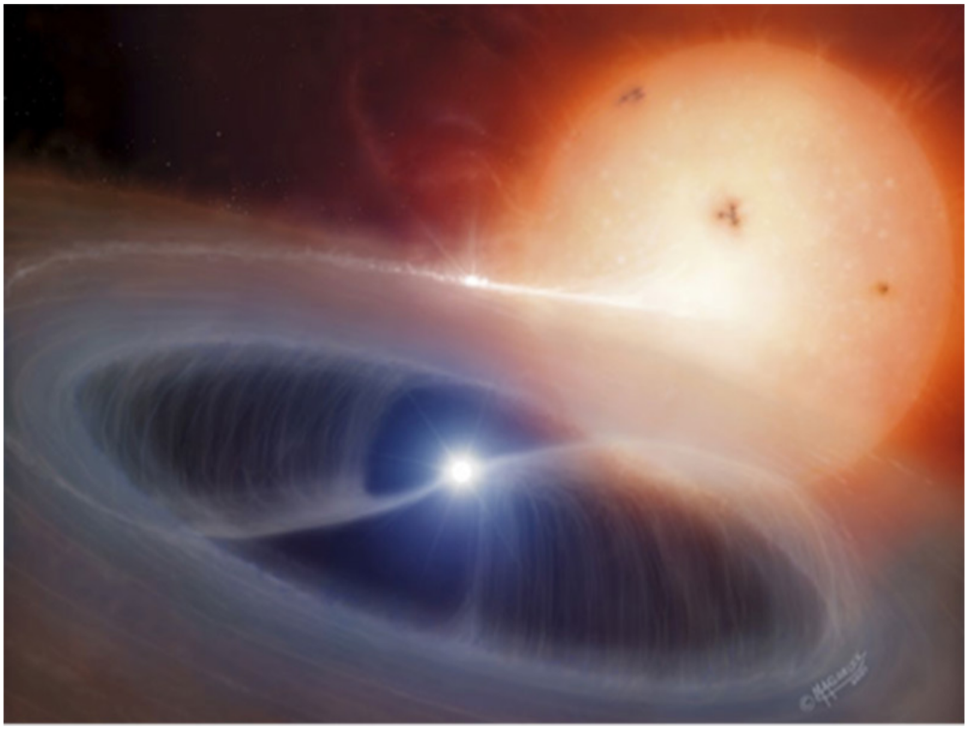


Public Domain | Image courtesy of NASA / EVA.

Public Domain | Image courtesy of NASA.

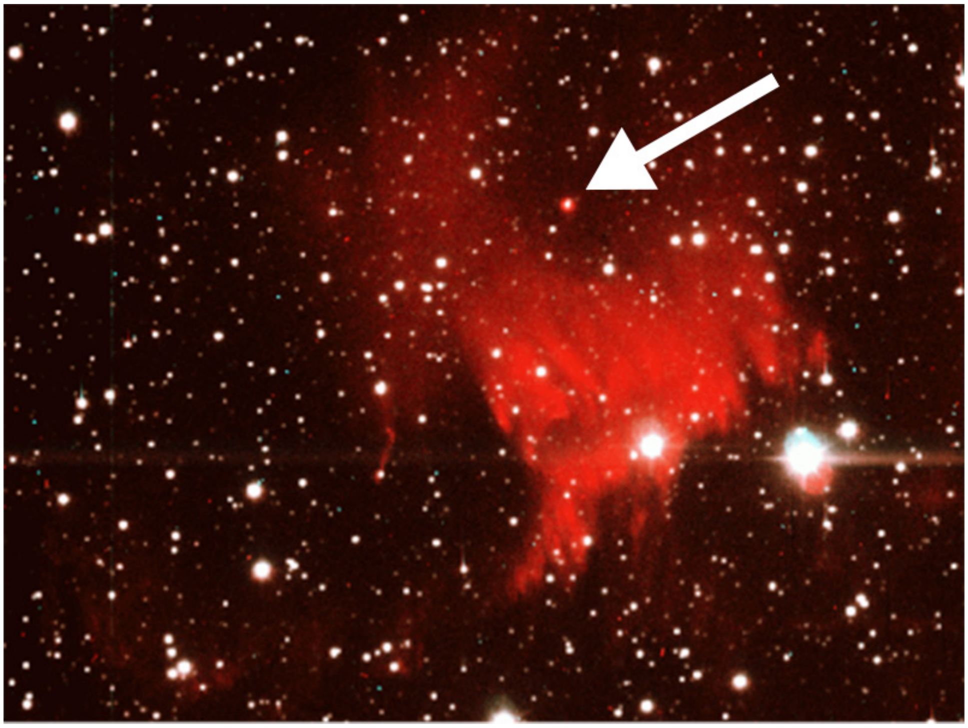
12.9: White Dwarfs and Neighbors

White Dwarf surrounded by its accretion disk. The star being cannibalized) is in the upper right. Note the differences between the White Dwarf's and the star's color and size. White Dwarf surrounded by its accretion disk. The star being cannibalized) is in the upper right. Note the differences between the White Dwarf's and the star's color and size.



Public Domain | Image courtesy of NASA.

The nova—indicated by the white arrows, provides the illumination to allow the reddish nebula to be seen. When the nova fades from view, the nebula will lose its illumination source, so it will no longer be seen.



Nova Cygni 1992 | NASA Hubble Space TelescopePublic Domain | Image courtesy of NASA.

12.10: Nova, Novae, and Supernova

The word nova comes from the Latin, for ‘new. ’ Novae can brighten as much as **100,000 Suns, 100,000L $_{sun}$**. Material from the Nova fusion event radiates outward from the White Dwarf; we can view this outward radiating material as a planetary nebula. The nova process can repeat itself, *but not infinitely* . When the White Dwarf accreting mass reaches the low-mass star 1. 33M $_{sun}$ limit, a **Type 1a Supernova** is possible. First the White Dwarf begins to collapse, with fast, quick heating. Carbon fusion begins (12 in the stellar core) and then the Star “ignites,” exploding as a White Dwarf Supernova. These are usually one-time events.

Type 1a supernovae produce elements up to iron on the atomic table, and also produce elements heavier than iron, like gold, silver, and uranium. These type of supernovae have the same characteristics, such as how bright they will become and length of maximum brightness. Therefore astronomers can use them as a “standard candle,” that is a standard brightness.

Supernovae may also produce **cosmic rays**, which are composed of electrons, protons and neutrons and move at close to the speed of light. **Ultra-high energy cosmic ray particles** were discovered in 2005. These are the brightest and fastest radio blasts ever seen on the sky, seen as radio light that appear more than 1000 times brighter than the Sun and almost a million times faster than normal lightning.

The very bright star in the lower left is Supernova SN1994D in Spiral Galaxy NGC4526. Compare the brightness of the supernova to its home galaxy.

Public Domain | Image courtesy of NASA.

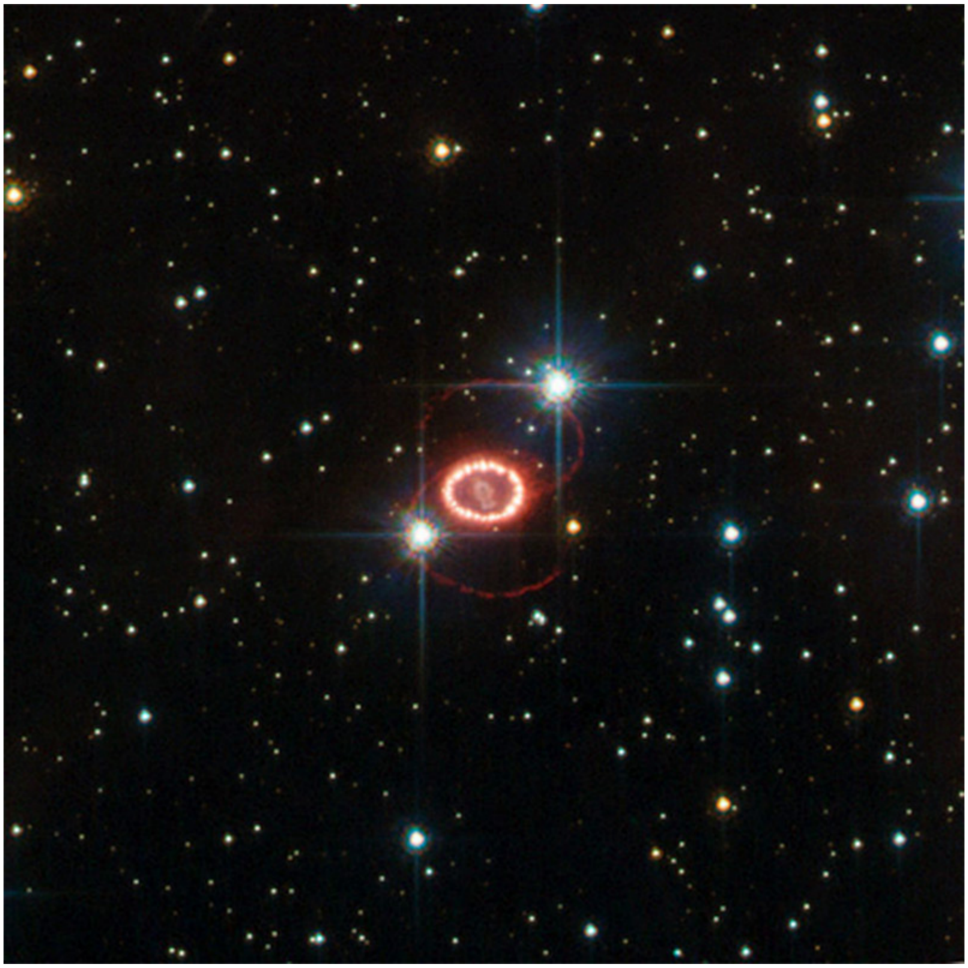
12.11: High-Mass Stars

High-Mass Stars have a very-short life when compared to low-mass and intermediate-mass stars. In high-mass stars, the fusion process includes heavy elements, the CNO Cycle; **C** arbon- **N**itrogen- **O** xygen:$\mathbf{H_2 \rightarrow He \rightarrow C \rightarrow N \rightarrow O \rightarrow \ldots \rightarrow Fe}$

High-mass star characteristics include:

- An example of a high-mass star is the red supergiant Betelgeuse; it is 500 times the size of our Sun.

  This supernova occurred about 168,000 *ly* from Earth.

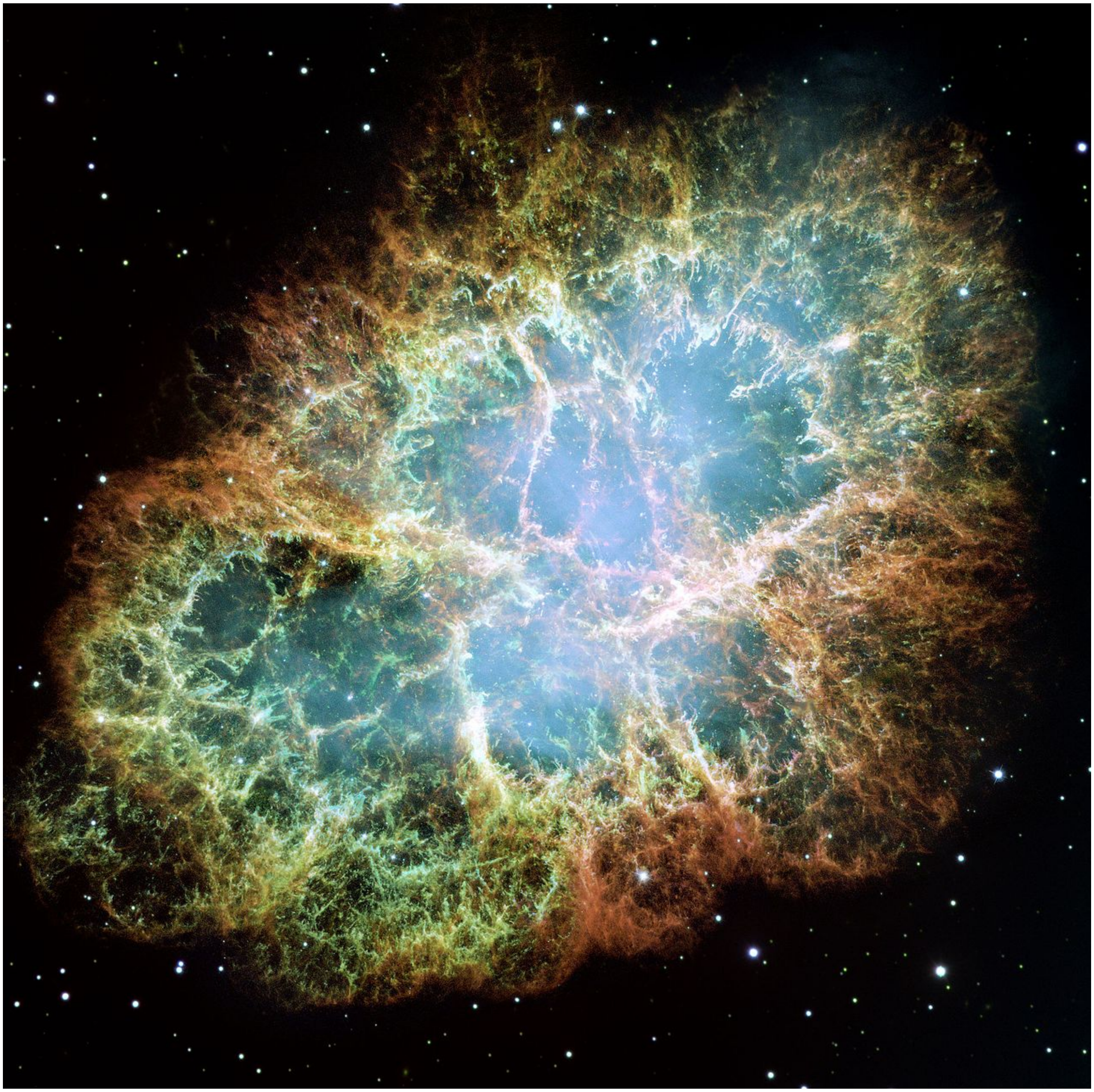


CC BY 3. 0 | Image courtesy NASA and ESA

A **supernova** is an explosion of a star that briefly outshines an entire galaxy, radiating as much energy as an ordinary star like the Sun over its entire lifetime. The supernova will fade from view over several weeks to months.

The star's core collapses in an instant into a sphere; it simply cannot withstand the immense pressure and gravitational attraction. At collapse a sphere of Neutrons remains. Heavier elements are now produced due to the supernova event, and enormous amounts of energy released. An average high-mass star supernovae within 30 *ly* of Earth pose a danger to life on Earth, due to the energy and particles released in this type of supernova event. Particles released by the supernova are very harmful to life as we know it. It would be much like being close to an atomic bomb going off.

The Crab Nebula ; M1, a Supernova Remnant.

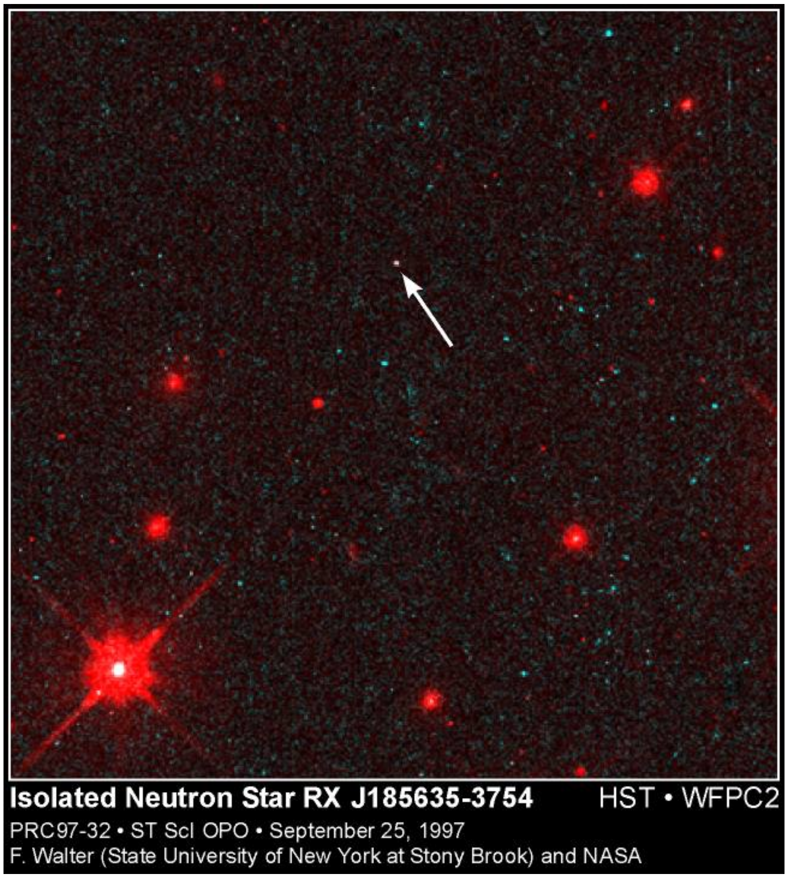


Public Domain | Image courtesy of NASA.

