Teacher's Manual

Chapter 3: Solar System Overview

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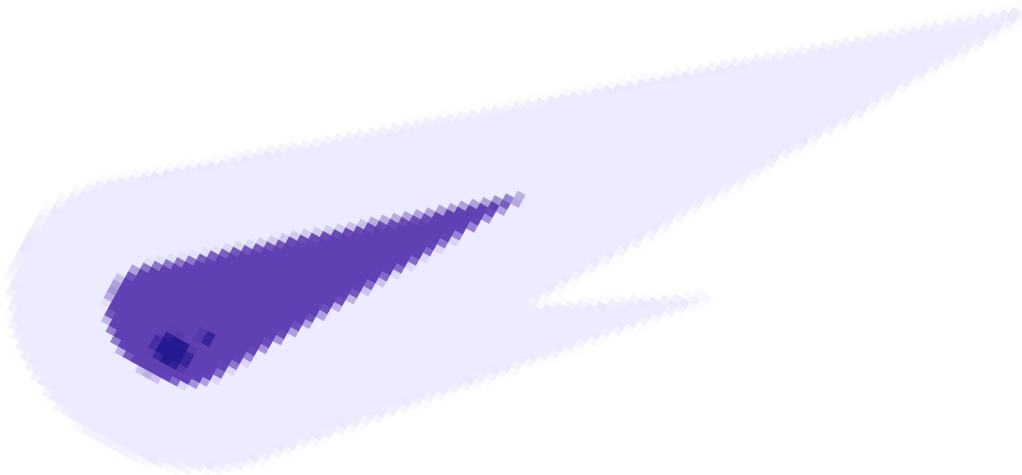
Work Package 3
StAnD Academy



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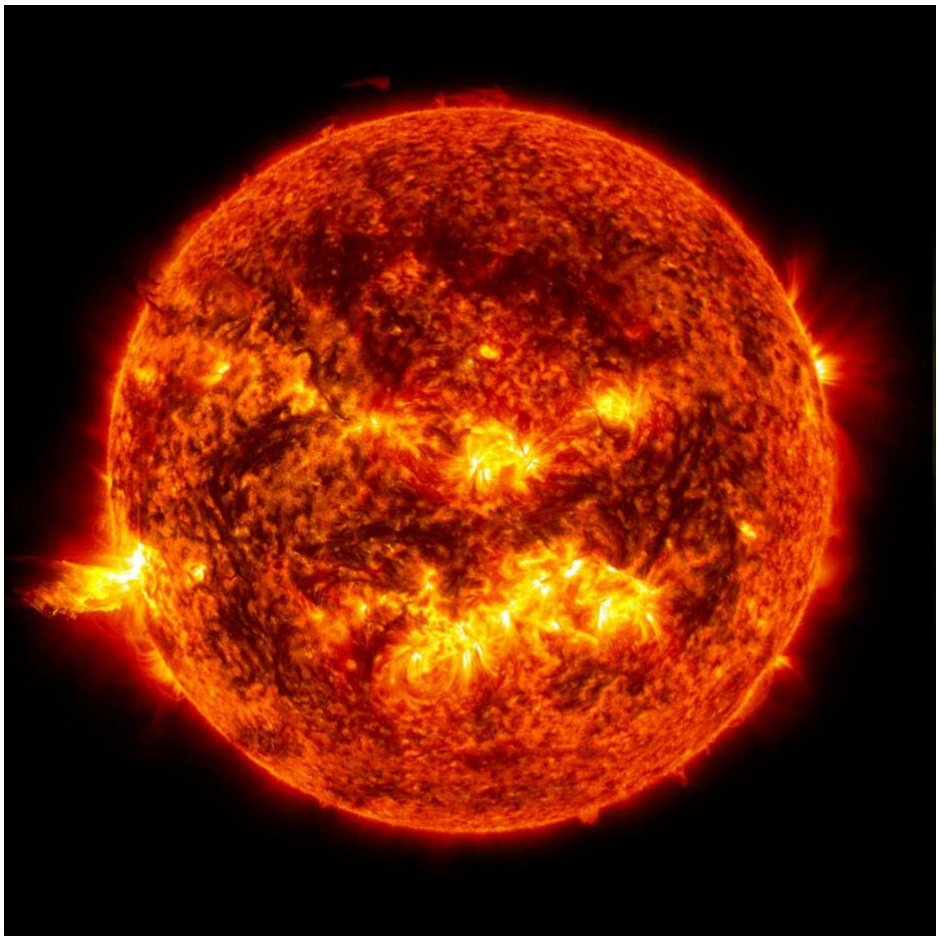
3.1 Objects in our Solar System

The solar system is our cosmic neighborhood, a vast and dynamic place filled with a variety of objects bound by the gravity of our central star, the Sun. Within this chapter you will find a short description of the celestial objects found in our Solar System and a short explanation of how it was formed about 4,5 billion years ago.

