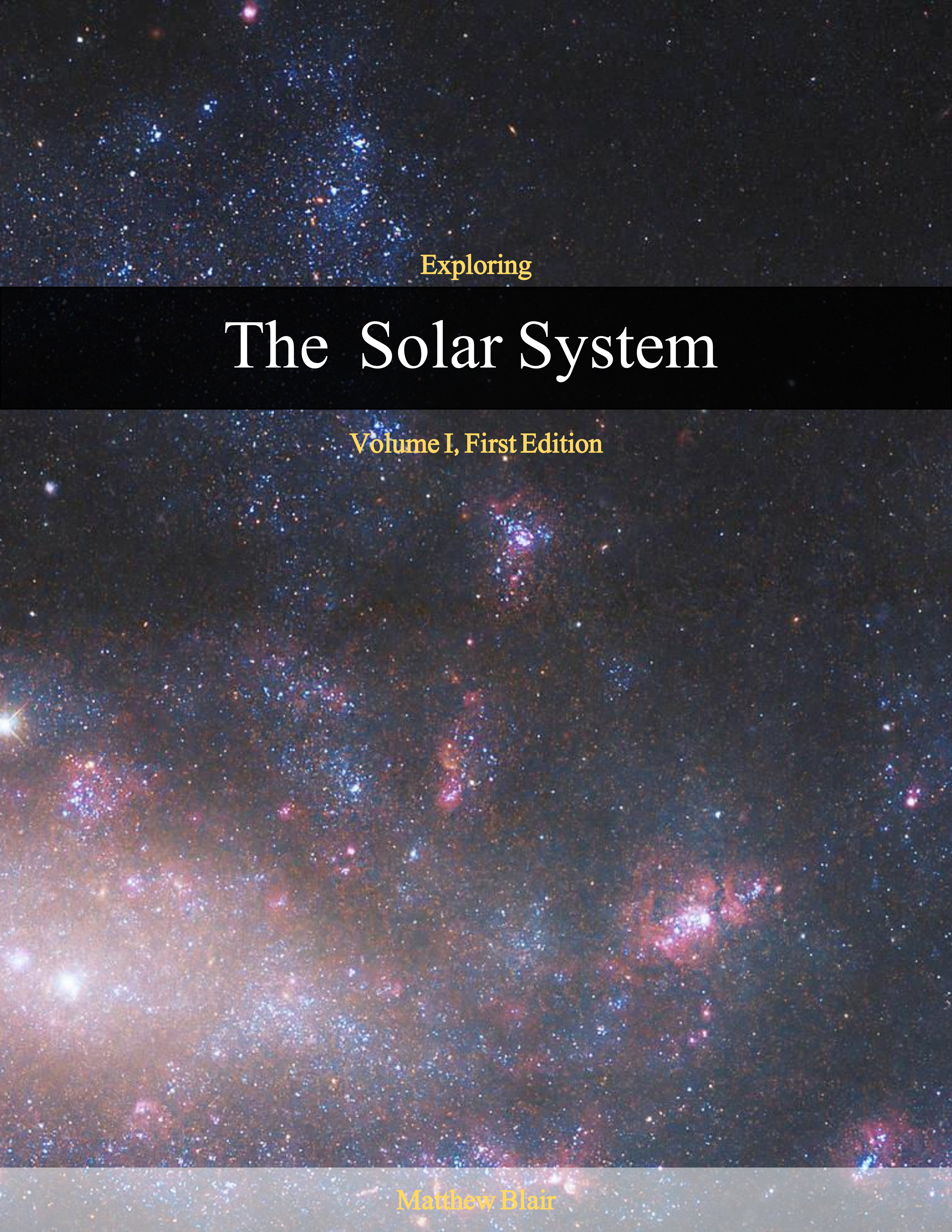

Exploring

The Solar System

Volume I, First Edition

Matthew Blair

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June 2023

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I Introduction

The solar system, a mesmerizing tapestry of celestial bodies, holds an unyielding fascination for humanity. From the scorching embrace of the Sun to the distant and icy depths of the outer planets, our cosmic neighborhood is a stage upon which the grandest of dramas unfolds. In this text, we will explore our solar system's most prominent features, including the Sun, planets, and moons, as well as other notable phenomena that, over the course of billions of years, have amalgamated to allow the flourishing of life as we know it.

Billions of years ago, a colossal cloud of interstellar gas and dust, delicately balanced between chaos and order, began its celestial dance. Within this cosmic nursery, gravity embraced its role as a sculptor, drawing the swirling tendrils of matter together. As the cloud collapsed upon itself, immense pressures and temperatures ignited a fiery spark, igniting the radiant heart of our system—*the Sun*. Around this stellar furnace, a swirling disk of material took shape, also known as a *Protoplanetary Disk*, birthed a family of diverse celestial bodies. But these celestial bodies were not the planets we know today. In fact, many would collide with each other, decompose, and reform over the course of thousands of years as the protoplanetary disk cooled, and gravitational forces from the Sun would pull them into stable orbits that more closely resemble the system we observe today.