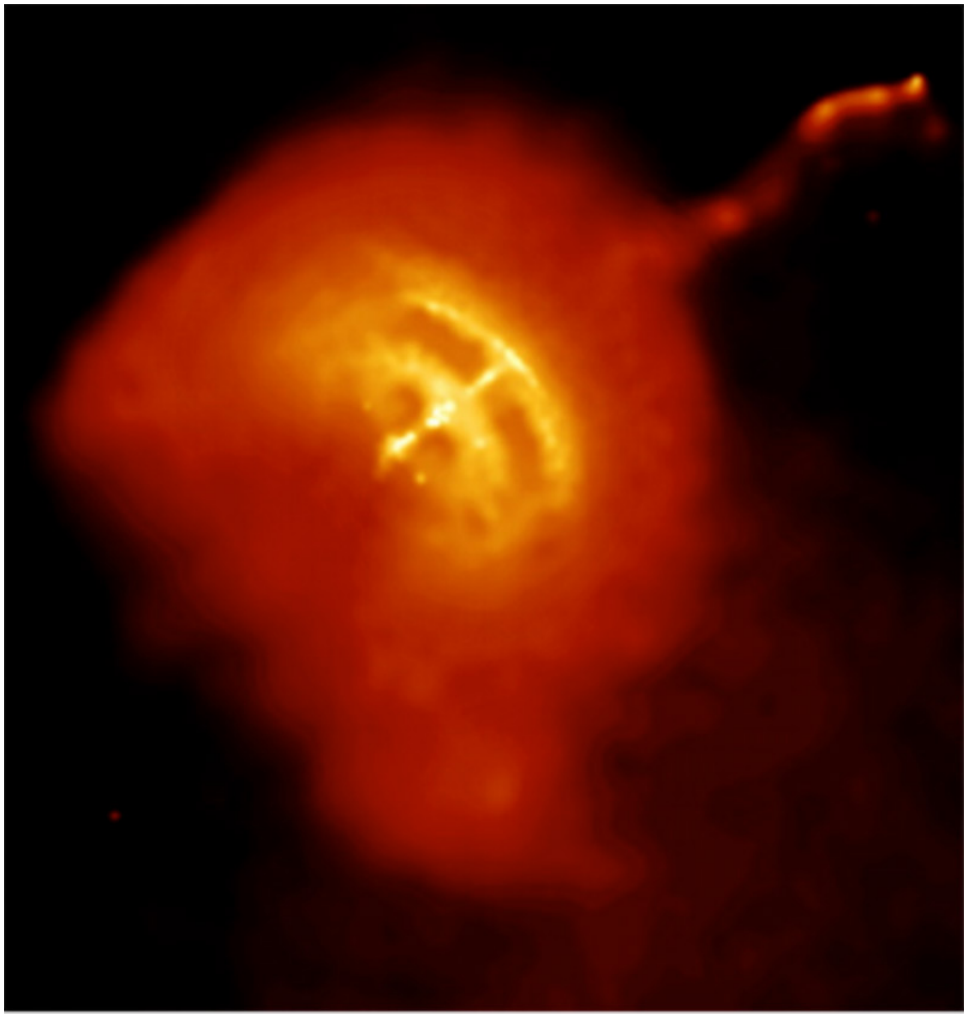
12.12: Neutron stars

Neutron stars are the spheres of neutrons created by the collapse of the iron core in a massive star supernova; roughly **10 miles** in diameter. The concept of a neutron star was first proposed in 1934 by Walter Baade and Fritz Zwicky, a year after the announcement of the discovery of neutrons. Neutron stars are composed completely of neutrons, n0; neutron stars are dim and intensely hot, and held together due to the gravitational attraction.

There are objects related to neutron stars. **Binary Neutron Stars** are two neutron stars orbiting each other. It is estimated that about 5% of all neutron stars are a part of a binary system. Pulsars – short for pulsating radio star – are rapidly rotating radio source and a type of neutron star. **Pulsars** were discovered in 1967 by Joycelin Bell and initially called LGM – ***Little Green Men*** – due to the regular electromagnetic radiation released from the pulsar. A small fraction of pulsars only emit gamma rays.



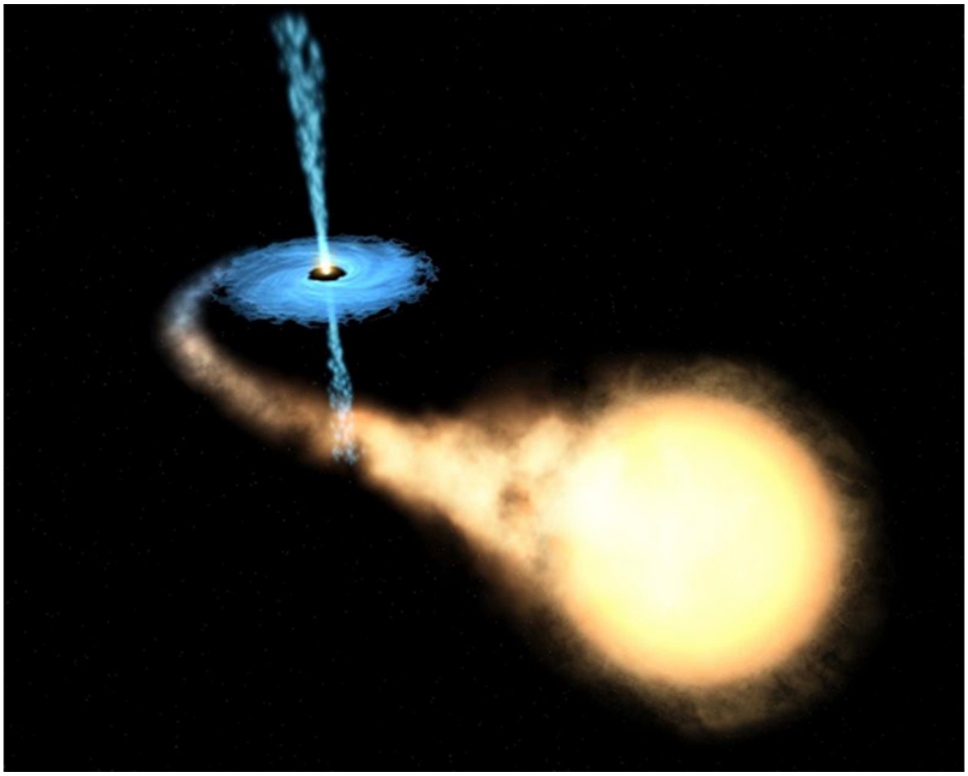
Public Domain | Image courtesy of NASA.



Public Domain | Image courtesy of NASA.

12.13: Neutron Star and Companion Star Scenario

Artist's concept of an X-ray binary—the donor star (right) and the star being cannibalized (shown in blue on the left); the X-ray star the Accretor star.



Public Domain | Image courtesy of NASA.

Close binary systems of neutron stars and companion stars are much like a White Dwarf and Companion Binary star scenario. An accretion disk can form from material taken from the companion star by the neutron star. Neutron Stars are much hotter and more luminous than the White Dwarf scenario; they become a powerful X-ray source, called an **X-ray Binary**. These type of objects emit bursts of energy and are called **X-ray Bursters**.

12.14: High-Mass Star Stellar Endings

There are two possible stellar ending scenarios, depending on the star's original mass. **If the star is less than three solar masses, <3 M $_{sun}$, this is the neutron star limit.** If it is a single star (*not* part of a binary star system), the star will eventually cool as a large cinder in space. Yet if the star is part of a **binary system**, the star will continue accreting material, jetting energy into space until all of the stellar fuel is exhausted.

If the star is greater than three solar masses, >3 M $_{sun}$, then the ultimate cosmic extinction occurs: a Black Hole. There is a discussion among astronomers how massive of a star is needed to form a black hole; ranges from >3 M $_{sun}$ to 25 M $_{sun}$. Black holes originate as the high-mass star's iron core collapses, just prior to the star going Supernova. This is called a **Type 2 Supernova**.

Public Domain | Image courtesy of NASA / JPL.

With a black hole scenario, a catastrophic collapse of the star's core continues. This does not allow matter, or even light, to escape a certain point, called the **Event Horizon**. That is due to the fact that the escape velocity from a black hole is greater than the speed of light. The event horizon size is called the **Schwarzchild radius**. Black holes eject energy back out when overloaded with matter flowing into the black hole. Eventually, black holes will crush to a final, infinitely dense and small point called a **Singularity**.

Questions astronomers are asking about black holes include:

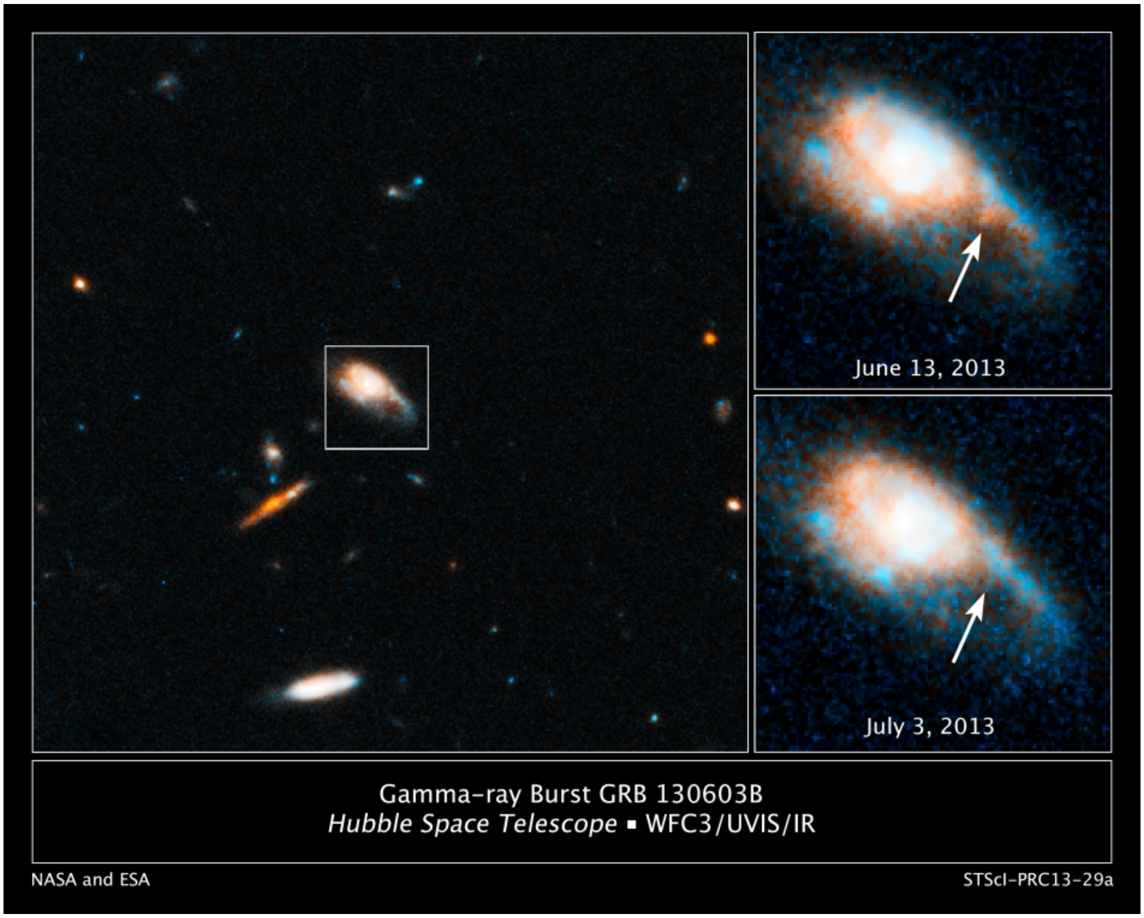
- The challenge with answering these questions at this time is that we can never know what happens inside a black hole because we cannot get the data out.

  We cannot see black holes directly, so how do we know they exist? There are several types of evidence of black holes. First, we see close binaries with gas flowing into nothing. The extreme Doppler shifts of stars has been observed, with apparently nothing in the area of the star to cause the extreme Doppler shift. A number of warped star fields have been observed, called **gravitational lensing**. And evidence that is somewhat direct occurs when a gas is pulled into a black hole by its strong gravitational force; the gas heats up and radiates back out into space.

12.15: Gamma-Ray Bursts (GRBs)

During the 1960s, there was great concern among the Superpower Countries that nuclear testing or even a nuclear attack could occur without notice. The United States developed a series of satellites to monitor gamma radiation pulses emitted by nuclear weapons tested or used in space. Gamma radiation outbursts were observed and determined to be coming from space. Further research showed these outbursts were fairly evenly distributed throughout the sky. **Gamma-ray bursts**, or **GRBs**, are flashes of gamma radiation related to extreme energetic explosions detected in very distant galaxies. GRBs are the brightest electromagnetic events known to occur in the Universe. These GRBs can range from ten milliseconds to several minutes. The initial GRB is usually followed by a longer lived afterglow, emitted at wavelengths such as X-ray, UV, visual, microwave, and radio wavelengths.

A number of satellites have been built to observe GRBs. The Compton Gamma Ray Observatory determined that GRBs were from outside our Galaxy. (There is a class of gamma-ray objects within our galaxy, but not with the extreme power of GRBs). Some have speculated that GRBs are possibly at the edge of the early Universe and the death throes of extremely massive stars, which only lasted about 1 million years. These stars appear to eject Gamma Rays after a **hypernova event**, an extreme supernova which produces gamma radiation. GRBs also appear to come from within stellar nurseries.



Public Domain | Image courtesy of NASA, ESA, N. Tanvir (University of Leicester), A. Fruchter (STScI), and A. Levan (University of Warwick).

Consider this…

“The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of starstuff. ”

—Dr. Carl Sagan *Cosmos* (2002)

CHAPTER OVERVIEW

13: Galaxies

13.1: Module Introduction

“There are at least as many galaxies in our observable Universe as there are stars in our galaxy. ”

Martin Rees
Lord Rees of Ludlow
Astronomer
(1942 -)

This module presents an overview of the islands of stars found throughout the Universe: the galaxies. Like many objects we have discovered, galaxies vary in characteristics such as size, shape, and age.

Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

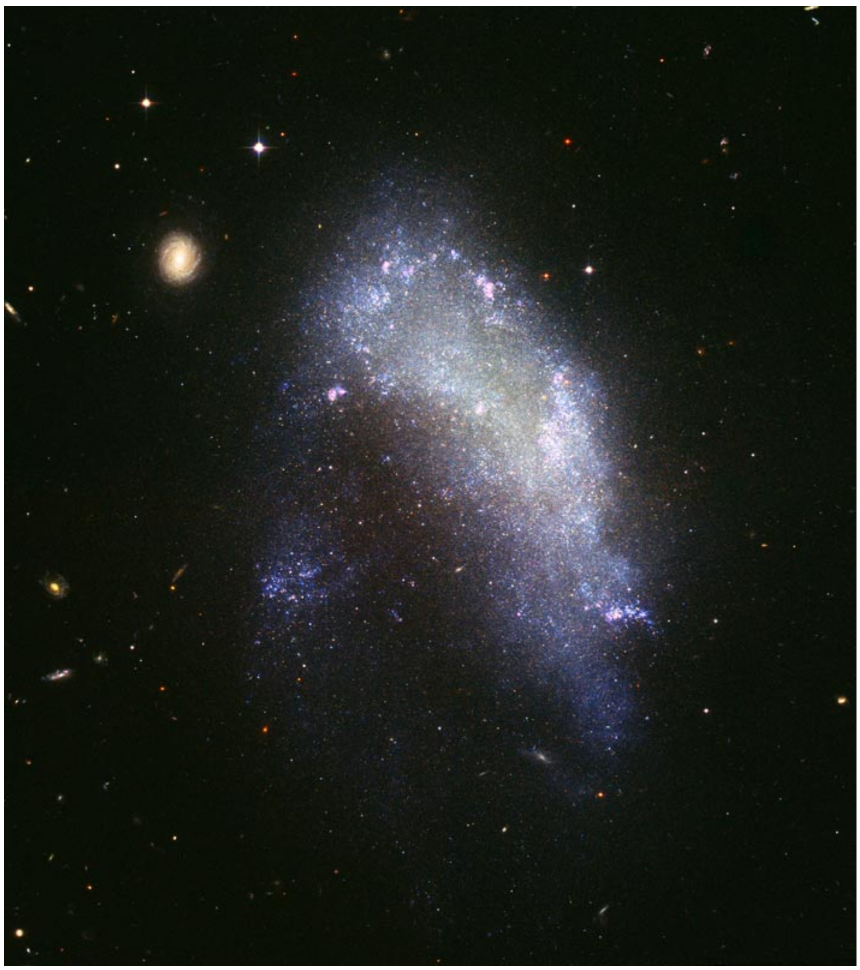
- Define what a galaxy is and the broad characteristics of galaxies, including galaxy types.
- Explain the history of observing galaxies.
- Recognize Hubble’s Law and its implications in astronomy.
- Differentiate among galaxy-related objects, including Quasars, Blazars, galactic grouping, WIMPs, gravitational lensing

13.2: What do you think?