3.1.1 THE SUN

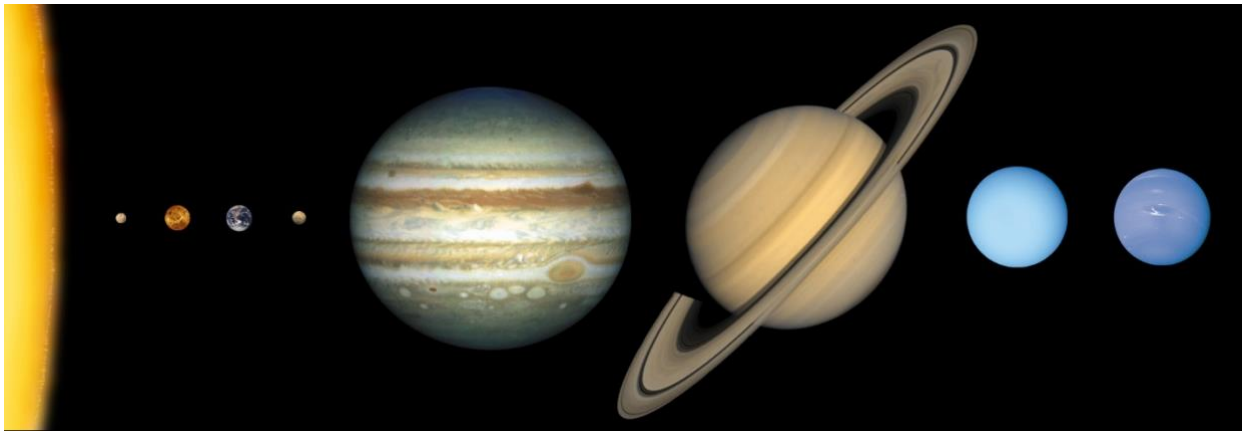
The Sun is the heart of our solar system, a giant ball of hot plasma held together by its own gravity. It's a star, classified as a yellow dwarf, about 4.5 billion years old. At its core, intense pressure and heat fuse hydrogen atoms into helium, releasing tremendous energy that reaches us as light and heat, fueling life on earth. The Sun's immense gravity (about 99,86% of the mass of our Solar System) keeps everything in our solar system orbiting around it, from planets and moons to asteroids and comets.



Ejection of a CME from the Sun (©NASA/Goddard/SDO https://science.nasa.gov/image-detail/amf-gsfc_20171208_archive_e001435/)

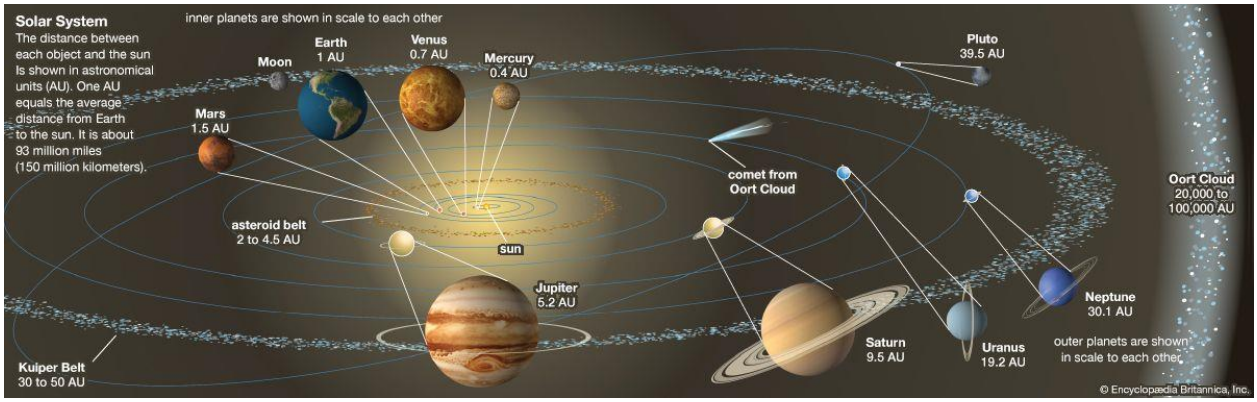
3.1.2 PLANETS

Orbiting the Sun are eight planets. These can be broadly divided into two categories. The first one is the inner planets, which are small (Image 2) and rocky and are also called terrestrial planets because they have similar composition with the Earth.