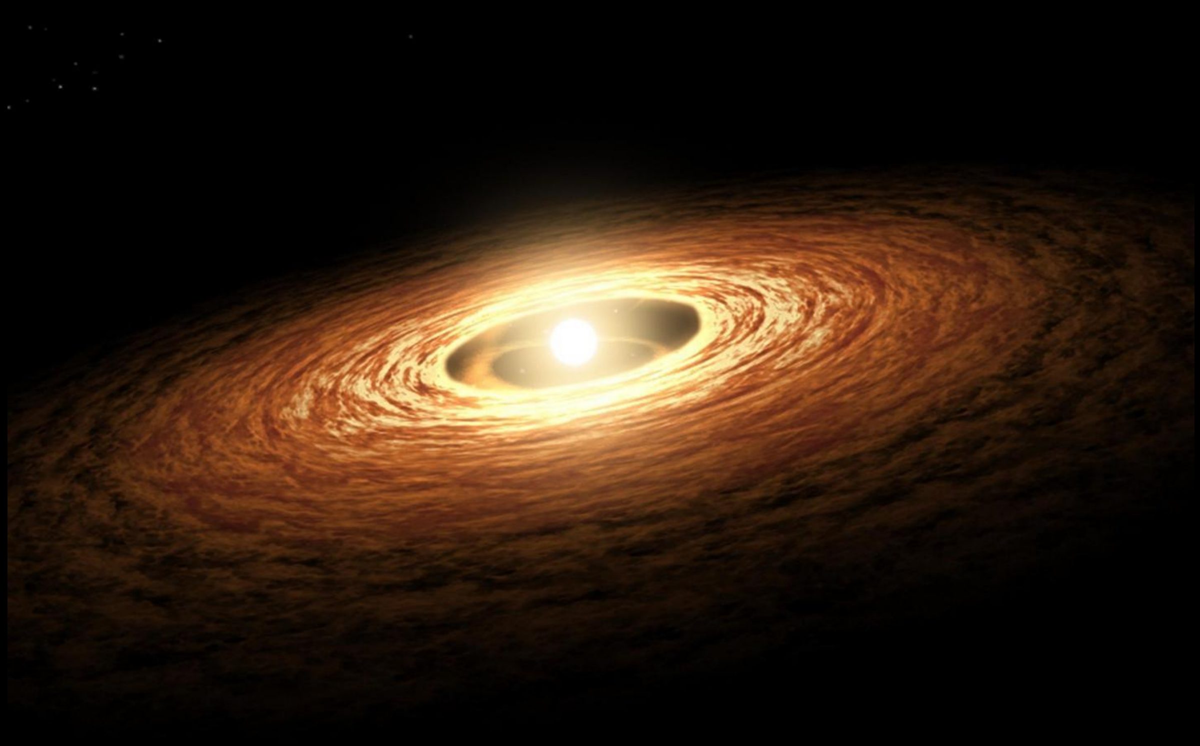

Figure 1: A Protoplanetary Disk around a newborn star

II The Sun

The Sun, also referred to as 'Sol', is a large fiery ball of plasma located at the center of our solar system. It is the lone celestial body which all planets, asteroids, and other stellar debris in our system orbit due to its high mass and resulting gravitational pull. The heat it produces is so intense that it can be felt on Earth and from hundreds of millions of kilometers away.

The Sun is categorized as a *G-type main sequence star* (G2V), or a yellow dwarf, although this term is a bit misleading since it is 330,000 times more massive than the Earth, and its radius is 109 times larger than that of Earth's. Our sun's specific temperature, size, and lifespan made it perfect for the formation of life on Earth. Despite how special the Sun seems to us, and how integral it has been to life as we know it, it is quite average when considering the range of possible stars that can exist in our universe.