Looking at these images, can you understand how astronomers could have misunderstood the nature of galaxies by what they saw in the night sky?

Public Domain | Image courtesy of NASA.

Public Domain | Image courtesy of NASA.



Public Domain | Image courtesy of NASA.

13.3: Galaxies

A **galaxy** is a massive, gravitationally bound system of stars, stellar remnants, interstellar medium, and dark matter. The term galaxy comes from the Greek galaxias, literally translated as milk or milky, referring to our Milky Way galaxy. Galaxies can range in size from the dwarf galaxies — as small as ten million stars, to giant galaxies with one hundred trillion stars. It is currently estimated that there are 170 billion galaxies in the Universe. It is believed that nearly all galaxies also contain stellar systems with planets orbiting many of their stars, like our Milky Way galaxy. However, that has not been confirmed, but is a solid theory based on what we have discovered in the Milky Way, and comparing the characteristics of the Milky Way to other galaxies.

A number of galaxies are believed to have **supermassive black holes** at their centers. The Milky Way's supermassive black hole is called **Sagittarius A** * or **SGR A** * . These supermassive black holes have been observed in a number of other galaxies; astronomers are trying to determine if this is a consistent characteristic.

These supermassive black holes are hypothesized to be the principal driver of the **active galactic nuclei** or **AGN**. An AGN is a compact region located at a galaxy's center, which has a significantly higher luminosity from one to several ranges of the electromagnetic spectrum.

13.4: The History of Studying Galaxies

The study and discussions of galaxies goes back millennia. **Abd al-Rahman al-Sufi**, a Muslim astronomer from Persia (modern Iran), was the first to recognize the Large Magellanic Cloud, an irregular galaxy, and in 964 AD made the earliest observation of the Andromeda Galaxy, in which al-Sufi described Andromeda as a *small cloud* . Al-Sufi was the first to observe other galaxies than the Milky Way galaxy.

In his text, al-Sufi discusses a number of astronomical observations and topics, including his observations of what he called Al Bakr, the Large Magellanic Cloud.

Thomas Wright hypothesized in 1750 that the Milky Way galaxy was a flattened disk of stars. Wright also thought that some of the 'nebulae' observed were actually objects like the Milky Way. (Nebulae was the term used to describe all of these nebula-like objects, many of which are now known to be galaxies.) Five years later, in 1755, **Immanuel Kant** coined the term *Island Universe* to describe these 'nebulae' that Wright had hypothesized.

During the search for comets from 1771 to 1784, **Charles Messier** completed a catalog listing of a number of bright nebulae. Several of the Messier Objects are now known to be galaxies. When**William Herschel** created his 1786 catalogue of deep sky objects, he used the phrase spiral nebula for a number of the objects, such as the Andromeda nebula. This indicated that Herschel was able to discern the *spiral nature* of these objects. **Lord Rosse** completed a new, large telescope in 1845 and was able to differentiate between elliptical and spiral nebulae.

Deep sky objects are those objects *other than* Solar System and stellar system objects, and individual stars. These include objects such as star clusters, nebulae, and galaxies.

A sketch of the Whirlpool Galaxy, Messier 51 by Lord Rosse in 1845. Public Domain | Image courtesy of NASA.

A photograph taken by the Hubble Space Telescope. Public Domain | Image courtesy of NASA.

13.5: Hubble's Major Contributions

California Institute of Technology, Mt. Wilson ObservatoryPublic Domain | Image courtesy of NASA.

Edwin Hubble was hired to work at the new Mt. Wilson observatory in 1919, studying cloudy patches called nebulae.

American astronomer Edwin Hubble made three major contributions to the field of galactic astronomy.

First Contribution

First, using the new 100-inch telescope at Mt. Wilson Observatory in California, he demonstrated that some of these nebulae, like the Andromeda nebula, were actually objects – galaxies – far beyond our Milky Way galaxy.

This contradicted the view at the time; the Milky Way was considered the Universe. Yet Hubble's observations of Cepheid variables in these galaxies and comparing them to Cepheids in the Milky Way led him to his controversial conclusion.

Second Contribution

Second, Hubble was the first to classify galaxies based on what he observed, from 1922 to 1923. He classified these based on shapes: elliptical, spiral, and irregular, called a galaxy's visual morphology. Hubble's classification led to his Hubble Galactic Tuning Fork or Hubble Sequence — how he thought galaxies evolve.

Third Contribution

The third contribution is Hubble's formulation of the redshift distance law in 1929, better known as Hubble's Law. The law states that the more distant a galaxy, the greater the redshift. We can determine a galaxy's receding velocity by its redshift— *most of the time* . (Receding velocity is how fast the galaxy is moving away from us.)

$\mathbf{V = H_o d}$

Where:

- **V** is the velocity
- $\mathbf{H_o}$ is Hubble 's constant
- **d** is the distance to the object

One of the ongoing controversies surrounding Hubble's Law is determining Hubble's constant, Ho. One of the goals of the Hubble Space Telescope, named for Edwin Hubble, was to determine H_o, which it was able to do through years of observation and data.

Rearrange the equation to find the distance:

$$\mathbf{d = v / H_o}$$

13.6: Hubble’s Law

The appearance of Hubble’s Law was not without controversy, either. Two years prior to Hubble’s formulation, **Georges Lemaître**, a Belgian Catholic priest, published a paper in the journal*Annales de la Société Scientifique de Bruxelles* , which detailed the relationship between distance and velocity, supporting an expanding Universe Model. Lemaître earned his doctorate in Astronomy at Massachusetts Institute of Technology, MIT, under the direction of Dr. Harlow Shapley.

It appeared, however, that astronomers wanted to acknowledge Hubble’s work instead of Lemaître. This might have been due to the fact that Lemaître’s doctorate advisor, Harlow Shapley, strongly opposed Hubble’s earlier extragalactic objects research and findings.

13.7: Classification of Galaxies

Edwin Hubble was the first to classify galaxies based on the shapes, which he observed. These observations included Elliptical galaxies, Spiral galaxies, and Irregular galaxies. This lead to his **Hubble Galactic Tuning Fork** (Hubble Sequence)—how Hubble thought galaxies evolved.

Astronomers now recognize four major groups of galaxies:

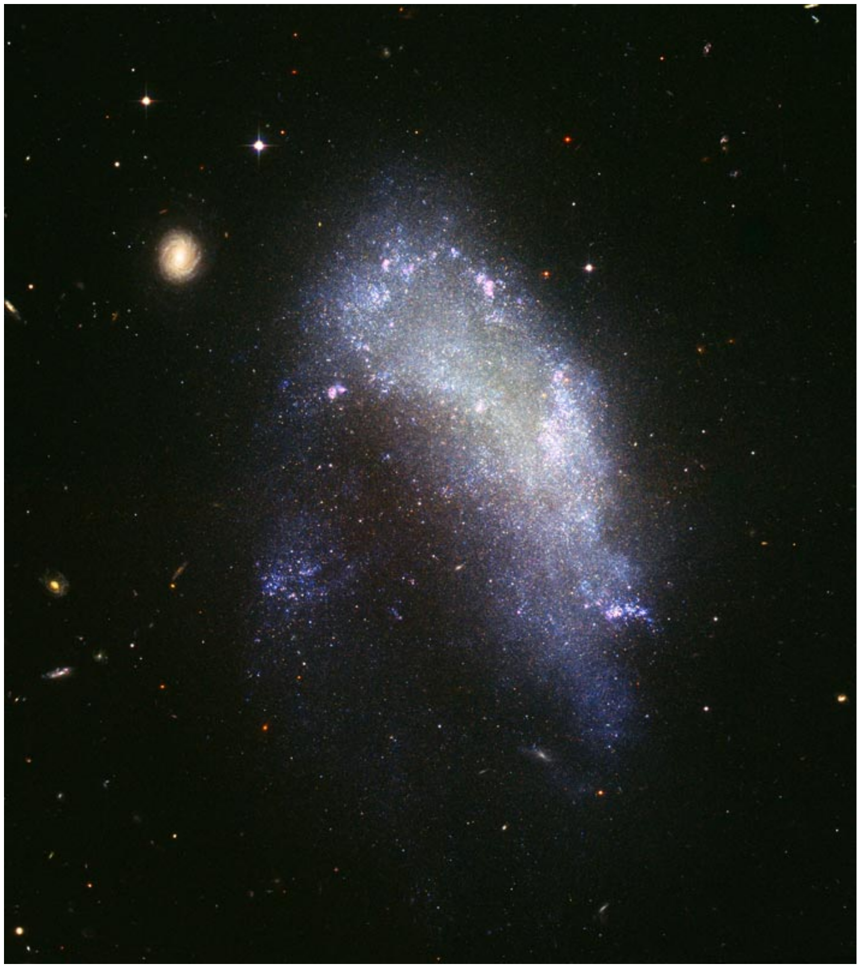
- Elliptical Galaxies
- Spiral Galaxies
- Irregular Galaxies
- Active Galaxies

13.8: Elliptical Galaxies

Elliptical galaxies are those galaxies classified according to their shape and size. The shapes go from round – soccer-ball like – to extreme elongated – football-like – and are classified E0 (soccer ball shapes) to E5 (football shapes). Elliptical galaxies have very little dust and gas, and appear to be the oldest class of galaxies. They are not the dominant type of galaxy found in the Universe; some estimates place Elliptical populations are at around 10% to 15% of all galaxies.

M87Public Domain | Image courtesy of NASA.

NGC 1316Public Domain | Image courtesy of NASA.


NGC 1132Public Domain | Image courtesy of NASA.

13.9: Spiral Galaxies

Spiral galaxies are those galaxies which appear like flattened disks with a central bulge, usually with arms. There are three main types or classes of Spirals based on their shapes.

Spiral Galaxy Types

Spirals

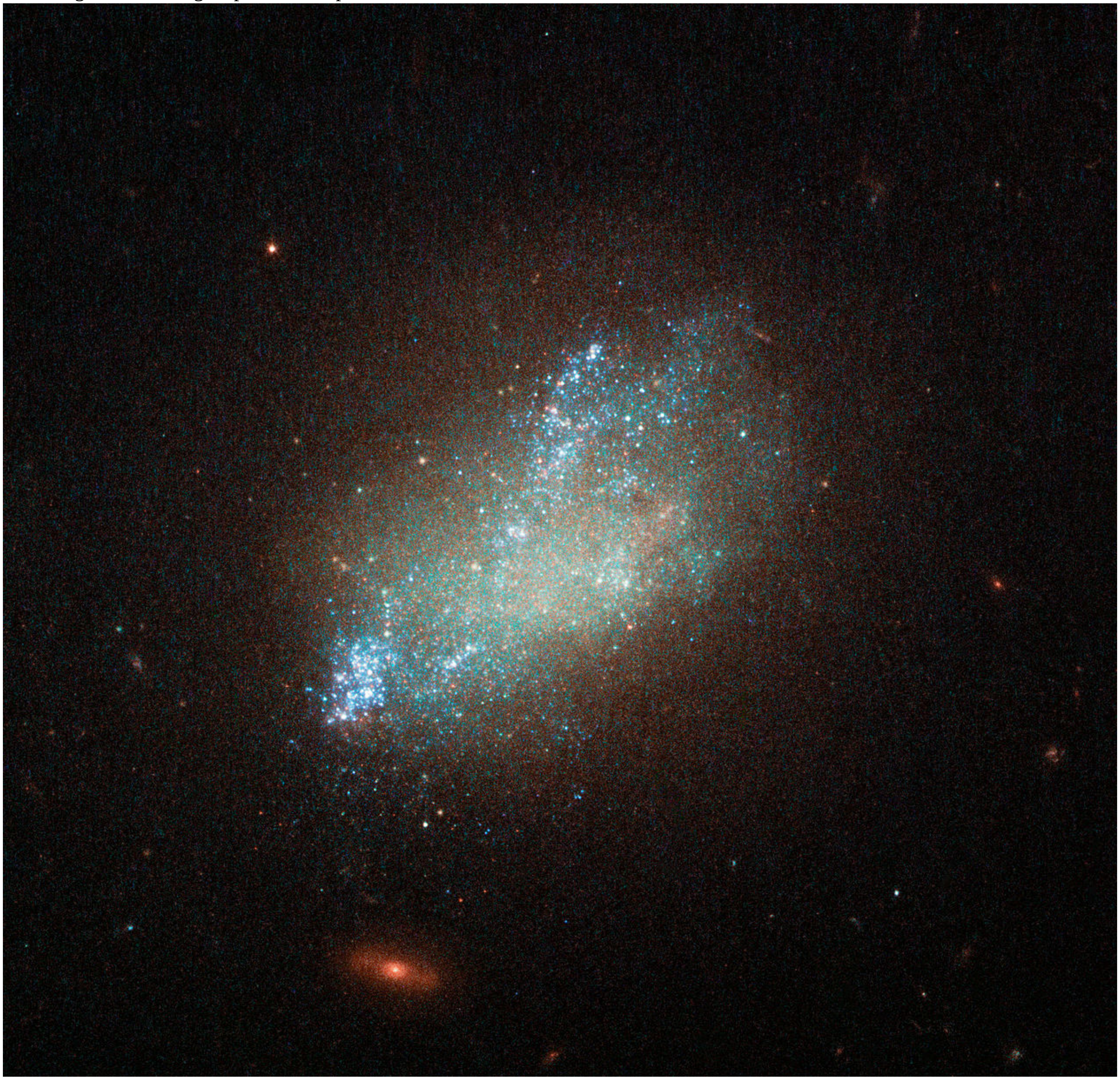
Classes

- **Descriptions**
  - **Classes**
    - **Descriptions**
      - **Classes**
        - **Descriptions**
          - No Spiral Arms, but disk-shaped. Appear to be old when compared to other spirals

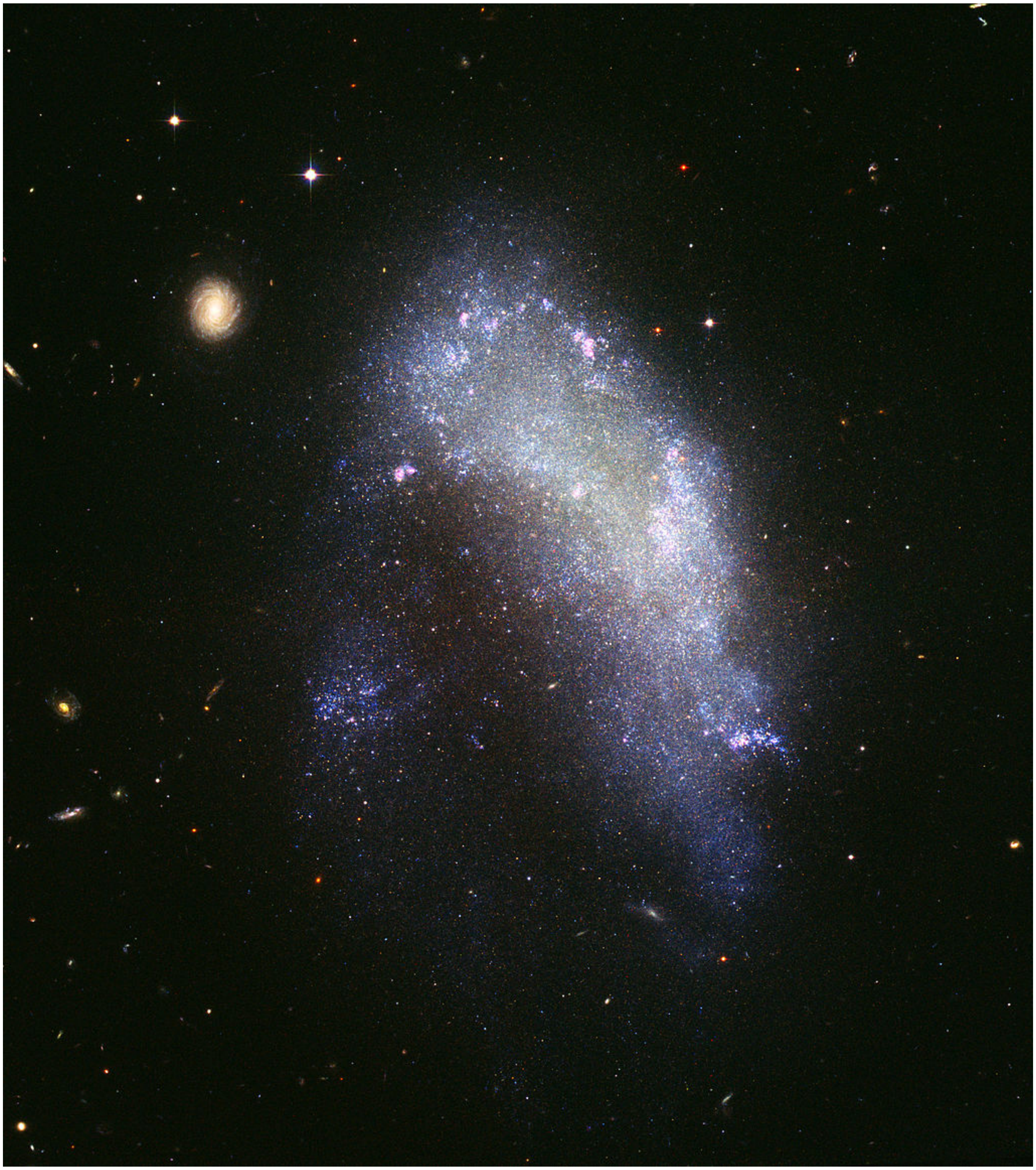
NGC 2787, Lenticular SpiralPublic Domain | Image courtesy of NASA.