The planets of our Solar System with their sizes to scale (©NASA https://science.nasa.gov/resource/solar-system-sizes/)

The inner planets are Mercury, Venus, Earth, and Mars and they are all relatively close to the Sun (Image 3) and have solid surfaces. The second category is the outer planets, which are much larger (Image 2) and consist mainly of gas. The planets that belong in this category are Jupiter, Saturn, Uranus, and Neptune which are also further away from the Sun (Image 3), compared to the inner planets.



The orbits of the planets in our Solar System with the distances to scale (©NASA https://science.nasa.gov/resource/solar-system-sizes/)

Besides the eight planets, the solar system also includes a number of other objects, including dwarf planets, moons, asteroids, comets and meteoroids.

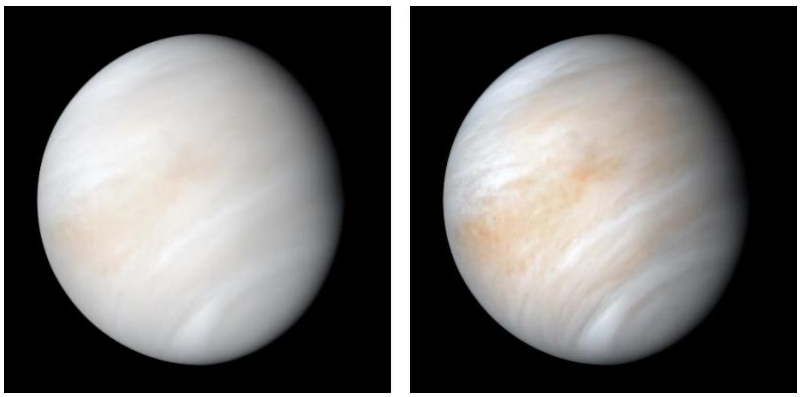
3.1.2.1 Mercury

Mercury is the solar system's smallest planet and the closest one to the Sun. It's a terrestrial planet with immense temperature variations on its surface. On the dayside that is facing the Sun, temperatures can reach up to 430 degrees Celsius, while the night side can go down to -180 degrees Celsius. These big temperature variations are explained by the lack of atmosphere, which is also partially responsible for the big number of craters covering its surface that have been created by various meteoroids that fell on the planet. Mercury got its name from the fast Roman messenger god, as it rotates around the Sun every 88 Earth days making it the fastest planetary orbit of our Solar System. Despite its proximity, it's not the hottest planet – that title belongs to Venus.

Colored image of Mercury's surface (©NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie https://science.nasa.gov/resource/mercurys-subtle-colors/)

3.1.2.2 Venus

Often called Earth's "twin planet" due to its similar size and mass, Venus is the planet with the higher temperature in our Solar System, reaching 462 degrees Celsius, hot enough to melt lead! This is due to the greenhouse effect caused by its thick atmosphere mostly composed of carbon dioxide. Surrounded by a thick, sulfuric acid cloud layer, Venus' surface remains hidden, by a dense atmosphere with a crushing pressure 95 times bigger than the one found on Earth.



Spacecraft's Mariner 10 image of Venus (©NASA/JPL-Caltech https://science.nasa.gov/resource/newly-processed-views-of-venus-from-mariner-10/)

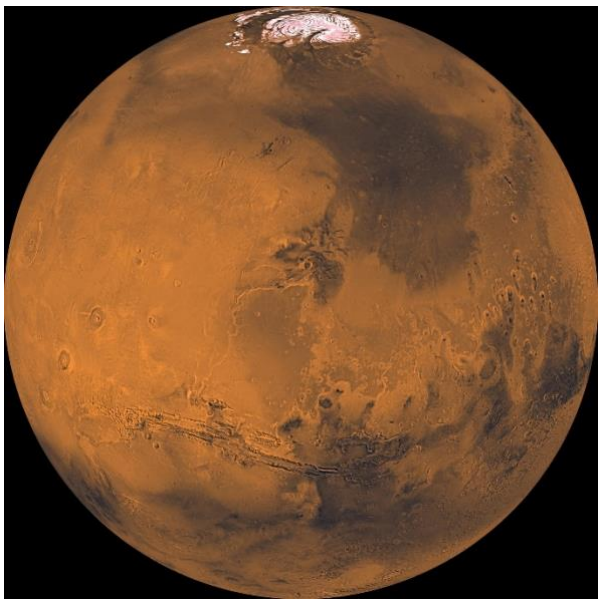
3.1.2.3 Earth

Earth, our home planet, is the third planet from the Sun and the only one in our solar system known to support life. Unlike its neighbors, Earth has a moderate temperature range thanks to its perfect distance from the Sun and its atmosphere. This atmosphere, composed mainly of nitrogen and oxygen, shields us from harmful solar radiation and allows liquid water to exist on the surface. Earth is a dynamic planet with a solid, rocky surface sculpted by volcanoes, mountains, and oceans. Our planet is 70% covered in liquid water, forming vast oceans that play a crucial role in regulating climate and harboring a rich and diverse biosphere. Continents, covered in forests, deserts, and ice caps, provide a habitat for an incredible variety of life forms.