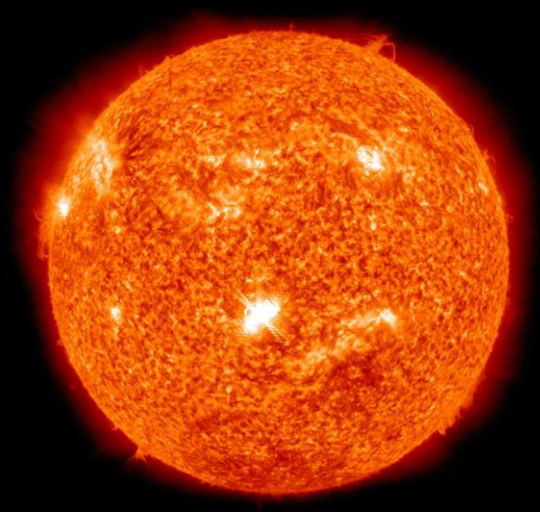

Figure 2: The Sun, a G - type star

Stars can fall into one of seven categories (O, B, A, F, G, K and M), determined by their surface temperature, which can also determine their color, and other features like luminosity. The hottest stars (type-O) typically shine a bright blue color and have a typical lifespan of only 10 million years. Type-O stars are exceedingly rare in the universe, making up only 0.00003% of all stars. This is likely because the hotter a star burns, the shorter its lifespan; not to mention that the conditions needed for stars like these to arise are uncommon in the universe today. The most common stars we observe are of type-M, also called *Red Dwarf* stars, which shine a reddish-orange color. These stars make up roughly 76% of all stars; they burn much dimmer than our Sun, and are much smaller in size, but are believed to have lifespans of up to a trillion years. For instance, type-G stars like our own typically last for about 10 billion years. Astronomers believe that red dwarves will be some of the last remaining stars in the universe for these very reasons.

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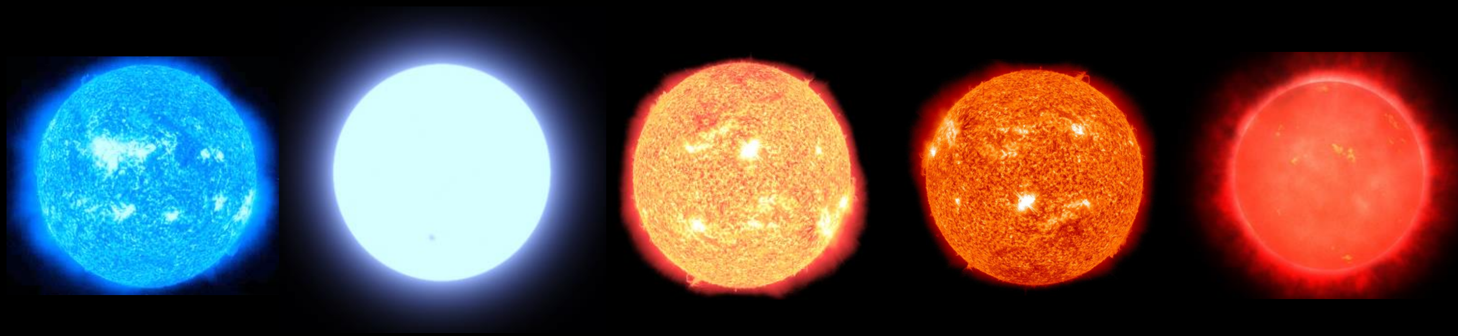


Figure 3: O, B A, G, & M - type stars (sizing not to scale for visual purposes)

At their core, stars are constantly undergoing the nuclear fusion of Hydrogen and Helium, which is what causes them to emit heat and radiation. This radiation and electromagnetic energy build-up is ejected in what are called *solar flares.* The severity and frequency of solar flares depends on the star and can be potentially dangerous to the formation of life. Our sun emits solar flares, and they have the potential to interfere with electrical grids and technology, albeit very rarely. In contrast, many red dwarf stars can produce violent flares called *Superflares*, occurring after long periods of dormancy, which is believed to harm the ability for life to form on surrounding planets; but this is also dependent on the relative distance between the planet and star, direction, as well as the strength of the planet's magnetic field.