13.10: Irregular Galaxies

Irregular galaxies are those galaxies, which look neither Elliptical nor Spiral and have no true shape or form. Irregulars make up a smaller percentage of all galaxies, estimated to be about 25%; they were probably more prevalent in the early Universe. Irregular galaxies are dusty, but not as much as spirals, and usually small in size when compared to other galactic types. They are often satellite galaxies of larger spirals or ellipticals.



IC 559CC BY 3. 0 | Image courtesy of ESA/Hubble, NASA, D. Calzetti (UMass) and the LEGUS Team.



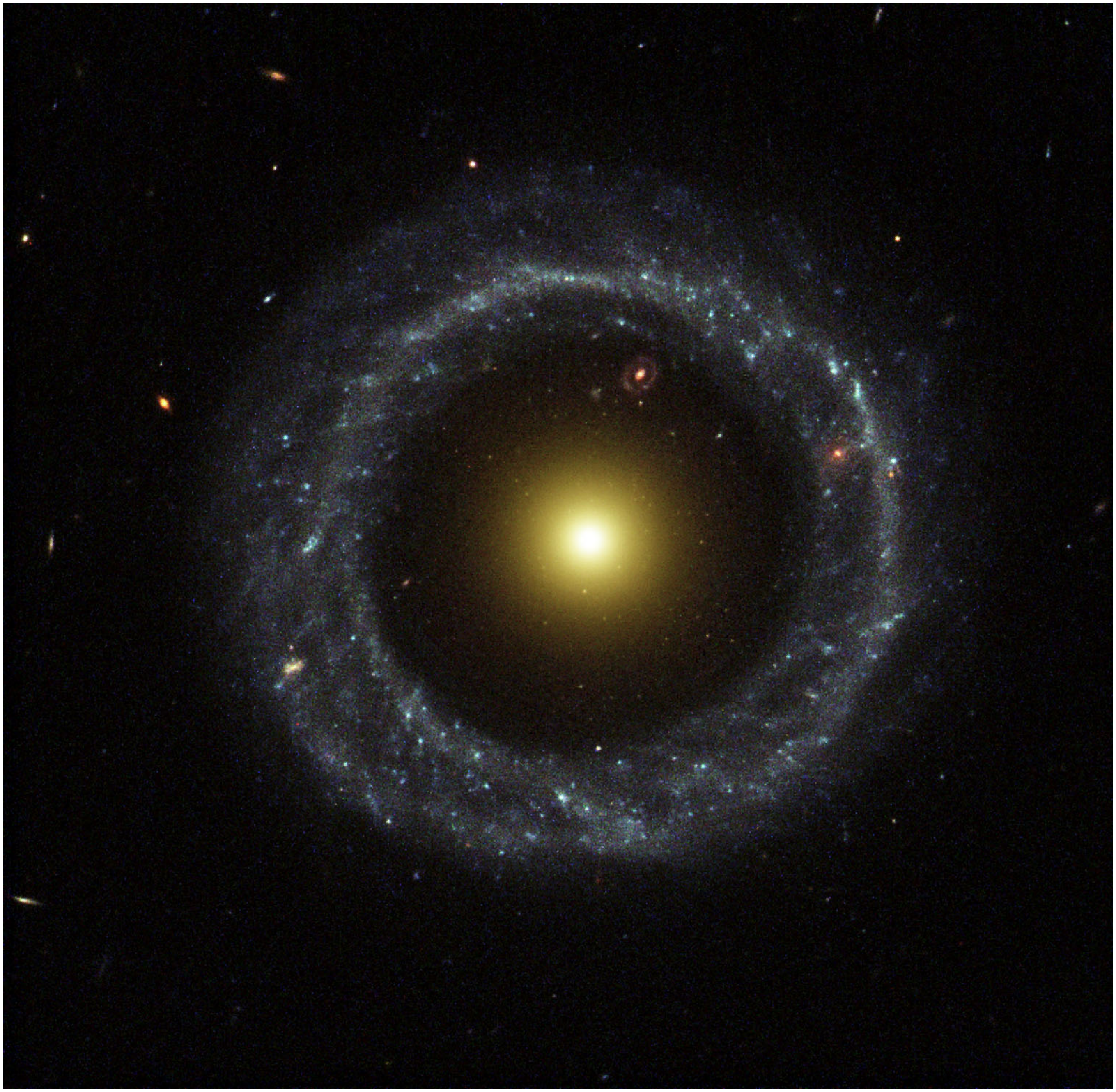
NGC 1427APublic Domain | Image courtesy of NASA.

DDO 80, Dwarf GalaxyCC BY 3. 0 | Image courtesy of ESA/Hubble.

13.11: Active Galaxies

Active galaxies are those galaxies with extreme energy output; approximately 10% of all known galaxies fall into this group. There are a number of types and classifications of Active galaxies. The**Seyfert galaxies** look like Spirals but produce extreme energy output. **Radio galaxies** emit large amounts of radio electromagnetic radiation. There are other galaxy related objects, such as Starburst galaxies, Quasars and Blazars.

Centaurus A, Radio galaxyCC BY 4. 0 | Image courtesy of ESO/WFI (Optical); MPIfR/ESO/APEX/A. Weiss et al. (Submillimetre); NASA/CXC/CfA/R. Kraft et al. (X-ray).



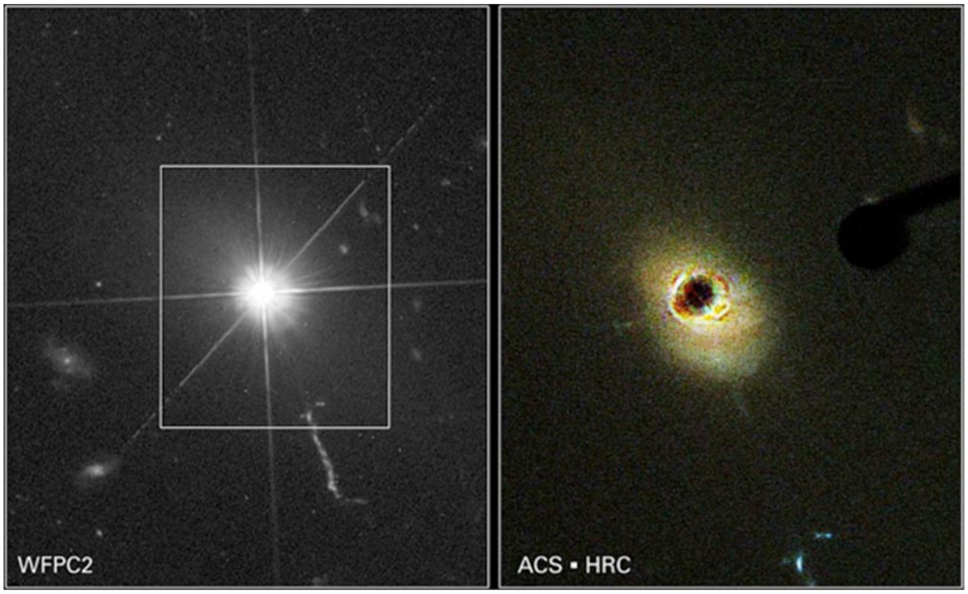
Hoag's Object, Ring galaxyPublic Domain | Image courtesy of NASA.

M82, Starburst galaxyPublic Domain | Image courtesy of NASA.

13.12: Quasar-stellar Objects

Quasars, or **Quasi-stellar Objects**, look like stars, yet are the most luminous, powerful, and energetic objects known in the Universe. Quasars, or QSOs, are extreme radio sources, emitting the energy of an entire galaxy or more — 1,000 times that of the Milky Way. The fuel source for QSOs appear to be very energy efficient, super-massive black holes. The left image shows the brilliant Quasar; the spikes of light also demonstrate the star-like appearance of the Quasar. This image was taken with the Hubble's Wide Field Planetary Camera, WFPC. The right image shows the bright Quasar blocked (appears black), providing a view of the Quasar's host galaxy. This image was taken with the Hubble Advanced Camera for Surveys, ACS.

Most QSOs are found at the edge of the observable Universe; representing the Universe in the distant past. They exhibit the highest-observable red shifts and the most distant of objects currently observable. A recently discovered (2010) Quasar was seen at 13. 3 billion light-years distant. This is considered to be near the limit of the observable Universe. Quasars were most likely formed through early galactic collisions. These collisions formed the super-massive black holes at the centers of Quasars.



Quasar 3C 273Public Domain | Image courtesy of NASA.

13.13: Blazars- Quasar-like Object

Blazars appear to be Quasar-like objects; they exhibit very focused jets of energy, which are traveling at 99%c – 99% of the speed of light. If one is in a Blazar's energy jet path, the Blazar will appear very bright. Blazars are classified as very compact Quasars. Often faint traces of the host galaxy is visible. Both Blazars and Quasars are classified as **Active Galactic Nuclei**, AGN. And some objects thought to be variable stars or extreme radio sources have been reclassified as either Quasars or Blazars.

13.14: Galaxies, Distance, and Age

There are a number of characteristics which galactic shapes, brightness, outputs, and specifics can tell us about galaxies. **Galactic distances** are more difficult to determine for the more-distant galaxies. Methods like radar and parallax are of no use. So astronomers have developed a **standard galactic brightness** ; there is a relationship between a spiral's luminosity and how fast it rotates. Called the **Tully-Fisher Relationship**, the faster a galaxy spins, the brighter the galaxy. So once the spin rate is determined, the brightness and then distance can be determined.

Another method is to examine a **galaxy's white dwarf supernovae** luminosities. This provides another "standard" brightness with which we can compare.

Galactic Distance and Position versus Galactic Age

Most of the galaxies are moving away from each other; each with a velocity of V. This infers that the galaxies must have been closer together at one time. Recall that Hubble's Law is a relationship between velocities and distances, and is related to expansion through the Hubble Constant, H_o.

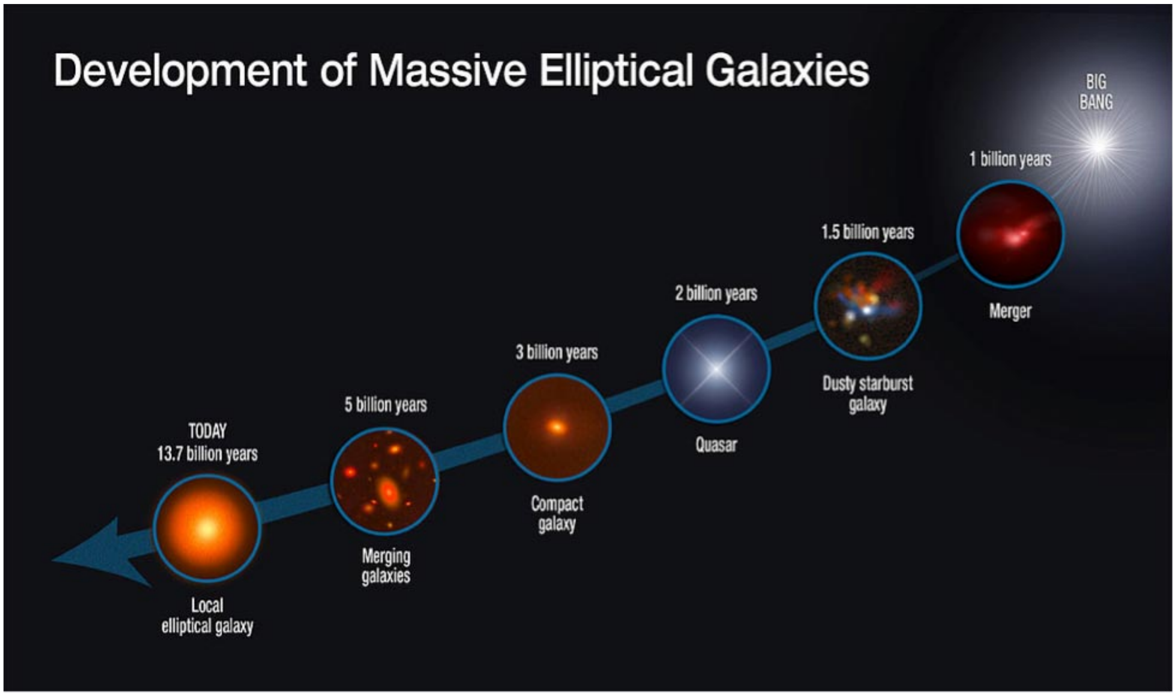
This goes back to rearranging Hubble's Law $\mathbf{V = H_o}$ **to** $\mathbf{d = v/H_o}$ and allows us to infer not only the age of galaxies, but the Universe itself, time. We have a good idea at the value of $\mathbf{H_o}$. So let's say we can determine how far galaxies are away at varying distances, **d**. We already know the velocity, **V**, from determining the distance; this is the velocity each galaxy is moving. Since you know the velocity and distance, use a simple formula and you can now calculate the time.

V = d/t t = d/VWhere: **V** is velocity | **d** is distance | **t** is time.

13.15: The Ages of Galaxies and What that Reveals

First, how did galaxies form? That concept is not as well understood. One current hypothesis is that just after the beginning of the Universe, there was a lot of hydrogen, H2, and helium, He; the simplest and first elements formed. The hydrogen and helium was probably not a uniform distribution of H2 and He, but in clumps. There was an initial expansion of the H2 and He and eventually gravity slowed the expansion, forming **Protogalactic clouds**. Stars and thus galaxies formed out of these Protogalactic clouds. The leading galaxy-formation hypothesis holds that the Milky Way and other galaxies began small and grew bit by bit for the most part, gravitationally acquiring intergalactic gas and dust and merging with galaxies in their immediate neighborhood.

A 2010 study suggests that several large and seemingly disparate chunks of the galaxy formed at the same time from the collapse of a single blob of gas and dust.



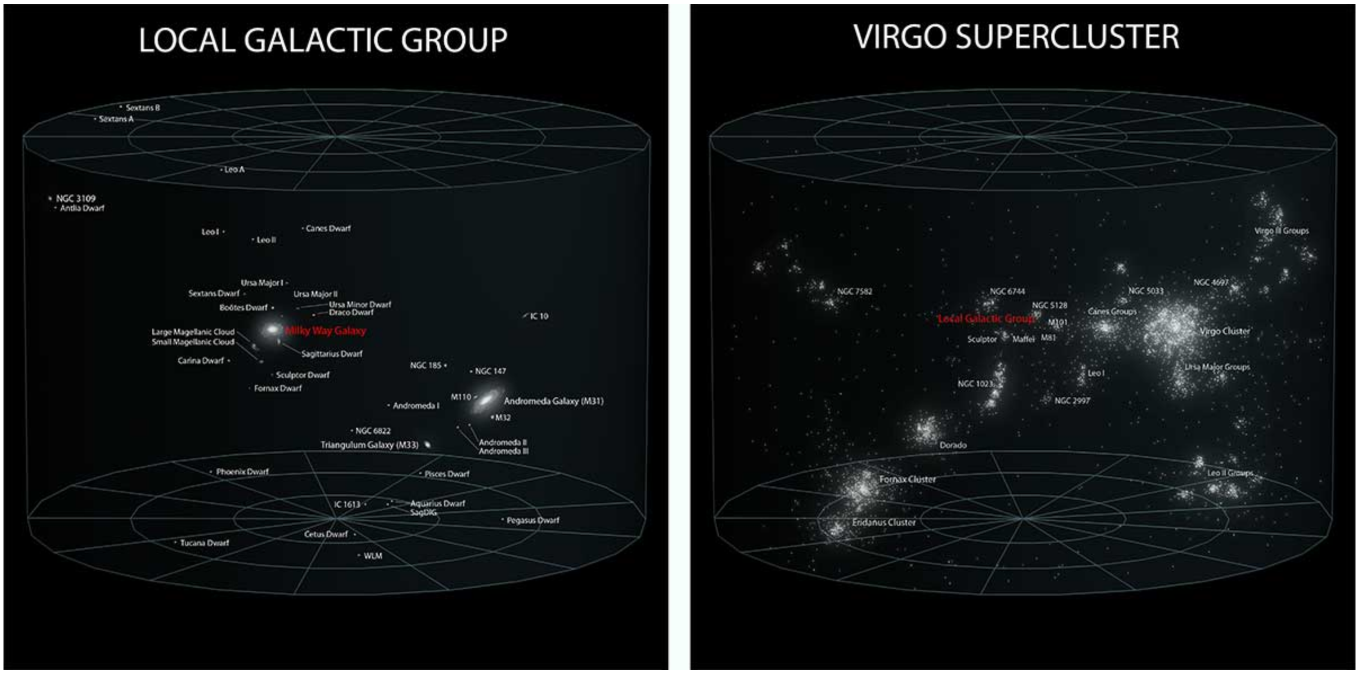
Public Domain | Image courtesy of NASA.