The Earth captured by the crew of the Apollo 17 mission. The image is known as the "Blue Marble" (©NASA https://explorer1.jpl.nasa.gov/galleries/earth-from-space/).

3.1.2.4 Mars

Mars is a terrestrial planet, similar to Earth in composition. However, Mars is significantly smaller, with a diameter roughly half that of Earth. Its most striking feature is its rusty red colored surface, caused by iron-rich minerals. Mars possesses a thin atmosphere, primarily composed of carbon dioxide, which contributes to dramatic temperature swings. Daytime temperatures can reach 27 degrees Celsius near the equator, but ca drop to -95 degrees Celsius at night. Evidence suggests Mars may have once possessed a thicker atmosphere and flowing water, potentially creating an environment that could host life. Mars is orbited by two small, irregularly shaped moons, Phobos and Deimos that are believed to be captured asteroids.



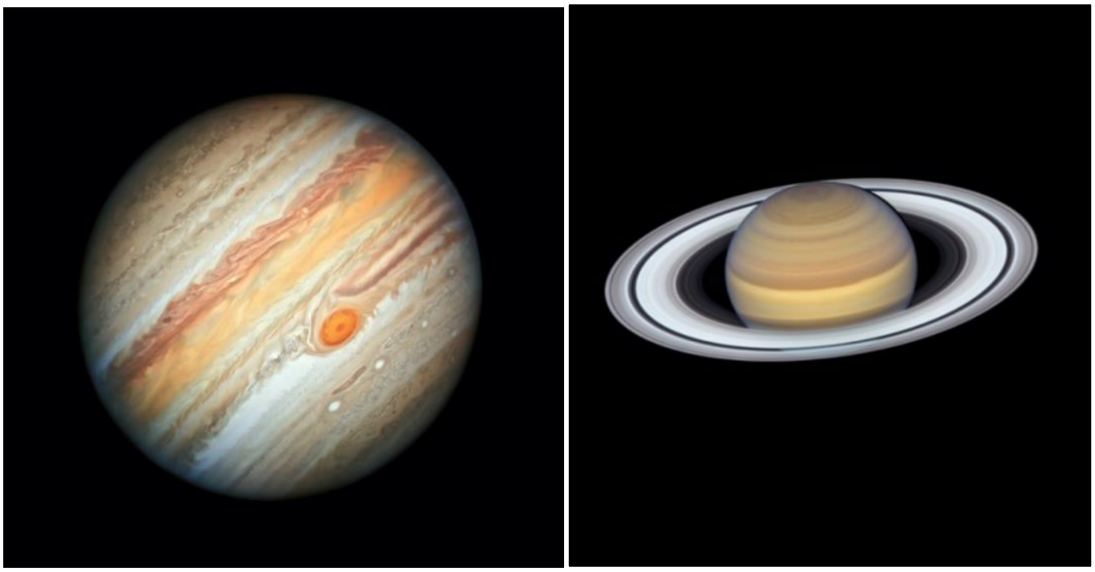
Mosaic of images from the Viking orbiter (© NASA/JPL-Caltech/USGS https://science.nasa.gov/resource/global-color-views-of-mars/)

3.1.2.5 Jupiter

Jupiter is the largest planet of our solar system, the fifth one out from the Sun. It's a gas giant consisting mostly of hydrogen and helium. Pressure and temperature increase towards its center, compressing the hydrogen gas into a liquid. Jupiter's famous for its colorful stripes and the Great Red Spot, a giant storm bigger than Earth that's been around for hundreds of years. It also has the shortest day in the solar system as it rotates around its axis in just 10.5 hours, despite its size. With its super strong gravity, Jupiter acts like a giant space vacuum cleaner, sucking in space dust and rocks and keeping the inner solar system clean and safer.

3.1.2.6 Saturn

Saturn, the sixth planet from the Sun, is a gas giant renowned for its dazzling ring system. Like Jupiter, Saturn is primarily composed of hydrogen and helium gas, but it has a density far lower than Earth's (it is actually less dense than water). This planet is surrounded by a complex system of icy rings. Saturn's rings are thought to be pieces of comets, asteroids, or shattered moons that broke up before they reached the planet, torn apart by Saturn's powerful gravity. They are made of billions of small chunks of ice and rock coated with other materials such as dust and their sizes vary from grain sized pieces to chunks as big as mountains. Saturn's atmosphere also exhibits a fascinating hexagonal vortex at its north pole, a unique feature that is not observed on other planets in our solar system.