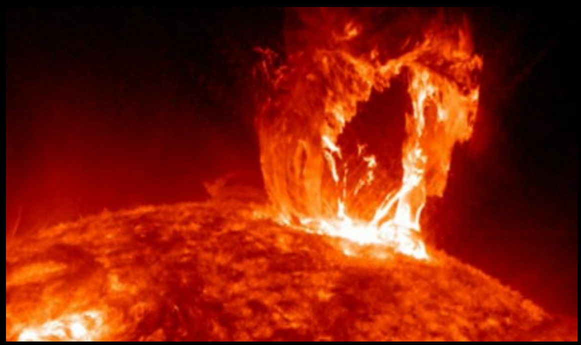


Figure 4: A solar flare emission

III Mercury

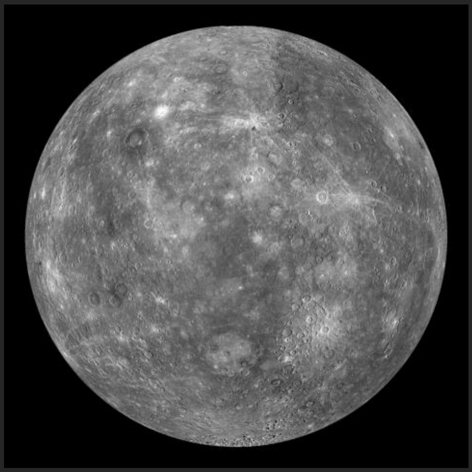


Figure 5: Mercury

Mercury is the closest planet to the sun, and the smallest planet in our solar system; in fact, it is not much larger than our moon, and is even smaller Saturn's moon Titan, which we will explore further on. Unlike Pluto, it is not considered a dwarf planet because it is the sole object in its orbital path around the Sun. Hence, it also has no moons of its own.

Mercury is one of the three rocky planets in our system, comprised mostly of Iron and Silicate. It is one of the densest objects in our solar system and is thought to be this way due to its large Iron core.

Mercury's past is believed to be a violent one. Given its proximity to the Sun (~56 Million km), it is constantly scorched with high levels of solar radiation, and only has a thin atmosphere, called an *Exosphere*. Its surface is covered in craters as well, which remain from the early history of the solar system as a result of a lack of internal geologic activity. If Mercury were geologically active, these craters would likely disappear over time as a result of tectonic fluctuations, yet they remain after millions of years, implying the planet hasn't been geologically active in quite some time, like our Moon.

IV Venus

Venus is the second closest planet to the Sun and is quite like Earth in terms of its shape and size. It joins Mercury and Earth as the solar system's only rocky planets and distinguishes itself from the rest by being the hottest planet, caused by its thick atmosphere. Venus orbits the Sun at roughly 100 Million km, in the inner portion of its *habitable zone*, which is a ring around a star believed to have suitable conditions for life to form on rocky planets within the zone. In comparison, Earth orbits the sun in the middle portion of this region. Even though Venus lies in this zone, it is considered one of the most inhospitable environments in the solar system.

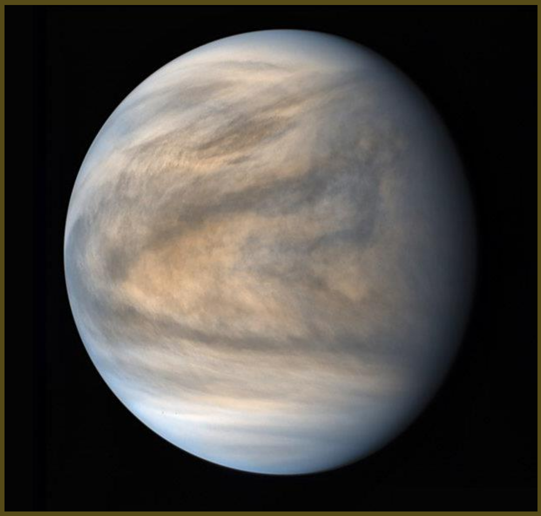


Figure 6: Venus

The reason Venus is so hostile to life is due to its yellow, thick, toxic atmosphere, which is made up of mostly Carbon Dioxide, a potent greenhouse gas. Carbon dioxide is remarkably good at trapping heat, hence over time this effect would amplify, leading to its current state today. This atmosphere is so thick that at its surface, the pressures exerted would be comparable to standing at the bottom of the ocean on Earth.

One of Venus's distinctive features is that it rotates around the Sun in the reverse direction, a designation shared only with Uranus.

Rather surprisingly, not everywhere on Venus is believed to be truly inhospitable. Recent studies of Venus suggest that in the upper levels of its atmosphere, there are conditions nearly identical to those on Earth, and has been considered as an alternative to Mars for potential future human exploration.

In 1981, the Soviet Union sent the Venera 13 probe to Venus, landing on its surface but was functional for only a few hours before succumbing to the harsh conditions.

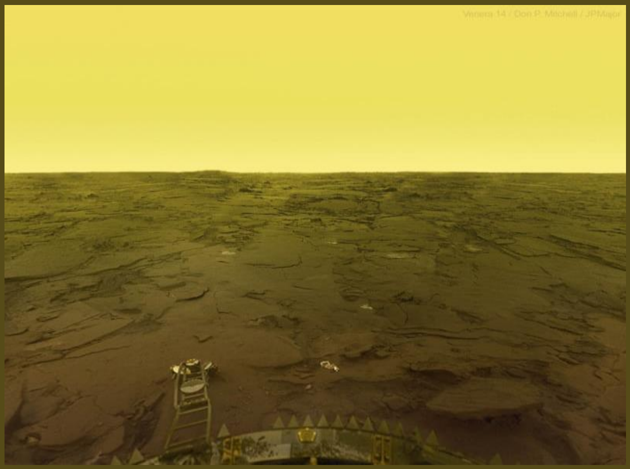


Figure 7: The surface of Venus, taken by Venera 13 (1981)

V Earth

Figure 8: Earth

Earth is the third planet from the Sun, and the only body in the solar system known to host life. It is home to a unique biosphere of plants and animals, a multi-layered atmosphere, liquid water on its surface, as well as a variety of diverse geographical features.