What type of galaxy formed first?

What we currently see as Elliptical Galaxies with reddish stars. Think about stellar color as an indicator of age. And think back to globular clusters as a retirement home for stars – red stars.

13.16: Galactic Groups

Galaxies appear to assimilate in groups throughout the Universe. For example, the Milky Way and Andromeda galaxies are members of **The Local Group**, more than 54 gravitationally bound galaxies, most are dwarf galaxies. Smaller galactic groups are a part of galaxy superclusters. The Local Group is part of the Virgo Supercluster, composed of at least 100 galaxy groups and clusters.



CC BY-SA 3. 0 | Image courtesy of Wikimedia Author: Andrew Z. Colvin.

13.17: Dark Matter

Dark Matter is matter believed to exist from its observed gravitational effects. We have never seen any light or energy from Dark Matter, yet we can "see" the effects of Dark Matter. Dark matter neither emits nor absorbs light, which is our primary means of observation. And it appears that this unseen Dark Matter is the vast majority of mass in the Universe. How do we know Dark Matter is there in the first place? We can **weight a galaxy** — look at the gravitational effects on objects in a galaxy. Does it match up with what we are seeing? We can also observe the **Mass-to-Light ratio:** the amount of mass versus the amount of light, which we observe.

It is important to understand Dark Matter if we want to ponder the fate of the Universe. Astronomers believe there are two possible scenarios: the Universe will continue to expand or the Universe will collapse, called the **Big Crunch**. The Big Crunch will occur if there is no or not enough Dark Matter.

The Milky Way's Mass-to Light Ratio

We only see about 10% of the mass of the Milky Way; 90% of the mass is unseen, thus, the term **Dark Matter**. In the 1930s, Fritz Zwicky first proposed Dark Matter in the galaxies. At first it was not readily accepted, but as astronomers realized the need to find the source for the Milky Way's (and other galaxies) missing matter, the concept of Dark Matter made sense. Galaxy mass physics shows Dark Matter exists. The challenge now is devising a method and instrumentation to physically observe Dark Matter.

13.18: WIMPs and String Theory

WIMP: Weakly Interacting Massive Particles

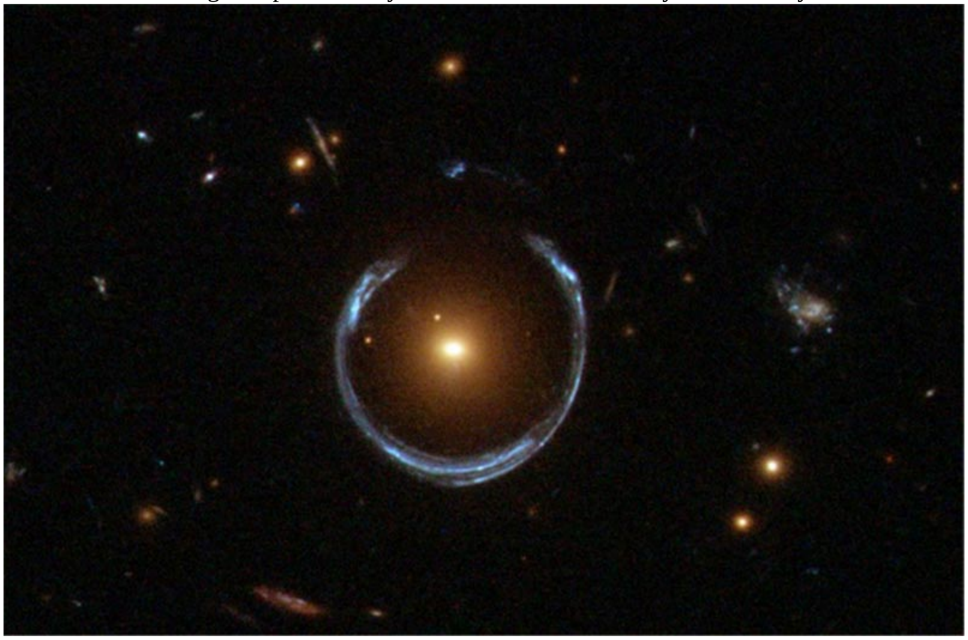
WIMPs are hypothetical extraordinary Dark Matter. Again, they are dark by their nature (WIMPs do not emit any sort of radiation that can be observed with our current technologies. They interact through weak forces, not gravity and are slow moving enough to collect into galaxies, called **cold dark matter**.

String Theory

A model of physics, which interprets all particles and forces in terms of specific vibration modes of submicroscopic particle *strings* . String theory originated in the late 1960s. **Strings** – elementary one-dimensional particles – must be stretched under tension through the Universe, like a guitar string. Supporters of the String Theory state that it unifies the natural known forces: electromagnetic, gravitational, strong and weak.

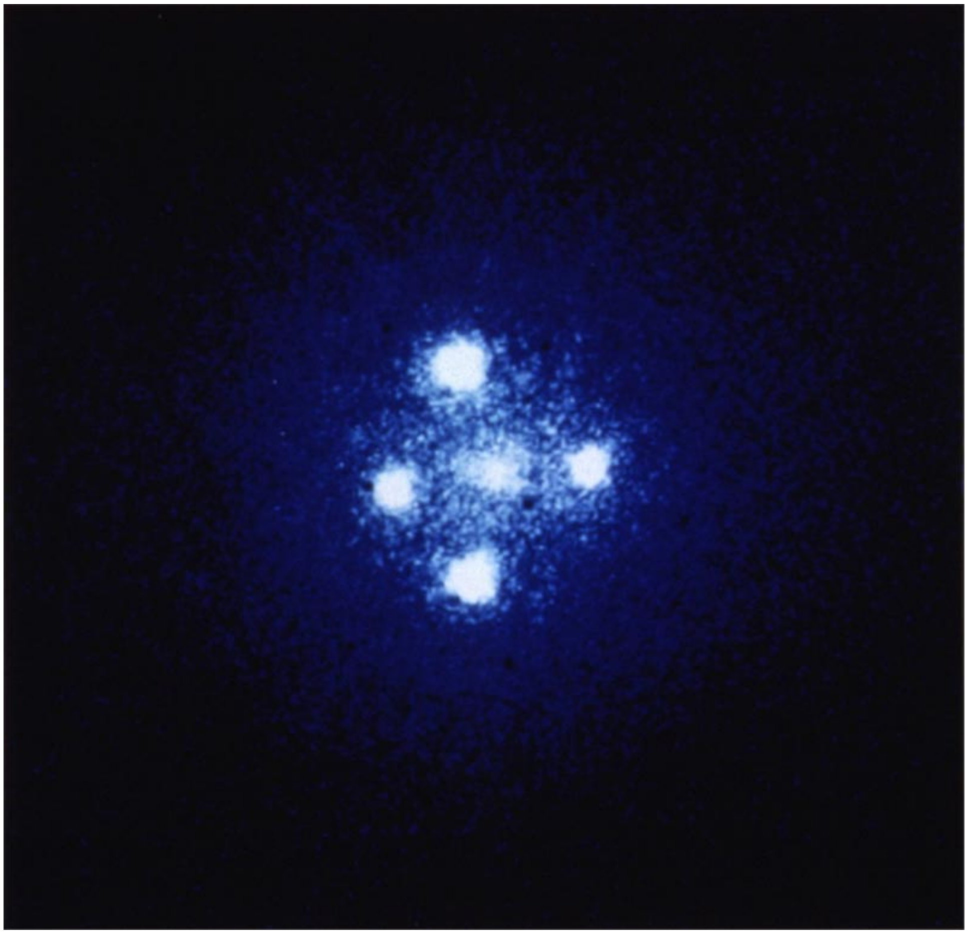
13.19: Gravitational Lensing

Massive Objects can act as **Gravitational Lenses**, which is the magnification or distortion of an image caused by light bending through a gravitational field. Light emitted from a *source* bends around intermediate mass usually called the *deflector or cluster mass distribution* . Gravitational lensing was predicted by Einstein's General Theory of Relativity.



Public Domain | Image courtesy of NASA.

Gravitational lensing can take place on several scales, from strong lensing to microlensing. Fritz Zwicky postulated in 1937 that this could allow galactic clusters to act as gravitational lenses. In 1979, Zwicky's galactic clusters lensing theory was confirmed through observations of the *Twin QSO, SBS 0957+561* .



Public Domain | Image courtesy of NASA / ESA.

Consider this …

Public Domain

Often called a “pioneer of the distant stars,” astronomer Edwin Hubble (1889–1953) played a pivotal role in deciphering the vast and complex nature of the universe. His meticulous studies of spiral nebulae proved the existence of galaxies other than our own Milky Way. Had he not died suddenly in 1953, Hubble would have won that year’s Nobel Prize in Physics.

CHAPTER OVERVIEW

14: The Milky Way Galaxy

14.1: Module Introduction

"See yonder, lo, the Galaxyë
Which men clepeth the Milky Wey,
For hit is shyt. "

Geoffrey Chaucer
The House of Fame, Circa 1380

This module presents an overview of our home galaxy, the Milky Way Galaxy, its characteristics, satellite galaxies, and how it compares to other galaxies.

Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

- Identify the characteristics of the Milky Way Galaxy
- Identify the contributors to our understanding of the Milky Way Galaxy

14.2: What do you think?

With the clear skies millenniums ago and celestial objects so brilliant like the Milky Way, it is no wonder that many ancient civilizations worshipped the heavens. If it was clear and no light pollution existed today, would people still worship the heavens? Why or why not?

14.3: The Milky Way — Our Home Galaxy

It is estimated that the Milky Way Galaxy has a population of 100 billion to 400 billion stars. Initially, astronomers did not associate the Milky Way Galaxy with other galaxies they saw through their telescopes. Recall, that they called these other galaxies "nebulae. "

Characteristics of the Milky Way Galaxy

The Milky Way Galaxy is a Spiral Galaxy and most likely a barred spiral. This characteristic is difficult to confirm due to our location within the Milky Way Galaxy and all of the nebulosity we have to look through. Recall, that the Milky Way Galaxy is part of the Local Group of galaxies, and that group is a part of the Virgo supercluster of galaxies.

This large barred spiral galaxy is believed to be similar in shape to the Milky Way Galaxy. Dust lanes, spiral arms, and a bar at the galaxy's center are visible.

Some have referred to this image as a 'picture postcard' of the Milky Way Galaxy.

NGC 6744, A Barred Spiral GalaxyCC BY 3. 0 | Image courtesy of ESO.

14.4: Milky Way Galaxy Satellites

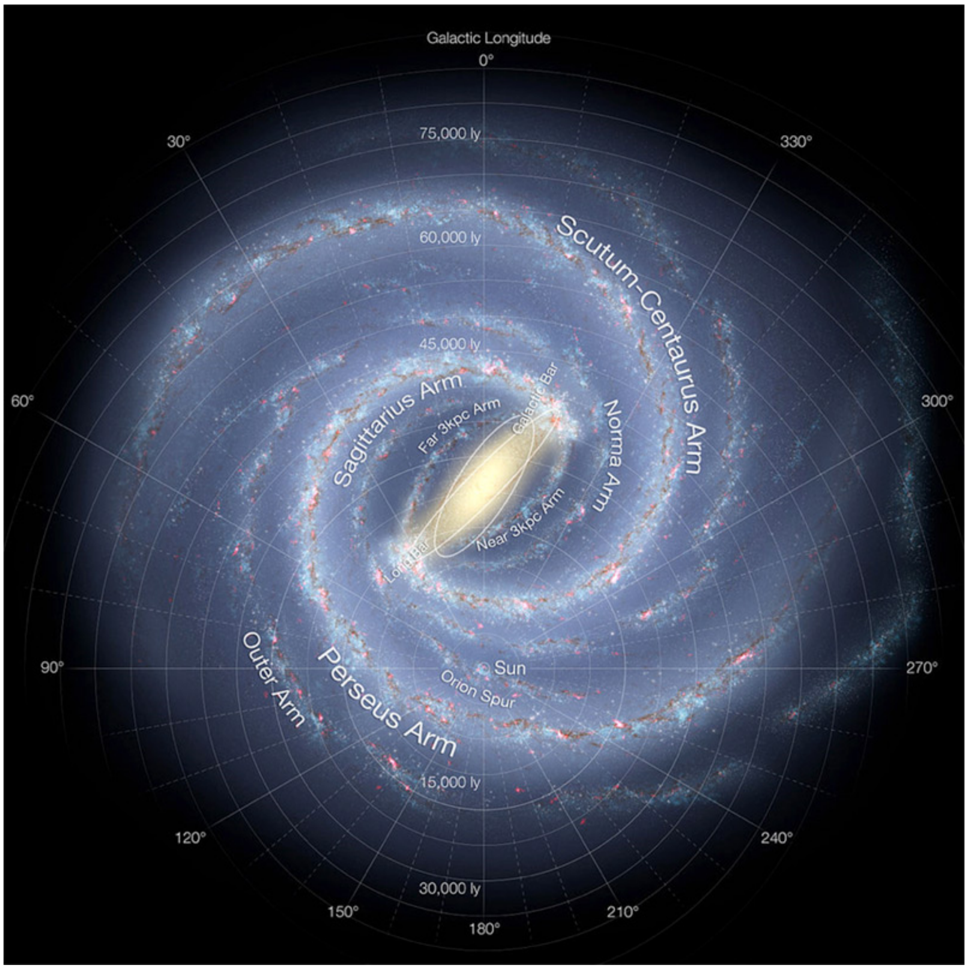
The Milky Way Galaxy has two major satellite galaxies: the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC). These are visible from the Southern Hemisphere. And there are also a number of dwarf galaxy satellites – at least ten – which orbit the Milky Way Galaxy. Some astronomers hypothesize that there could be hundreds of Milky Way dwarf galaxy satellites.

Milky Way Galaxy Satellites

Our galaxy is 100,000 light years in diameter, that is, across the disk. And it is 1,000 light years wide – "thick. " Think of spiral galaxies like a Frisbee in shape — thin, flattened discs.

The Sun is 28,000 light years from the Galactic Center. From our position within the Milky Way Galaxy, it is challenging to study the Milky Way Galaxy due to the Interstellar Medium. Remember that spiral galaxies are dusty; the Milky Way Galaxy is "dusty" and we cannot see through the Interstellar Medium. We are able to look through the Milky Way Galaxy using radio astronomy and infrared observing techniques.

This detailed annotated artist's impression of the Milky Way Galaxy shows the galaxy's structure, including the location of the spiral arms, the Sun, and other galactic components, such as the central bulge.



Public Domain | Image courtesy of NASA.

14.5: Milky Way Galaxy Research

The Milky Way Galaxy: A brief astronomical history

Aristotle (384-322 BC) wrote in *Meteorologica* that **Anaxagoras** (500-428 BC) and Democritus (460-370 BC) thought the Milky Way might consist of distant stars. Aristotle thought that the Milky Way was due to the ignition [that] *takes place in the upper part of [Earth's] atmosphere, in the region of the world which is continuous with heavenly motions* . Other contemporaries of Aristotle argued against his idea about the Milky Way, including the argument that the galaxy's parallax would be measurable if Aristotle's idea was correct.

Recall, Abū al-Rayhān al-Bīrūnī (973-1048), a Persian astronomer and one of the most-respected Muslim scientists of his time, proposed that the Milky Way was a collection of countless fragments of the nature of nebulous stars.