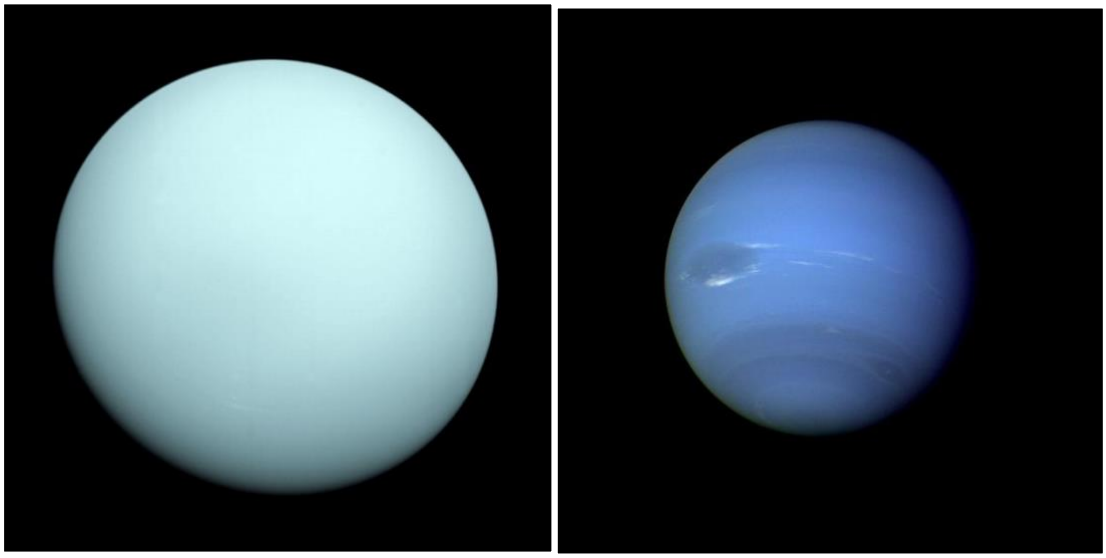
Left: Hubble's New Portrait of Jupiter (©NASA, ESA, A. Simon (Goddard Space Flight Center), And M.H. Wong (University Of California, Berkeley) https://science.nasa.gov/resource/hubbles-new-portrait-of-jupiter/)Right: Hubble's portrait of Saturn and its rings (©NASA, ESA, A. Simon (GSFC), M.H. Wong (University Of California, Berkeley) And The OPAL Team https://science.nasa.gov/resource/saturns-rings-shine-in-hubble-portrait/)

3.1.2.7 Uranus

Uranus, the seventh planet from the Sun, is an icy giant and the coldest planet of our Solar System. Unlike the rest of the planets, Uranus also has a unique tilt on its axis, causing it to spin almost sideways around the Sun. This ice giant primarily consists of water, methane and ammonia. Its vibrant blue color is due to the methane gas in its atmosphere. Even though Uranus lacks the prominent ring system of Saturn, it does possess two sets of rings that consist of an inner system of nine rings and two outer rings.

3.1.2.8 Neptune

Neptune, the eighth and farthest planet from the Sun, shares the icy giant classification with Uranus. Like its icy neighbor, Neptune is composed primarily of water, methane, and ammonia. Its deep blue color is due to the abundance of methane gas in its atmosphere. Neptune also has a ring system fainter than Saturn's. It has at least five main rings and four prominent ring arcs that we know of so far. Neptune is our solar system's windiest world with winds that can be three times stronger than Jupiter's and nine times stronger than Earth's. These winds whip clouds of frozen methane across the planet at speeds of more than 2,000 kilometers per hour.