The Earth orbits the Sun at about 150 Million km, and this length is used as a standard unit for measuring the distance of all objects in space, which we denote as 1 Astronomical Unit, or 1 AU.

Earth is comprised mostly of liquid water, which makes up about 70% of its surface. The remainder of its surface is made up of rocky land masses, that over time, have drastically changed due to tectonic activity within the Earth's core. Today, Earth's land masses are organized into seven continents.

The atmosphere on Earth is made up of gases, such as Nitrogen, Oxygen, and Carbon Dioxide, the composition of which allowed for humans to evolve and breathe freely. It is also made up of masses of condensed water vapor, known as *clouds*, which circulate due to winds and other factors like differences in temperature and pressure by region. Clouds disperse liquid water as rainfall which later evaporates from bodies of water at the surface in what is referred to as the *water cycle*. All these features combine to generate complex weather patterns, and overall aid in the formation of life on Earth.

Earth's surface and oceans make up a very wide and diverse biosphere. How the continents formed long ago gave rise to features like lakes, islands, mountain ranges, oceans, rivers and a host of complex, plant, animal, and fungal life. Much of the Earth's surface has already been explored and studied, but the same cannot be said of the Earth's interior, or its deep oceans, which to this day, mostly remain a mystery.

Figure 9: An ocean (left), a forest (middle), & a city (right)

V.I The Moon

The Moon is a rocky body orbits Earth at an average distance of 384,000 km along an elliptical orbit. The histories of the Moon and Earth are inexplicably tied. The origin of the Moon is still contested in the current day, but the most widely accepted explanation is the *Giant Impact Hypothesis*. Computer simulations hint that it is a remnant of a collision between a rocky mass that would become the Earth and another proto-planet named Theia in the early solar system. Others believe that the Moon formed alongside Earth, or even came from inside the Earth itself, due to the similarly of their chemical compositions.

Figure 10: The Moon, as seen from Earth

The Moon is *tidally-locked* with Earth, meaning one side of it always faces the planet, while the other always faces away. The Moon's gravitational pull on Earth exhibits tidal forces in its oceans, allowing for the circulation of ocean flora and fauna, produces renewable energy, and aides in navigation of its water masses. Based on current models of how life arose on Earth, it is believed that these forces were crucial in the evolution of early organisms and multi-cellular life.

The Moon's surface is covered in impact craters, gray dust and rocky debris. It is also the only other solar system object that humans have physically visited, and due to its low mass, the Moon's gravity is much less than Earth's. The Moon doesn't

There have been several manned-expeditions to the Moon in recent history; the first successful attempt was in 1969 on NASA's Apollo 11 mission, and the last was by their Apollo 17 mission in 1972. In recent years, various private organizations and NASA have expressed interest in revisiting the Moon and potentially setting up long-term settlements for mining and research. NASA's Artemis program is scheduled to have an unmanned mission in 2024, and is expected to send astronauts in its second mission in 2025.

Figure 11: The surface of the Moon

VI Mars

Mars is the fourth planet from the Sun and the farthest orbiting rocky planet in the solar system. Its distance from the Sun is 250 Million km. It has a wide variety of geographic features on its surface, such as volcanoes, canyons, dried lakes. Its surface is coated in a sandy red dust comprised of iron oxides (rust), and clay particles.

The atmosphere on Mars is much thinner than Earth's,

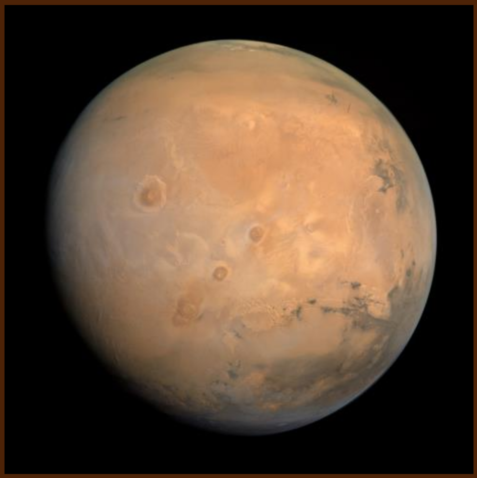


Figure 12: Mars

Figure 13: The surface of Mars, as seen by the Curiosity rover

VII The Asteroid Belt

The Asteroid Belt is a torus-shaped region of the solar system situated between the orbit of Mars and Jupiter. It contains mostly irregularly-shaped rocky masses, or *Asteroids*, that in total are less massive than the Moon