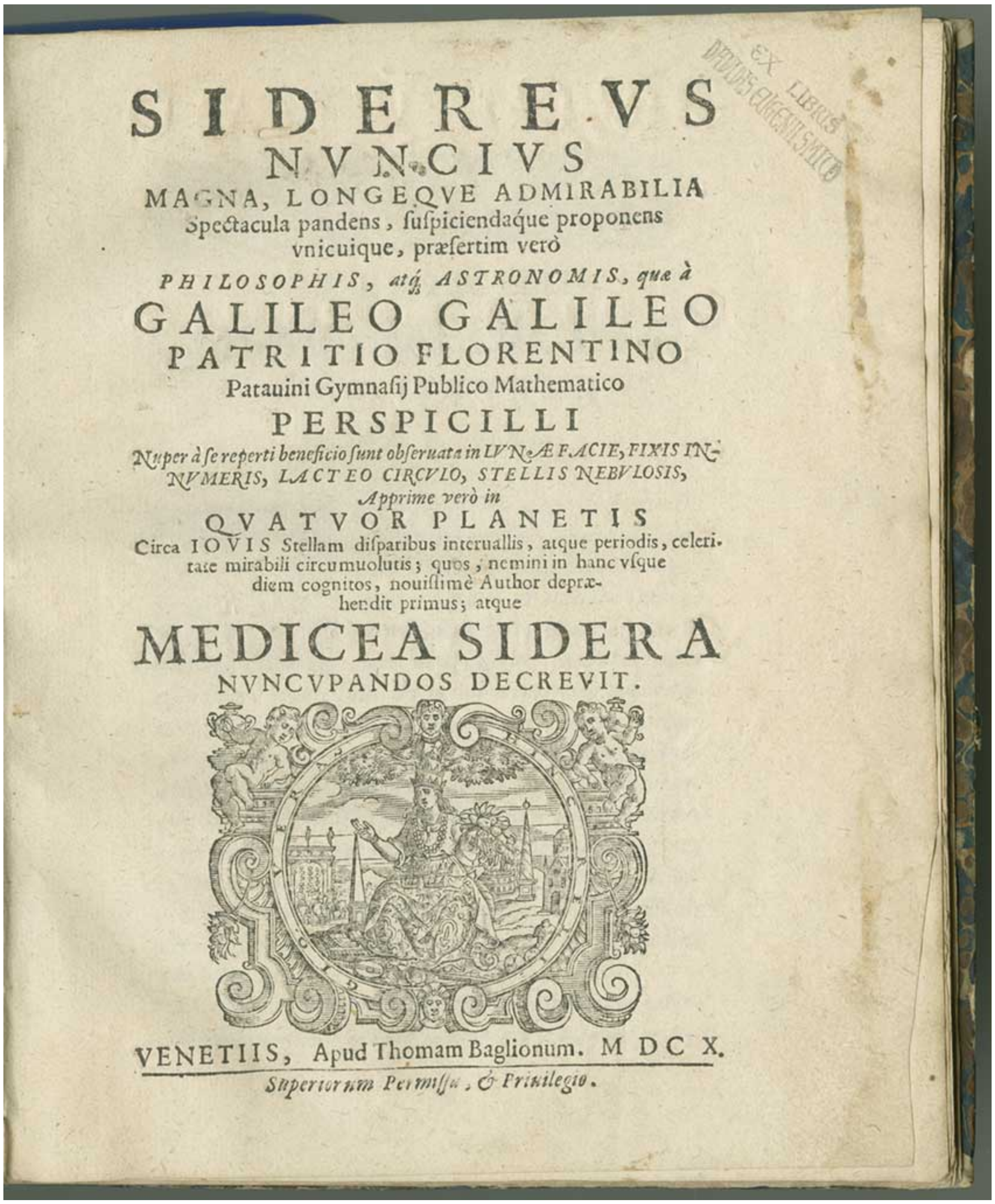
This 180 ^{o} photograph is bounded on the horizon towards the image's bottom by the trees surrounding Yosemite Valley. The dark lanes within the broad band of stars are dust lanes within the Milky Way Galaxy.

The Milky Way as seen from Earth; Yosemite Valley, CA. Image courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

14.6: Galileo Galilei, First to See the Milky Way Galaxy

Galileo was the first to see the Milky Way Galaxy in 1610 as individual stars through the telescope. Instead of seeing a cloud, he saw countless stars through his simple telescope. In this book, the first published work of observations made through a telescope, Galileo first noted the nature of the Milky Way Galaxy as seen through his telescope. His comments about the Milky Way stars included that the *"congeries of innumerable stars grouped together in clusters too small and distant to be resolved into individual stars by the naked eye. "*

Here, you see a vintage picture of title page of Sidereus nuncius (Starry Messenger) 1610, by Galileo Galilei (1564-1642).



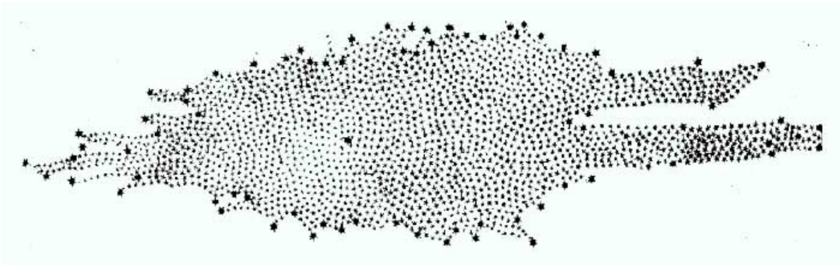
SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in LVNÆ FACIE, FIXIS IN-
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

Public Domain | Image courtesy of NASA.

14.7: The Milky Way Galaxy’s Shape

In his 1755 work *Allgemeine Naturgeschichte und Theorie des Himmels* , **Immanuel Kant** (1724-1804) correctly hypothesized that the Milky Way Galaxy might be a rotating body of an innumerous number of stars that were held together by gravitational forces, much like our Solar System yet on a more-grand scale. Kant based his work on that of Thomas Wright.

Here, you see a prepared sketch by William Herschel of the Milky Way Galaxy’s shape based on his 1785 star counts. Herschel believed the Solar System was at or near the center of his sketch.



Public Domain | Image courtesy of NASA.

14.8: Andromeda Galaxy

In 1917, **Heber Curtis** (1872-1942) was observing a nova in the Andromeda “nebula. ” Researching previous novae, including those in the Milky Way Galaxy, Curtis was convinced that Andromeda was indeed a galaxy much like the Milky Way Galaxy, and that the dust lanes seen in Andromeda were similar to those in the Milky Way Galaxy. **Edwin Hubble** (1889-1953) settled that question a couple of years later when his research and observations determined “nebula” like Andromeda were indeed actually galaxies.

One of the questions at the time was the location of our Solar System within the Milky Way Galaxy. Harlow Shapley (1885-1972) used globular clusters to show where we “live” in our galaxy. Shapley was also able to estimate the size of the Milky Way Galaxy. Yet not all of Shapley’s observations or hypotheses were correct; perhaps the biggest error was his continued argument that spiral ‘nebulae’ were actually galaxies outside the Milky Way Galaxy. Shapley actually referred to Hubble’s work and findings as “junk science. ”

Also visible in this image are two companion galaxies of the Andromeda Galaxy. Note the dark lanes within the broad band of stars; these are the dust lanes within the Milky Way Galaxy.

Most modern Milky Way Galaxy research has covered such questions as the type and size of the galaxy, the existence of a supermassive black hole at the Milky Way Galaxy’s center, and satellite galaxies associated with the Milky Way Galaxy.

Recall, **Sagittarius A *, SGR A ***, the Milky Way Galaxy’s supermassive black hole, was discovered in 1974. Its characteristics were speculative for a number of years. Continued observations of stars near Sagittarius A* indicate that the object is indeed a supermassive galactic black hole.

The **Virgo Stellar Stream** was discovered in 2006. This is a collection of stars which rises close to perpendicular to the plane of the spiral arms of the galaxy; most likely this structure is a dwarf galaxy.

The Andromeda Galaxy, *M31*Image courtesy of Mike Reynolds, Ph. D. of Florida State College at Jacksonville.

14.9: X-Ray and Gamma-Ray of the Milky Way Galaxy

Two **high-energy emission spherical bubbles**, X-ray and gamma-ray in nature, were detected north and south of the Milky Way Galaxy's core in 2010 by the Fermi Gamma-ray Space Telescope. It is estimated that the diameter of each bubble is about 25,000 light years. In 2014, **Ray Villard** of the Space Telescope Science Institute estimated that the Milky Way Galaxy contains at least 100 billion planets. This would result in each of the Milky Way Galaxy population of 100 billion stars to have an average of one planet per star.

Public Domain | Image courtesy of NASA.

14.10: Earth's Position within the Milky Way Galaxy

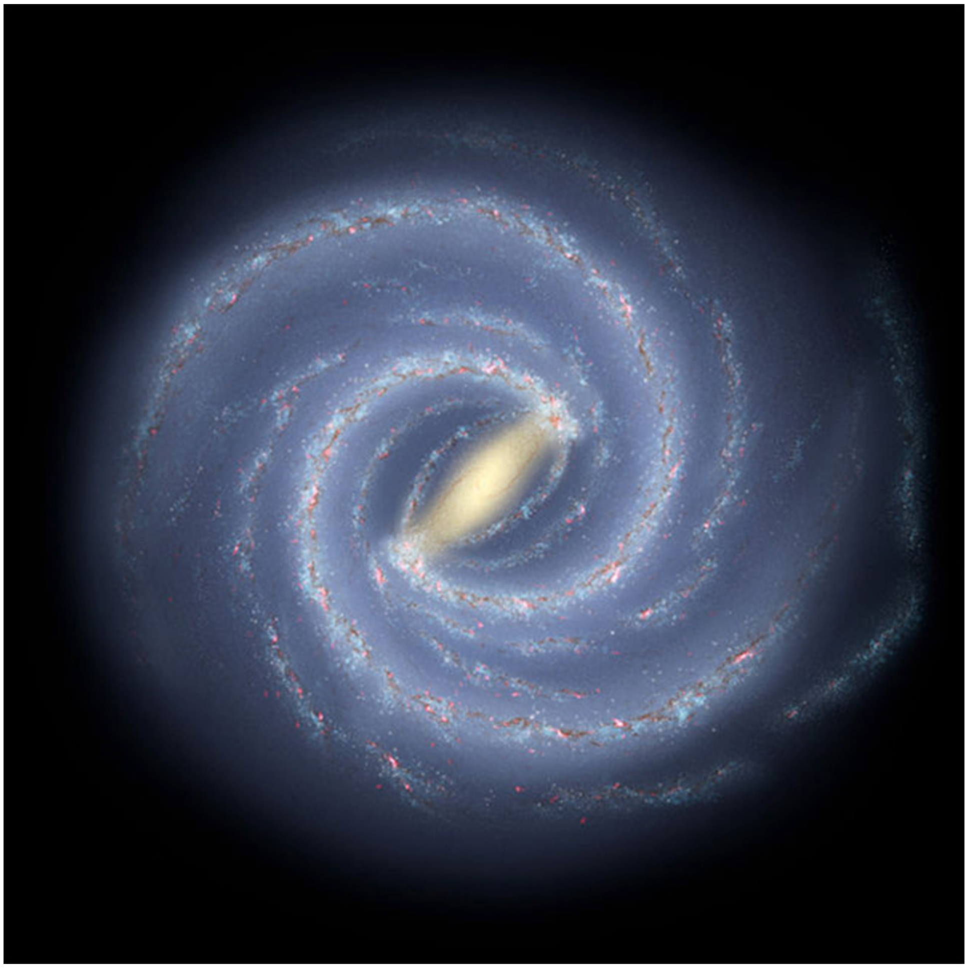
The Solar System is not in the middle of Interstellar Medium lanes. If this was the case, we could not see out into space because the dust would block our view.

We are also not too close to the Galaxy's center. Some postulate it would always be daytime if we were near the Milky Way Galaxy's center because there are so many stars. And, also there are dangerous levels of radiation due to the Sagittarius A * supermassive black hole at the galactic center.

14.11: A Spinning Spiral

The Milky Way Galaxy rotates, undergoing what is known as differential rotation: everything rotates at about the same speed. This type of rotation is different than a rotating tire. Our Sun and Solar System orbits around the Milky Way Galaxy once every 230 million years. Observing the Milky Way Galaxy's rotation helps astronomers determine where the galaxy's mass is located. **Collision Alert!**

Current observations show that the Andromeda Galaxy is approaching the Milky Way Galaxy at 100 to 140 kilometers/second. It appears as if a collision may occur in 3 to 4 billion years. If Andromeda Galaxy and Milky Way Galaxy collide, individual stars within the galaxies would not collide, but instead the two galaxies will merge to form a single elliptical galaxy over the course of about a billion years.



Public Domain | Image courtesy of NASA.

Consider this…

"A Descent into the Maelstrom"

I became possessed with the keenest curiosity about the whirl itself. I positively felt a wish to explore its depths, even at the sacrifice I was going to make; and my principal grief was that I should never be able to tell my old companion on the shore about the mysteries I should see.

—*Edgar Allan Poe* 1841

CHAPTER OVERVIEW

15: Cosmology

15.1: Module Introduction

“The scientific issues that engage people most are the truly fundamental ones: is the universe infinite? Is life just a sideshow in the cosmos? What happened before the Big Bang? Everyone is flummoxed by such questions, so there is, in a sense, no gulf between experts and the rest. ”

Dr. Martin Rees, The Lord Rees of Ludlow
Astrophysicist
(1942-)

This module presents an overview of our home galaxy, the Milky Way Galaxy, its characteristics, satellite galaxies, and how it compares to other galaxies.

Objectives

Upon completion of this module, the student will be able to:Upon completion of this module, the student will be able to:

- Describe the Big Bang Theory, including the theory’s strengths and weaknesses
- Describe different cosmological views of the Universe

15.2: What do you think?

Our Universe is spectacular – yet there is evidence of powerful events as we have seen throughout this course. The Universe appears to have started in the most powerful of events: the Big Bang. Does this surprise you? Why or why not?

15.3: In the beginning…

The study of the origin of the Universe is called **Cosmogony**. This is where science-philosophy-theology-religion meet. Was Creation a supernatural event; that is, did creation of the Universe take place outside of the natural realm? Or was it an event that can be naturally explained? Different philosophies have different views on these questions. Yet the heart of the question is: *can one verify creation through science & technology?* **Cosmology**, from the Greek **kosmos**, is the study of the origin, evolution, and eventual fate of the Universe. Physical cosmology is the scientific study, whereas religious cosmology is based on a body of beliefs and traditions.

Physical cosmology was studied during most of the 20th century, with large telescopes and radio astronomy. From 1989 forward, Earth-based telescopes utilized new technologies, specialized spacecraft were designed and launched, and the Hubble Space Telescope was used to study many cosmological questions. Cosmology deals with the nature of the Universe as a whole … *including science, philosophy, and religion* .

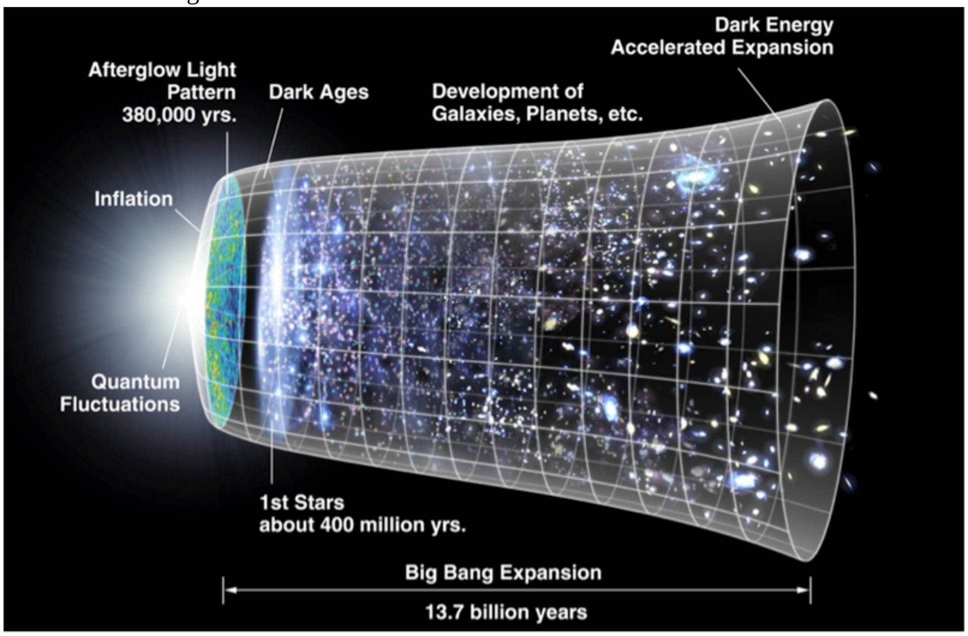
15.4: Physical Cosmology

The Big Bang is a theory of the Universe's earliest moments and its development over time. The Big Bang presumes that the Universe began from an incredibly small, hot, dense collection of all matter and radiation. A sudden rapid expansion and cooling of this matter and radiation occurred. The simplest of particles were first formed, then atoms, finally stars, stellar systems and galaxies.