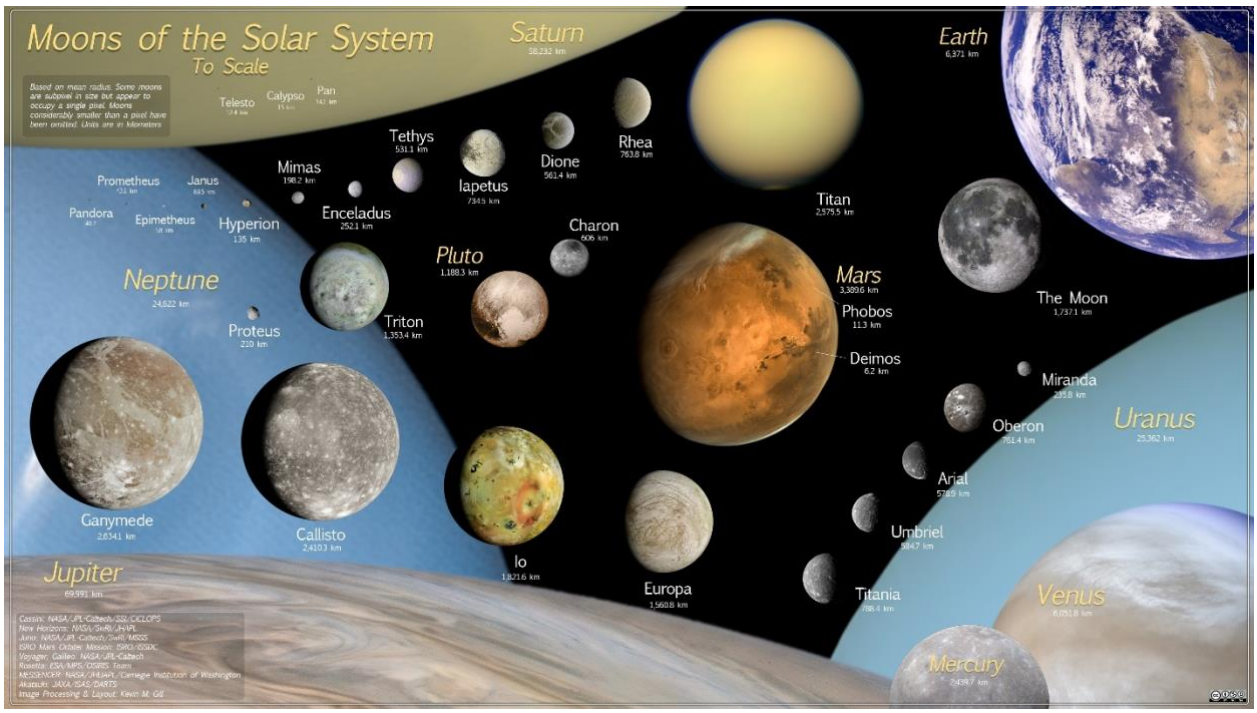
Left: Uranus as seen by NASA Voyager 2 (©NASA, JPL https://science.nasa.gov/image-detail/amf-pia18182/) Right: Neptune image from Voyager 2 (©NASA, JPL https://photojournal.jpl.nasa.gov/catalog/PIA00046)

3.1.3 MOONS

Moons, or natural satellites, are celestial bodies that orbit planets. The solar system has many, diverse moons, ranging from small, irregularly shaped objects to large, spherical worlds.

Mercury and Venus are the only planets in our Solar System that have no moons. Our planet has one natural satellite that is relatively large compared to Earth. Among other things, its gravitational influence stabilizes our planet's axial tilt and influences Earth's tides. The Moon's surface is characterized by numerous craters, formed by the impact of asteroids and comets. These craters, along with lunar mountains and valleys, provide valuable information about the Moon's geological history.

Mars has two small, irregularly shaped moons, called Phobos and Deimos. They are considered to be asteroids that were captured by the planet's gravity, or debris from the formation of our solar system. Jupiter and Saturn have the most extensive moon systems, with dozens of satellites each. These moons vary greatly in size and composition, with some exhibiting geological activity and even possessing atmospheres. Neptune and Uranus also possess moon systems, that compared to Jupiter and Saturn, include fewer and smaller moons.



The planets of the Solar System and some selected moons in scale, based on their mean radius. (© Cassini: NASA/JPL-Caltech/SSI/CICLOPS, New Horizons: NASA/SwRI/JHAPL, Juno: NASA/JPL-Caltech/SwRI/MSSS, ISRO Mars Orbiter Mission: ISRO/ISSDC, Voyager, Galileo: NASA/JPL-Caltech, Rosetta: ESA/MPS/OSIRIS Team, MESSENGER: NASA/JHUAPL/Carnegie Institution of Washington, Akatsuki: JAXA/ISAS/DARTS, Image Processing & Layout: Kevin M. Gill)

3.1.4 DWARF PLANETS

Dwarf planets are celestial bodies that orbit the Sun and are nearly round, but unlike planets, they have not cleared the area around their orbit of other objects. These intriguing bodies reside primarily in the Kuiper Belt, a region beyond Neptune. So far, the IAU has recognized five dwarf planets: Ceres, Pluto, Haumea, Makemake, and Eris.

Pluto, once classified as a planet, is the most famous dwarf planet. It was recategorized in 2006 due to its relatively small size and the presence of other similar objects in its orbital path. Pluto is known for its diverse and complex terrain, including mountains, plains, and even a possible subsurface ocean. Ceres is the largest object in the asteroid belt, located between Mars and Jupiter. It was initially classified as an asteroid but was later recategorized as a dwarf planet. Ceres is believed to have a rocky core and an icy mantle, and it may harbor subsurface water. Eris is a distant dwarf planet located in the Kuiper Belt. It is slightly larger than Pluto and has a similar icy composition. Eris is known for its highly elliptical orbit and its moon, Dysnomia. Haumea is a dwarf planet located in the Kuiper Belt. It has an elongated shape and is known for its rapid rotation, which has given it an unusual oblong form. Haumea also has two moons, Hi'iaka and Namaka. Makemake is another dwarf planet located in the Kuiper Belt. It is similar in size and composition to Pluto, and it has one known moon, MK2. These celestial bodies offer valuable insights into the formation and evolution of the solar system.