VIII Jupiter

Jupiter is the 5th planet from the Sun, the first gas giant, and orbits the Sun at ~780 Million km. It is the most massive planet, so much so that its mass is greater than that of all other planets in the solar system combined. It hosts a large system of 95 moons, and its most impressive feature is its *Great Red Spot*, an atmospheric storm that is comparable to Earth in size. Despite its size, Jupiter is only 0.001% the size of the Sun. Jupiter is sometimes referred to as a *Failed Brown Dwarf*, a type of a pseudo-star that lacks the mass to become a fully-sized sun but is far larger in size and temperature to a typical planet.

Figure 16: Jupiter, featuring its Great Red Spot

Since Jupiter is a gas giant rather than a rocky planet, it has no true surface and consists of large bands of gaseous mixtures, mostly made up of hydrogen, helium, ammonia and methane. Jupiter's atmosphere also consists of bands of gases that extend to the circumference of the planet. Within these bands are many violent storms, cyclones and anticyclones. At the poles, storms have assembled into colorful octagonal and pentagonal formations.

The Great Red Spot is a massive storm that has been observed for hundreds of years. It is uncertain how storms of this size form, but in recent years its size has fluctuated, and some believe it may be in the process of dispersing.

VIII.I Io

Io is the innermost moon of Jupiter, and the fourth largest moon in the solar system. Its surface features over four-hundred active volcanoes, sulfur dioxide frost, and silicate rock. Due to tidal heating between Jupiter and its other outer moons, Io is one of the most geographically active bodies in the solar system. Its many volcanoes erupt producing vibrant color changes on its surface of shades of yellow, red, white, black and green.

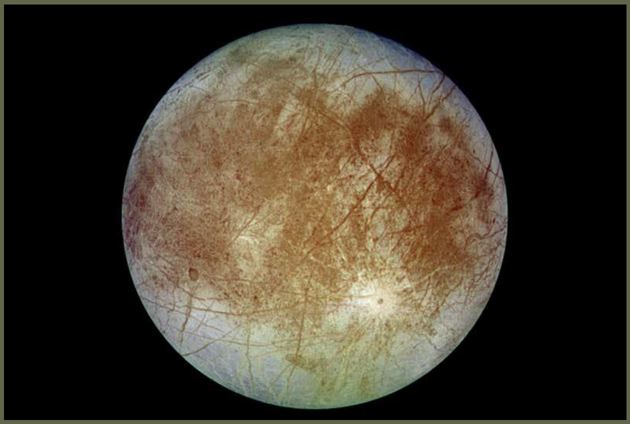
Despite the sheer scale of Jupiter, Io plays an important role in shaping its magnetic field. Due to its relative proximity to the planet, Io is responsible for nearly doubling the size of Jupiter's magnetosphere, which in turn lifts dusty material from Io's surface into the space between the two bodies and into Jupiter's magnetic field.

Figure : Io

Io orbits Jupiter in what is called the *Io plasma torus,* a belt of intense radiation that is the result of the previously mentioned tidal heating. Simultaneously, Io has the lowest amount of water of any known object in the solar system, making it quite an improbable home for life. And as a result of its highly active interior and tectonic activity, Io boasts mountains that surpass Mount Everest in height.

Io's atmosphere is quite thin, made up of mostly Sulfur Dioxide particulate from its surface, which gets stripped by Jupiter, whose gravitational forces sweep up more particles from its surface, creating a cycle. The resulting radiation is said to produce auroras on Io, like those on Earth, which result from solar winds.

VIII.II Europa



VIII.III Ganymede

IX Saturn

The sixth planet from the Sun is Saturn, orbiting at 1.4 billion km, and is the second largest planet in the solar system. Some of Saturn's most unique features include its prominent ring system, over 140 moons (the most of any planet), and a complex hexagonal shaped storm in its southern polar region.

Saturn is a gas giant that is, much like Jupiter, made up of mostly hydrogen and helium; while its rings contain mostly large quantities of small icy particulate. These rings are quite thin vertically (roughly 1km thick), so much so that if aligned properly with the Earth, they seemingly disappear.