Belgian Catholic priest and scientist **Georges Lemaître** first suggested the Big Bang in 1927. English astronomer **Sir Fred Hoyle** is credited with creating the phrase Big Bang during a 1949 British Broadcasting Company (BBC) radio broadcast. It is popularly believed that Hoyle, who favored the alternative Steady State Theory, intended the phrase to be derogatory. The phrase stuck, even though it is not a good descriptor of what the Big Bang tries to detail. There was actually a contest to rename the Big Bang, yet no other suitable phrase was found.

15.5: The Big Bang in Eras

To look at the development of the Universe through the Big Bang, astronomers have divided the development into steps or **eras**. These eras are our best scientific match to the data we currently have; they seem scientifically sensible. New data is being used to revise and heighten our understanding of these eras.



Public Domain | Image courtesy of NASA.

The generally accepted Big Bang Eras include:

1. Planck
2. Grand Unification Theory (GUT)
3. Electroweak
4. Particle
5. Nucleosynthesis
6. Nuclei
7. Atoms
8. Galaxies

A summary of the Big Bang events occurred in this order:

1. Big Bang beginning – a bright and hot event →
2. **Planck Era** ; initial energy →
3. **Elementary Particles** – photons create particles and antiparticles →
4. **Inflation** of the Universe →
5. **Four Forces** become distinct (strong, weak, electromagnetic, and gravity) →
6. **Protons, Neutrons, Electrons, and Neutrinos** formed →
7. **Hydrogen ions fusion into helium ions** →
8. **Stable, Neutral Atoms** formed →
9. **Protoclouds** formed →
10. **Stars, stellar systems, galaxies** formed →
11. **Life, Humans; today**

15.6: The Planck Era

One of the biggest puzzles is what occurred during the **Planck era**. This was an extremely short time span; the instant after the Universe began. This instant is so small we cannot even measure its length with modern technology. At the beginning, the Universe was extremely hot – so hot everything was pure energy; there was no initial matter. Over time, the Universe expanded, and just like the gas expanding as it comes out of a can of compressed air, the expanding Universe cooled. By the end of the first three minutes, atomic nuclei had solidified, and the Universe was a mix of electrons, light, and nuclei. **Inflation** was the sudden and dramatic expansion of the Universe thought to have occurred at the end of the Grand Unification Theory (GUT) era. Most likely, Inflation shaped the way the Universe looks today: structured and smooth. The Universe also reached a point of critical density.

The **four fundamental forces** we observe today became distinct after the era of inflation. It appears that these four forces were, at the beginning of time, united as one force … the Grand Unification Theory.

These Four Fundamental Forces include:

- **Gravity** is the dominant force on a large scale; the weakest of the four forces.
- **Electromagnetic** is the force that dominates atomic and molecular interactions.
- **Strong** is the force which holds atomic nuclei together.
- **Weak** is the force that mediates nuclear reactions.

15.7: Big Bang Evidence

There is respectable and solid evidence to support a Big Bang-type development of the Universe. Three of these lines of evidence are considered major.

Cosmological Redshift

The Universe is expanding **–** Referred to as the **Cosmological Redshift**.

Redshift analysis confirms the Universe is expanding, and the expansion rate is accelerating. The evidence for an accelerating expansion comes from observations of the brightness of distance supernovae. We observe the redshift of a supernova, which tells us by what the factor the Universe has expanded since the supernova exploded.

The redshift of an object is the amount by which the spectral lines in the source are shifted to the red. That is, the wavelengths become **l-o-n-g-e-r**. To be precise, the redshift Z is given by:

Z = [λobs-λem]/λem Z = Ho d/c (for small distances)

Where:

- Noise" found in all directions throughout the Universe; this "Noise" is radiation remaining from the initial Big Bang.

  Background "Noise" was discovered by accident by Arno Penzias and Robert Wilson, Bell Labs in 1965. They heard a hiss at their radio telescope receiver and after investigation, thought it was due to pigeon droppings on the antenna.

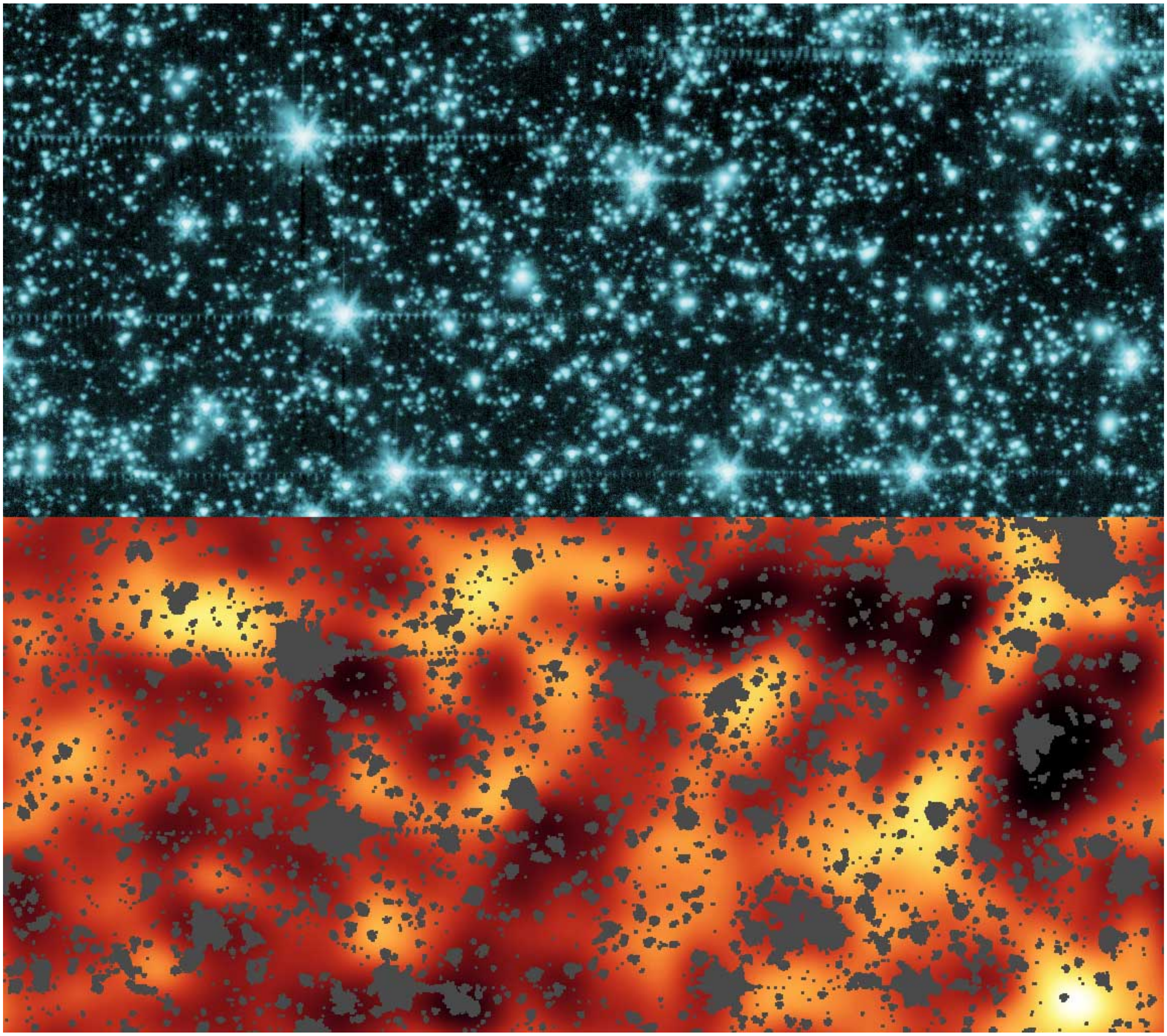
Initial Hydrogen-Helium Fusion

If the H-He early fusion theory is correct, we should find a specific amount of He in the Universe today.

Knowing the current microwave background radiation temperature of 2. 73 K allowed astronomers to mathematically predict the amount of He in the Universe; **Helium should account for approximately 25% of the mass of the Universe.** (This does not include Dark Matter/Dark Energy.) *So…what is the amount of Helium found in the Universe? 25%*

Additional lines of evidence supporting a Big Bang type of development:

- We find **large-scale homogeneity** throughout the Universe.
- There is an **abundance of light elements** : Hydrogen, Helium, Lithium, and Beryllium.
- The **Cosmic Microwave Background Radiation** itself is **uniform**.
- The temperature of the Cosmic Microwave Background Radiation is extremely uniform.
- Large-scale structure of the Universe; the **distribution of objects**.
- The **ages of stars**.



Public Domain | Image courtesy of NASA/GSFC/JPL-Caltech.

Look for that “glow” of those first stars…

- The top image was taken with the Spitzer Space Telescope. This image shows all the objects visible, as very bright lights.
- The bottom image has all objects taken out and is only in infrared. The red, orange, yellow “glow” or bright blobs are likely from the first stars: short-lived yet massive and bright

15.8: Recent Data on the Universe

Wilkinson Microwave Anisotropy Probe or WMAP is a new satellite, which is providing solid data in support of cosmological research. WMAP has helped to significantly refine the age of the Universe to 13. 7 billion years old +1% (137 million years).

WMAP has also provided data in regard to the matter in the Universe:

- Dark Matter: 73%
- Cold Dark Matter: 23%
- Atoms (& Molecules): 4%

This infers that the matter we are used to – and what we are composed of – only makes up 4% of the Universe. This brings us back to the problem: where is the Dark Matter?

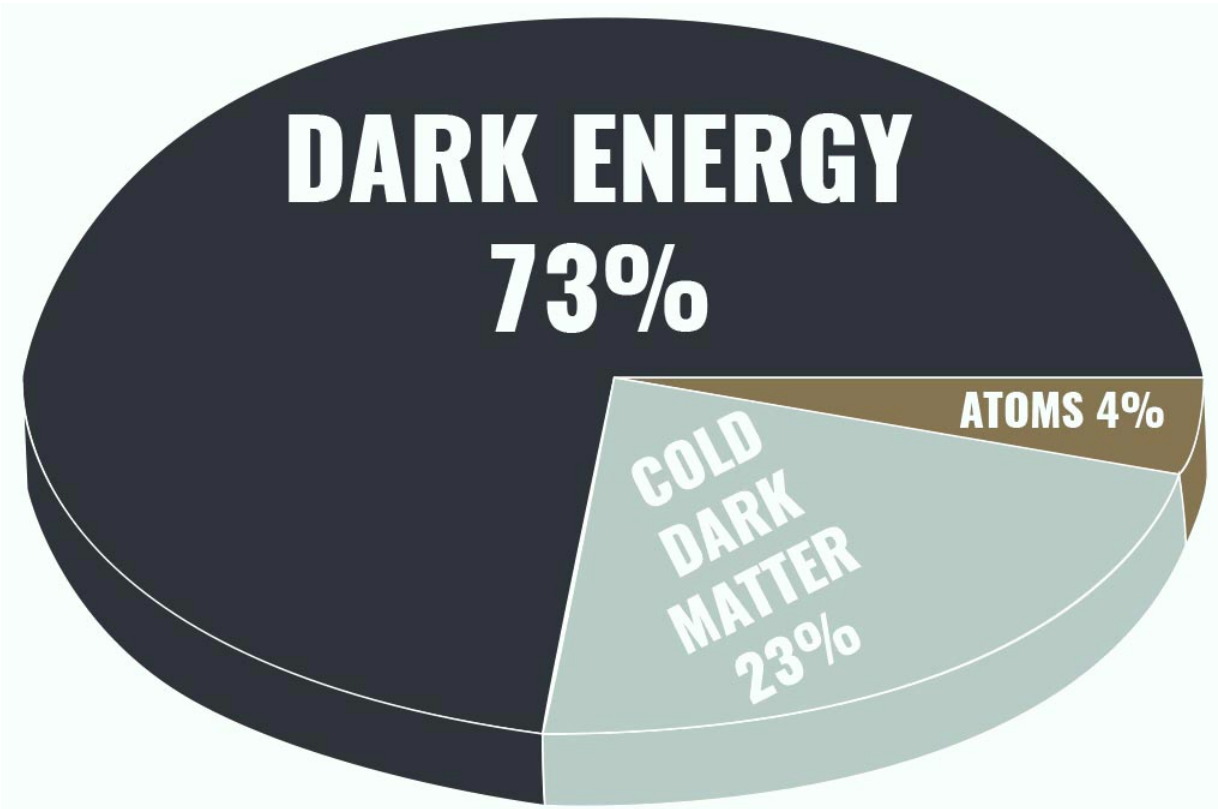


Image courtesy of Florida State College at Jacksonville.

15.9: Issues with the Big Bang

There are several issues and questions surrounding the Big Bang Theory.

- Technically, physical cosmologists do not see any of these issues as unsolvable, even the question of where did everything come from since they are mostly concerned with what happened after the Big Bang. Cosmologists look at three technical but important problems:
  - The scope and detail of these problems is beyond this course.

15.10: Beyond the Big Bang

Why not other theories besides the Big Bang?

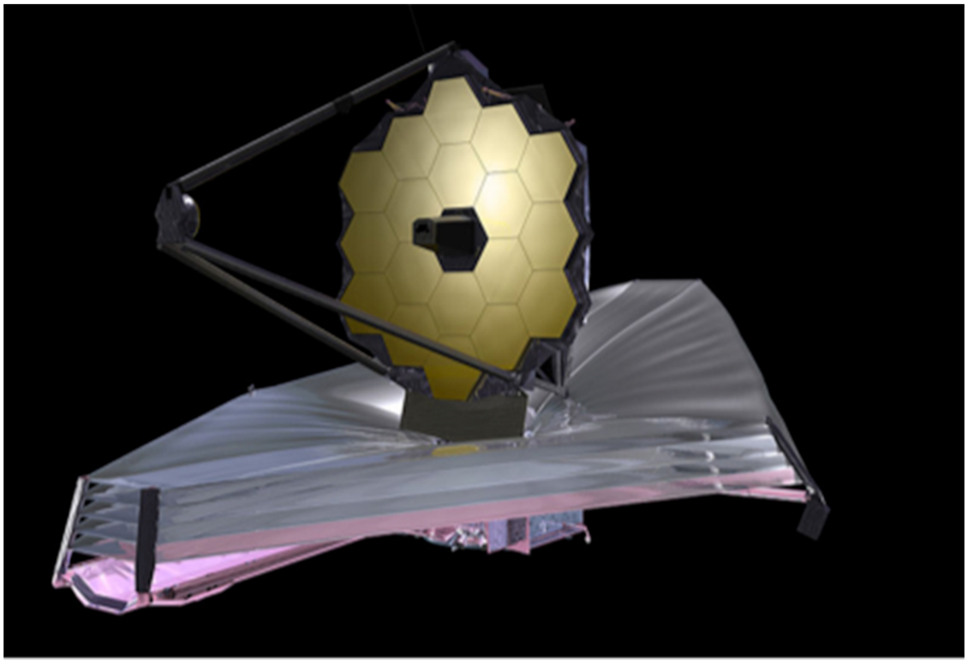
There are some astronomers and scientists who do not believe the Big Bang is correct. Other theories have been proposed, including:

- **Oscillating Universe:** the Universe expands and contracts regularly on an infinite basis. This is sometimes called the *Big Bounce* in deference to the Big Bang.
- **Steady State/Quasi-Steady State:** the Universe is as it was and as it will always be… basically no changes. As matter disappears, more matter is 'created' to take its place.
- Modification Of Newtonian Dynamics **(MOND)**. Newton's laws have changed over the life of the Universe.
- **Tired Light:** Light loses energy.

These theories and several others similar to these are supported by a very small minority of astronomers. Mostly you will see arguments against the Big Bang and in support of one of these theories.

15.11: What is Next for the Big Bang Theory?

- Continue collecting data with the **Hubble Space Telescope** until it stops functioning.
- Improved **Earth-based telescope technology** will lead to enhanced earth-based data collecting; such as new optics, adaptive optics, and far-advanced computers and software.
- Additional data with other **orbital satellites** : infrared, ultraviolet, gamma-ray, etc., such as the **James Webb Space Telescope (JWST)** (potential launch in 2018).



Public Domain | Image courtesy of NASA.

15.12: Questions Regarding the Eventual Fate of the Universe

What is the Universe expanding into?

There is nothing whatsoever that we have measured, or can measure, that will show us anything about this larger space. Everything that we measure is within the Universe, and we see no edge or boundary or center of expansion. Thus the Universe is not expanding into anything that we can see, and this is not a profitable thing to think about.