Known dwarf planets of our Solar System. (© NASA https://science.nasa.gov/dwarf-planets/)

3.1.5 MINOR BODIES IN OUR SOLAR SYSTEM

Besides the planets, moons and dwarf planets, our Solar System has a big amount of smaller celestial objects that are the main topic of this document and will be analyzed in the following pages.

Asteroids are rocky bodies that orbit the Sun. They are primarily located in the asteroid belt between Mars and Jupiter. They vary in size, from small rocks to objects that are hundreds of kilometers. Some of them have irregular shapes, while others are nearly spherical.

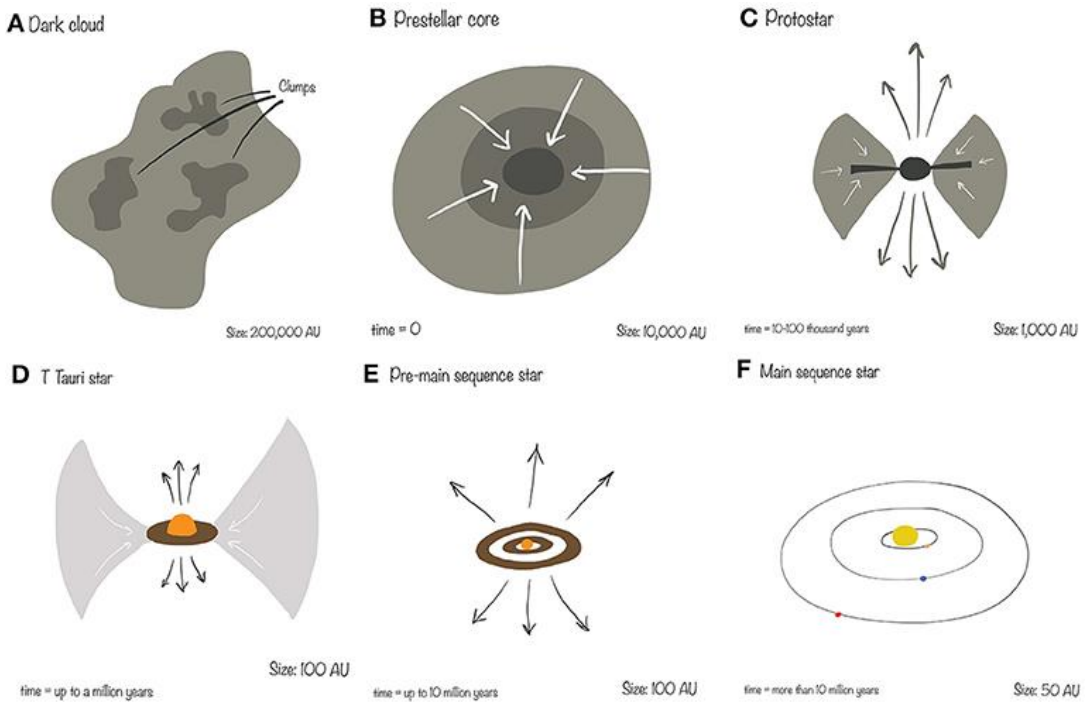
Another category of minor bodies is **comets**. They are icy bodies that originate from the outer reaches of the solar system and they develop characteristic tails of gas and dust as they approach the Sun.

Meteoroids, on the other hand, are small fragments of asteroids, comets, or other celestial bodies. When a meteoroid enters Earth's atmosphere, it becomes a meteor, commonly known as a "shooting star" and if a meteor survives its passage through the atmosphere and reaches the Earth's surface, it is then called a meteorite.

Learn more about the Difference Between Asteroids, Comets, and Meteors HERE.

3.2 STAR AND SOLAR SYSTEM FORMATION

Our solar system was born from a vast, swirling cloud of gas and dust, approximately 4.6 billion years ago. This cloud, primarily composed of hydrogen and helium, began to collapse under its own gravity. As it contracted, the center of the cloud grew denser and hotter, eventually forming the Sun.