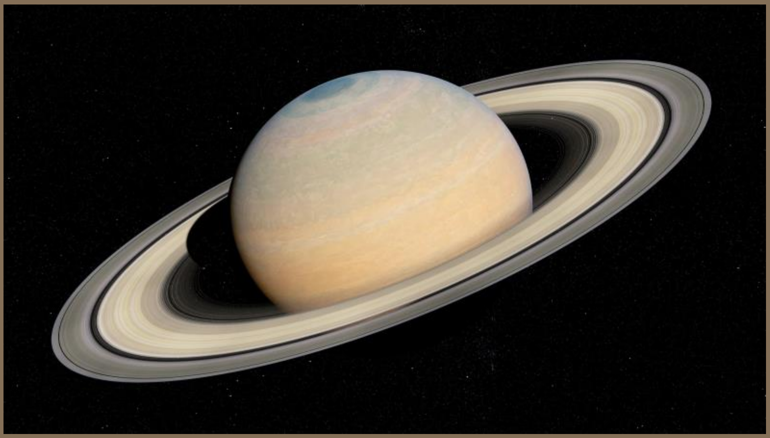


Figure : Saturn with its inner rings

Its ring system is broken up into numerous subsections, denoted the D, C, B, A, F, G and E rings in order from the planet. The D through F rings contain most of the matter that make up Saturn's rings, whereas the E ring extends much farther outward, appearing only as a dull cloud of dust around the outer reaches of the planet's gravitational influence; many of Saturn's more substantial moons orbit within in this ring.

One of Saturn's most visually striking features is its hexagonal-shaped polar vortex (pictured below), colored with tints of blue, magenta and gold. This massive storm was first observed by NASA's Voyager I probe in 1981, and later during NASA's Cassini-Huygens mission, which primarily studied the Jovian and Saturnian systems. It is not well understood how cloud formations can form with such a seemingly unnatural shape, but recent laboratory experiments show that such a formation can naturally occur under the right conditions.

The Cassini-Huygens mission, lasting from 1997 to 2017, form the basis for much of our modern knowledge about the planet and its moons. The Huygens lander module focused on the observation of Saturn's moon Titan, which it landed on during its final hours. The Cassini probe mostly studied Saturn's ring system and magnetosphere, and plunged into Saturn's atmosphere after its purpose was served.

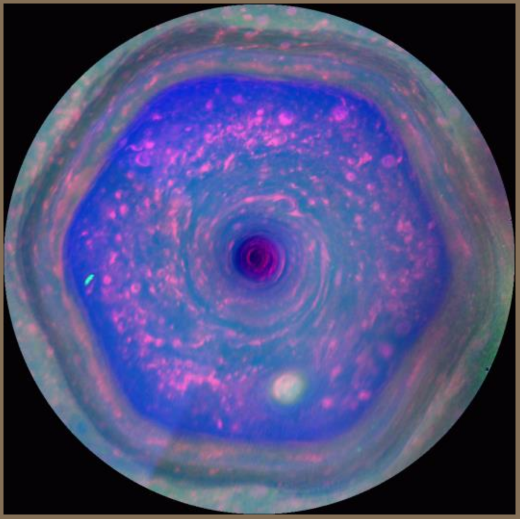


Figure : Saturn's southern polar vortex

IX.I Titan

Titan, the largest moon of Saturn, is one of the most fascinating moons we've observed. Unlike many other moons in our solar system, Titan more closely resembles a planet than a moon but is classified as such because it is gravitationally bound to its orbital parent, Saturn. In scale, it is larger than Mercury, although less massive, and has a variety of geographic features, as well as a substantial atmosphere.

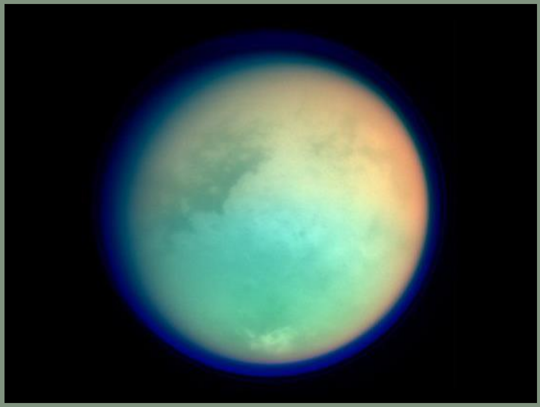


Figure : Titan

Titan's atmosphere is thicker than Earth's, and such a feature is quite uncommon compared to other moons in the solar system. It is composed of mainly nitrogen, methane and hydrogen, and is characterized by an opaque dark, yellow tint. Despite its atmosphere's opacity, it seldom acts as an insulator of heat from the sun because the average surface temperature is -179°C. Most impressively, Titan's surface features mountains, valleys, a thick crust of water ice, as well as rivers, and seas of liquid methane.

As a result of its atmospheric and geographic complexity, some believe that Titan mat harbor life within its icy crust, or a form of life we have yet to observe within its liquid methane water bodies, but these have seldom been confirmed.