Will the Universe keep expanding, come to a stop, or begin to collapse?

This depends on the ratio of the density of the Universe to the critical density necessary to support continued expansion. If the density of the Universe is higher than the critical density, the Universe would recollapse in a **Big Crunch**. But current data suggest that the density is less than or equal to the critical density so the Universe would expand forever.

Even if the Universe continues to expand, what will eventually happen to the Universe?

From our current knowledge and understanding, the Universe will continue to expand. Matter will be converted to energy. This is understood from the Laws of Thermodynamics: matter cannot be created out of nothing; the Universe would undergo the conversion of its matter to energy. Finally, with matter converted into energy, eventually the Universe will become dark. This would happen in about 100 trillion years!

Astronomers believe Dark Matter and Dark Energy exist. If so, why can't we see either?

Probably because our sensors cannot register Dark Matter and/or Dark Energy. Yet every time scientists turn a higher fidelity instrument toward the Universe, they find something new. Consider this as a science history lesson: we didn't see individual cells until the microscope was invented and scientists theorized about the atomic nucleus; now we see the parts of the nucleus.

What of Parallel Universes or Multiverses?

Some current thinking points to the possibility of numerous universes, of which we are in one universe. Think of our Universe as a bubble; now, think of multiple bubbles. Is there any evidence? Yes, what appears to be "bumps" in our bubble. These bumps appear in the Cosmic Microwave Background images. It has been hypothesized that the bumps represent distinct collisions between Universes (December 2010).

15.13: Religious or Philosophical Cosmology

Some texts and writings use the term “creation” when discussing the Big Bang Theory, as well as alternate theories.

Yet is creation an appropriate term?

Creation:

1. The act of creating or causing to exist. Specifically, the act of bringing the Universe or this world into existence.
2. Works such as art, music…

American Heritage® Dictionary of the English Language, 4th Ed. Copyright © 2000

Creation:

1. Making something. The bringing of something into existence.

Encarta® Dictionary; English Copyright © 2010

15.14: Views on Creation

It is interesting to explore various religious cosmologies, especially since astronomers cannot answer the question “where did it all come from” or “who did it? ” The laws of thermodynamics provide us with a certainty that something can be created out of nothing.

Buddihism

Nothing is really there… The Buddhist belief of emptiness; lacking reality, substance, meaning. So is there a relationship between the early, empty Universe and Zen Buddhism?

Daoist

The Way gave birth to unity; unity gave birth to duality; duality gave birth to trinity; trinity gave birth to the myriad creatures.

Daodejing, 4th century BC.

Hindu

Brahmā is the god or deva of creation. At the beginning of the process of creation, Brahmā creates the four Kumāras, the four sages. However they refuse to procreate, so Brahmā creates in his mind ten sons to carry on the creation.

Islam

The **Qur’an** contains numerous verses describing creation of the Universe. Muslims believe Allāh created the heavens and Earth in six separate eras, with the Earth being created in two eras, and in two other eras (for a total of four), Allāh furnished the creation of the Earth with mountains, rivers and fruit-gardens.

Judeo-Christian

The **Bible** has several creation passages; the most-well known is in the book of Genesis. This is also the most controversial, where the Genesis passage describes creation and development of the Universe in time periods identified as days. In other biblical text, such as the book of Job, the Universe is described as *“created out of nothing, and then being stretched. ”*

One of the religious cosmology controversies is the **age of the Universe**. Some interpret the Biblical Genesis passage as a literal six days of creation. Those who espouse this idea – called Young Earth proponents – point to other Biblical text in the Psalms and 2 Peter, which states, *“a day is to a thousand years to the Lord. ”* They reason that there were six days of creation, thus 6,000 years plus another 3,000 to 4,000 years of documented civilization, therefore a young earth and Universe of about 10,000 years. An age of the Universe at 10,000 years is extremely young in comparison to a 13. 7 billion year old Universe. This is a ratio of 1 to 1,370,000.

Yet other Biblical and religious scholars contend that the passage has been incorrectly translated from the original old Hebrew text. If one examines the original Old Testament Hebrew text, the term “day” was not used; instead the Hebrew text uses the term **Yom**.

In Hebrew, yom takes on three meanings, depending on the terms preceding or following its use:

- The Genesis use of yom appears to be a “period of time”, which means it could be a long period of time, or a short period of time. This yom period of time is not specified. Old Universe proponents contend that this interpretation of yom is the correct one, in addition to the fact the Genesis days cannot be 1,000 years because the seventh day of creation as recorded in Genesis is still ongoing.

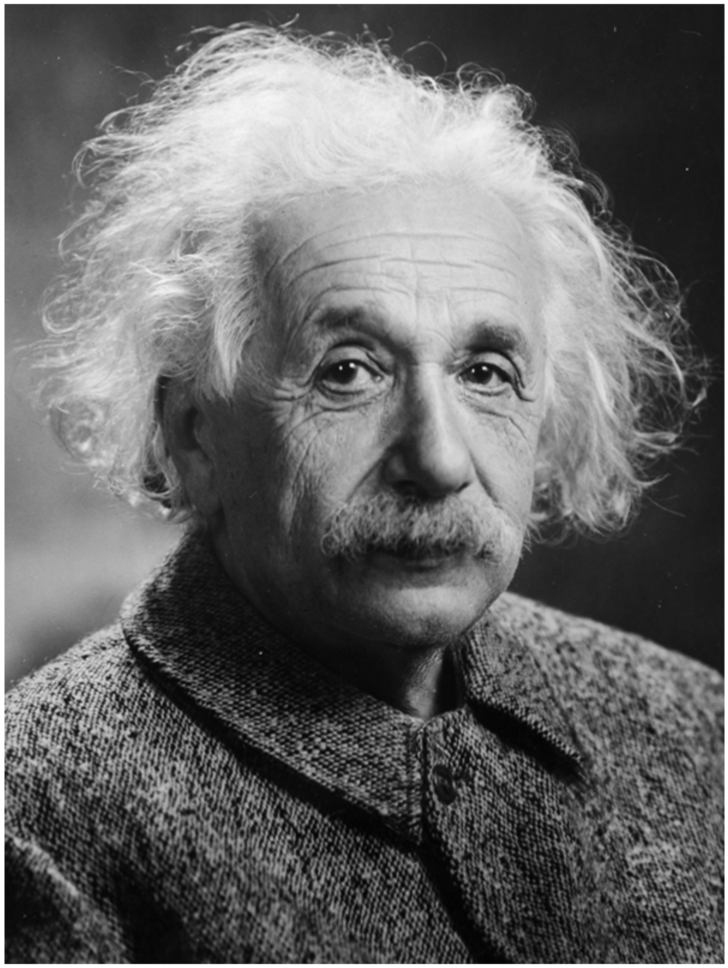
Consider this…

—Michio Kaku (1947-) Physicist

The most beautiful thing we can experience is the mysterious. It is the source of all true art and science.

God does not play dice with the Universe…

—Albert Einstein (1879-1955)



Public Domain

Index

C

Glossary

Sample Word 1 | Sample Definition 1

Detailed Licensing

Overview

Title: Introduction to Astronomy (Lumen)

Webpages: 222

All licenses found:

- CC BY 4.0: 98.2% (218 pages)
- Undeclared: 1.8% (4 pages)

By Page

- Introduction to Astronomy (Lumen) - *CC BY 4.0*
  - Front Matter - *CC BY 4.0*
    - TitlePage - *CC BY 4.0*
    - InfoPage - *CC BY 4.0*
    - Table of Contents - *Undeclared*
    - Licensing - *Undeclared*
  - 1: Introduction to Astronomy - *CC BY 4.0*
    - 1.1: Module Introduction - *CC BY 4.0*
    - 1.2: Basic Objects in the Universe - *CC BY 4.0*
    - 1.3: Scale of the Cosmos - *CC BY 4.0*
    - 1.4: The Constellations - *CC BY 4.0*
    - 1.5: Other Patterns - *CC BY 4.0*
  - 2: Historical Astronomy - *CC BY 4.0*
    - 2.1: Module Introduction - *CC BY 4.0*
    - 2.2: The Study of Science - *CC BY 4.0*
    - 2.3: What Time Is It? - *CC BY 4.0*
    - 2.4: Ancient Observations - *CC BY 4.0*
    - 2.5: Contributions to Science - *CC BY 4.0*
    - 2.6: The Wanderers - *CC BY 4.0*
    - 2.7: Claudius Ptolemy - *CC BY 4.0*
    - 2.8: Astronomy and Astrology - *CC BY 4.0*
    - 2.9: The Birth of Modern Astronomy - *CC BY 4.0*
    - 2.10: Observations of Motion- Brahe, Kepler, and Galilei - *CC BY 4.0*
    - 2.11: Observations of the Heavens- Galileo - *CC BY 4.0*
    - 2.12: The Mathematical Finish- Newton - *CC BY 4.0*
  - 3: Motions of the Moon, Sun, and Stars - *CC BY 4.0*
    - 3.1: Module Introduction - *CC BY 4.0*
    - 3.2: Motions of Objects - *CC BY 4.0*
    - 3.3: Our Night Sky - *CC BY 4.0*
    - 3.4: The Sun and the Moon - *CC BY 4.0*
    - 3.5: Seasons and Seasonal Changes - *CC BY 4.0*
    - 3.6: The Moon in our Skies - *CC BY 4.0*
    - 3.7: Eclipses - *CC BY 4.0*
  - 4: Light and Spectra - *CC BY 4.0*
    - 4.1: Module Introduction - *CC BY 4.0*
    - 4.2: Looking at a rainbow, what do you see? - *CC BY 4.0*
    - 4.3: Thermal Radiation - *CC BY 4.0*
    - 4.4: The Electromagnetic Spectrum - *CC BY 4.0*
    - 4.5: Spectra - *CC BY 4.0*
    - 4.6: Moving Objects, Spectra, and the Doppler Effect - *CC BY 4.0*
  - 5: Telescope and Observing - *CC BY 4.0*
    - 5.1: Module Introduction - *CC BY 4.0*
    - 5.2: The Telescope - *CC BY 4.0*
    - 5.3: Early Telescopes - *CC BY 4.0*
    - 5.4: Telescopic Observations - *CC BY 4.0*
    - 5.5: Telescope Optical Types - *CC BY 4.0*
    - 5.6: Telescope Mounts - *CC BY 4.0*
    - 5.7: Images from the Telescope - *CC BY 4.0*
    - 5.8: Space-Based Telescopes - *CC BY 4.0*
    - 5.9: Light Pollution - *CC BY 4.0*
    - 5.10: Space-based Telescope - *CC BY 4.0*
    - 5.11: Hubble Space Telescope - *CC BY 4.0*
  - 6: Solar System Formation and Other Stellar Systems - *CC BY 4.0*
    - 6.1: Module Introduction - *CC BY 4.0*
    - 6.2: Our Solar System - *CC BY 4.0*
    - 6.3: The Nebular Theory - *CC BY 4.0*
    - 6.4: What is a Planet? - *CC BY 4.0*
    - 6.5: The Nebular Theory- Other Important Evidence - *CC BY 4.0*
    - 6.6: The Nebular Theory- Proplyds - *CC BY 4.0*
    - 6.7: Systems and Extrasolar Planets - *CC BY 4.0*
    - 6.8: The Discovery of Extrasolar Planets - *CC BY 4.0*
    - 6.9: The Kepler Mission - *CC BY 4.0*
    - 6.10: What We Have Learned about Stellar Systems and Extrasolar Planets? - *CC BY 4.0*
    - 6.11: The Circumstellar Habitable Zone - *CC BY 4.0*
    - 6.12: Some Interesting Exoplanets - *CC BY 4.0*
    - 6.13: Extrasolar Planets - *CC BY 4.0*
  - 7: The Rocky Planets - *CC BY 4.0*
    - 7.1: Module Introduction - *CC BY 4.0*
    - 7.2: What do you think? - *CC BY 4.0*

Detailed Licensing

Overview

Title: Introduction to Astronomy (Lumen)

Webpages: 222

All licenses found:

- CC BY 4.0: 98.2% (218 pages)
- Undeclared: 1.8% (4 pages)

By Page

- Introduction to Astronomy (Lumen) - *CC BY 4.0*
  - Front Matter - *CC BY 4.0*
    - TitlePage - *CC BY 4.0*
    - InfoPage - *CC BY 4.0*
    - Table of Contents - *Undeclared*
    - Licensing - *Undeclared*
  - 1: Introduction to Astronomy - *CC BY 4.0*
    - 1.1: Module Introduction - *CC BY 4.0*
    - 1.2: Basic Objects in the Universe - *CC BY 4.0*
    - 1.3: Scale of the Cosmos - *CC BY 4.0*
    - 1.4: The Constellations - *CC BY 4.0*
    - 1.5: Other Patterns - *CC BY 4.0*
  - 2: Historical Astronomy - *CC BY 4.0*
    - 2.1: Module Introduction - *CC BY 4.0*
    - 2.2: The Study of Science - *CC BY 4.0*
    - 2.3: What Time Is It? - *CC BY 4.0*
    - 2.4: Ancient Observations - *CC BY 4.0*
    - 2.5: Contributions to Science - *CC BY 4.0*
    - 2.6: The Wanderers - *CC BY 4.0*
    - 2.7: Claudius Ptolemy - *CC BY 4.0*
    - 2.8: Astronomy and Astrology - *CC BY 4.0*
    - 2.9: The Birth of Modern Astronomy - *CC BY 4.0*
    - 2.10: Observations of Motion- Brahe, Kepler, and Galilei - *CC BY 4.0*
    - 2.11: Observations of the Heavens- Galileo - *CC BY 4.0*
    - 2.12: The Mathematical Finish- Newton - *CC BY 4.0*
  - 3: Motions of the Moon, Sun, and Stars - *CC BY 4.0*
    - 3.1: Module Introduction - *CC BY 4.0*
    - 3.2: Motions of Objects - *CC BY 4.0*
    - 3.3: Our Night Sky - *CC BY 4.0*
    - 3.4: The Sun and the Moon - *CC BY 4.0*
    - 3.5: Seasons and Seasonal Changes - *CC BY 4.0*
    - 3.6: The Moon in our Skies - *CC BY 4.0*
    - 3.7: Eclipses - *CC BY 4.0*
  - 4: Light and Spectra - *CC BY 4.0*
    - 4.1: Module Introduction - *CC BY 4.0*
    - 4.2: Looking at a rainbow, what do you see? - *CC BY 4.0*
    - 4.3: Thermal Radiation - *CC BY 4.0*
    - 4.4: The Electromagnetic Spectrum - *CC BY 4.0*
    - 4.5: Spectra - *CC BY 4.0*
    - 4.6: Moving Objects, Spectra, and the Doppler Effect - *CC BY 4.0*
  - 5: Telescope and Observing - *CC BY 4.0*
    - 5.1: Module Introduction - *CC BY 4.0*
    - 5.2: The Telescope - *CC BY 4.0*
    - 5.3: Early Telescopes - *CC BY 4.0*
    - 5.4: Telescopic Observations - *CC BY 4.0*
    - 5.5: Telescope Optical Types - *CC BY 4.0*
    - 5.6: Telescope Mounts - *CC BY 4.0*
    - 5.7: Images from the Telescope - *CC BY 4.0*
    - 5.8: Space-Based Telescopes - *CC BY 4.0*
    - 5.9: Light Pollution - *CC BY 4.0*
    - 5.10: Space-based Telescope - *CC BY 4.0*
    - 5.11: Hubble Space Telescope - *CC BY 4.0*
  - 6: Solar System Formation and Other Stellar Systems - *CC BY 4.0*
    - 6.1: Module Introduction - *CC BY 4.0*
    - 6.2: Our Solar System - *CC BY 4.0*
    - 6.3: The Nebular Theory - *CC BY 4.0*
    - 6.4: What is a Planet? - *CC BY 4.0*
    - 6.5: The Nebular Theory- Other Important Evidence - *CC BY 4.0*
    - 6.6: The Nebular Theory- Proplyds - *CC BY 4.0*
    - 6.7: Systems and Extrasolar Planets - *CC BY 4.0*
    - 6.8: The Discovery of Extrasolar Planets - *CC BY 4.0*
    - 6.9: The Kepler Mission - *CC BY 4.0*
    - 6.10: What We Have Learned about Stellar Systems and Extrasolar Planets? - *CC BY 4.0*
    - 6.11: The Circumstellar Habitable Zone - *CC BY 4.0*
    - 6.12: Some Interesting Exoplanets - *CC BY 4.0*
    - 6.13: Extrasolar Planets - *CC BY 4.0*
  - 7: The Rocky Planets - *CC BY 4.0*
    - 7.1: Module Introduction - *CC BY 4.0*
    - 7.2: What do you think? - *CC BY 4.0*