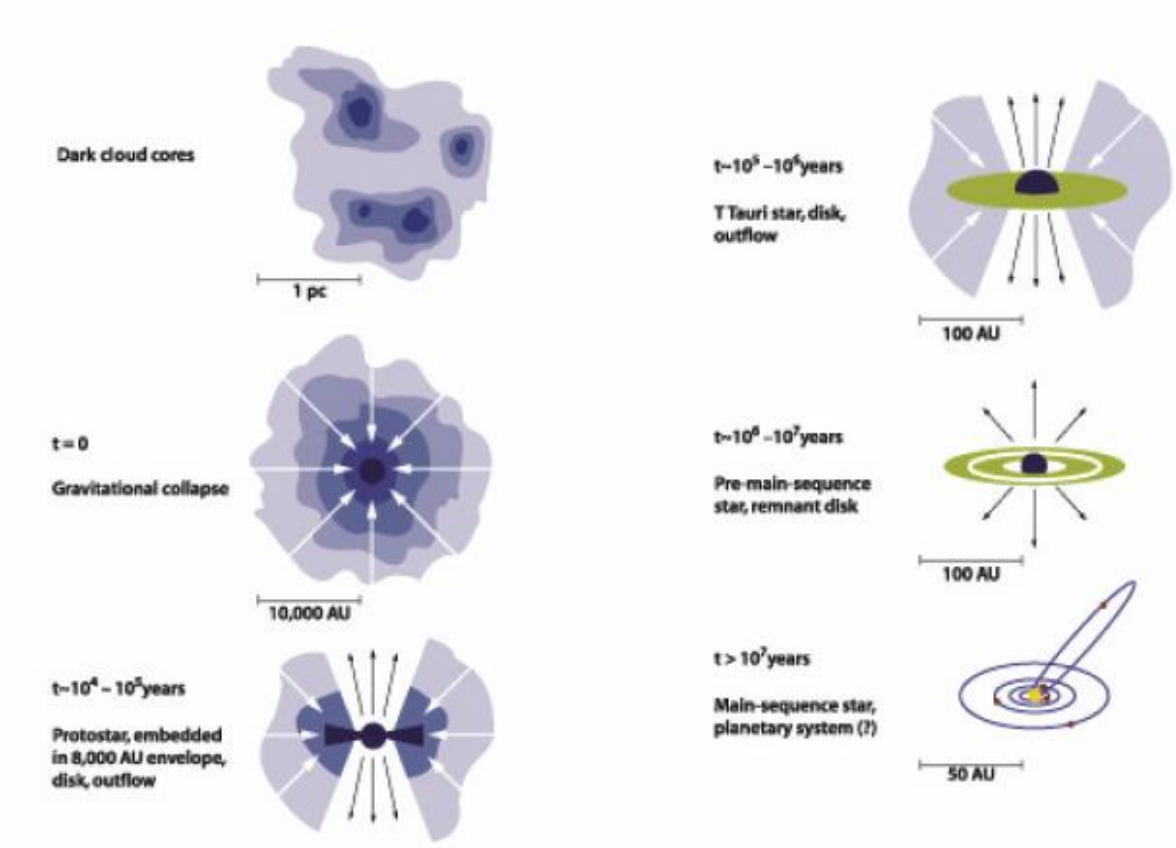


Process of star formation (sizes and time duration are noted).
(https://kids.frontiersin.org/articles/10.3389/frym.2019.00092)

The remaining material was flattened into a disk and tiny particles of dust and ice collided and stuck together, gradually forming larger and larger bodies known as planetesimals. Over millions of years, these planetesimals continued to collide and merge, eventually forming the protoplanets. Based on their distance from the Sun and therefore the temperature and gravity conditions the planets of our Solar System were eventually created and can be distinguished to the inner, denser, terrestrial planets (Mercury, Venus, Earth and Mars) and to the icy, gas giants (Jupiter, Saturn, Uranus and Neptune).

The process of the formation of our Solar System was violent and chaotic, with countless collisions and near-misses. It's a complex process that scientists continue to study and refine our understanding of how our solar system came to be.

In a similar way to our star and solar system, stars in general are born from vast clouds of gas and dust known as nebulae. These nebulae are usually primarily composed of hydrogen and helium.



Phases of star (and solar system) formation. (Casasola, Viviana. (2008). The Small Scale Physical Evolution of Molecular Gas in Nearby Galaxies. https://www.researchgate.net/publication/37677690_The_Small_Scale_Physical_Evolution_of_Molecular_Gas_in_Nearby_Galaxies)

The process begins when a section of the nebula becomes denser due to gravitational pull. As this denser region contracts, it spins faster and heats up. The core of this collapsing cloud eventually becomes hot and dense enough to initiate nuclear fusion, the process where hydrogen atoms combine to form helium, releasing immense amounts of energy. This marks the birth of a star.

The remaining gas and dust around the newly formed star often forms a disk, which can eventually give rise to planets, asteroids, and comets. The size and mass of the star will determine its evolution overtime.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