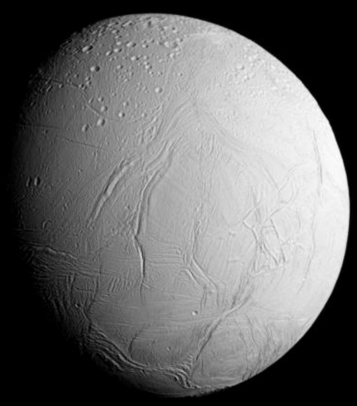
In 2005, NASA's Cassini-Huygens mission was launched to study the system of Saturn and its moons. At the end of its mission, the Huygens probe plunged into the atmosphere of Titan, returning the following image of its surface. To date, it is the farthest celestial body a spacecraft has successfully landed on the surface of.

Figure : The surface of Titan, photographed by the Huygens probe

IX.II Enceladus

Enceladus is a rocky, ice shell moon, and the sixth largest moon of Saturn, orbiting in it's E-ring. It is a relatively small moon, being only 0.1% as large as Titan, Saturn's largest moon. It is a rather interesting moon because of the presence liquid water oceans underneath thick sheets of ice on its surface, as well as large active geysers at its southern pole. Along with Titan, Enceladus is considered one of the most likely candidates for hosting life in our solar system.

Enceladus' surface is made up of grooves and ridges, impact craters, and plains of thick sheets of water ice. It is believed that the core of Enceladus is geothermally and tectonically active, due to recency in which these ice sheets formed. During NASA's Cassini-Huygens mission in 2005, the Cassini probe flew through the exhaust of plumes located at its south pole, confirming the existence of hydrocarbons in its interior believed necessary for life. And given the presence of internal geologic activity, it is considered to contain geothermal vents which may insulate the interior, possibly producing internal temperatures suitable for life to form. It is also believed that the exhaust of these plumes may be responsible for Saturn's E-ring, which have similarities in chemical composition.



X Uranus

Uranus is the seventh planet from the Sun and is referred to as an *ice giant*, rather than a gas giant because of its distance to the Sun (~2.9 Billion km) and the abundance of ice-forming materials in its atmosphere like ammonia and water.

Uranus has some eccentricities in comparison to the other outer solar system planets, such as an equator that is at a right angle to its orbital plane, and like Venus, it orbits in the opposite direction to the rest of the planets. It also has a thin ring system that orbits the planet along its equator.

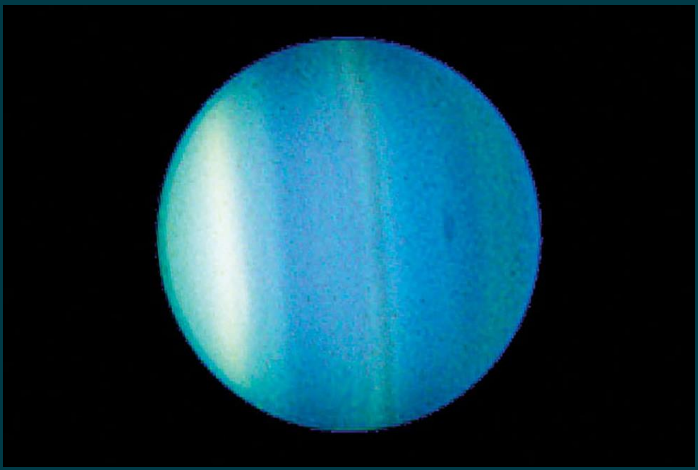
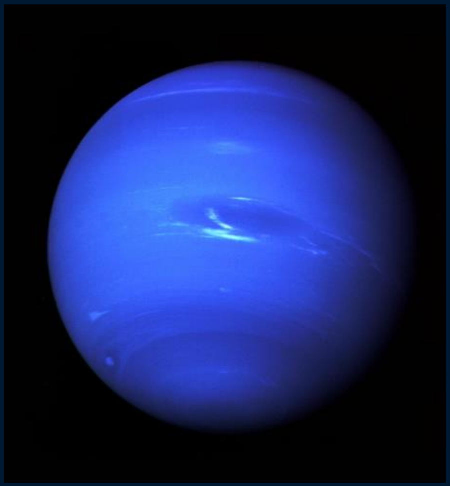


Figure : Uranus

As a result of its distance, much like Neptune, not much is known about Uranus in comparison to the rest of the planets. Space exploration missions tend to focus on Jupiter or Saturn due to their moons and their life likelihood. As we progress deeper into the outer reaches of the solar system, we find that fewer objects are suitable for life, and are mostly dormant, icy or rocky bodies since it takes longer for the Sun's heat to reach them.

XI Neptune



XII The Kuiper Belt

XIII Dwarf Planets