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Prospective Celestial Destinations: A Comprehensive Review for Human Exploration

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Abstract: Human space exploration is crucial for our future beyond Earth, offering vital insights while overcoming challenges. Unmanned missions are predominant due to the harsh conditions of distant astronomical bodies, but manned missions facilitate direct study of biological factors. Informed by a meticulous examination of unmanned missions, this research assesses celestial bodies for potential human missions, promising ground-breaking scientific discoveries. This systematic analysis comprehensively evaluates various parameters, yielding a comparative overview of potential celestial bodies. Critical environmental conditions for human missions receive thorough consideration. These conditions will be rigorously validated and aligned with a suitable sequence of celestial bodies or moons to ensure mission feasibility, thereby advancing our comprehension of space exploration's potential.

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1. Introduction

Astronomical body exploration is integral to enhancing our comprehension of the cosmos and establishing a sustainable human presence in space, providing a wider and deeper understanding of our solar system. This endeavour encompasses the evaluation of celestial bodies within and beyond our solar system, addressing various pertinent factors including accessibility, scientific potential, resource availability, cost, habitability, technological challenges, and safety considerations. In pursuit of deep space habitation, a comprehensive examination of these factors is essential, alongside exploration of terrestrial colonization prospects. Parameters such as atmospheric conditions, radiation exposure, chemical composition, and medical hazards are meticulously considered [33, 48] and discussed in light of research findings. Collaborating with agencies, industry, and global partners, NASA focuses on achieving national goals in human and robotic exploration, research, and technology development [8]. The report contains a detailed discussion about opportunities, issues, and outlook for space activities beyond GEO, including commercial activities, human exploration, and colonization.

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2. Scientific Methodology

The proposed objectives of this report range from defining optimal conditions for manned space missions to assessing the potential for sustaining life on distant celestial bodies, aligning the essential objectives in a sequence:

- Identifying numerous essential prerequisites for human space missions to exist.
- Including celestial bodies with potential habitability based on analyzed datasets.
- Examining the critical parameters and environmental factors of each celestial body, including planets and moons.
- Aligning acquired data with the previously deliberated critical parameters for human space missions.

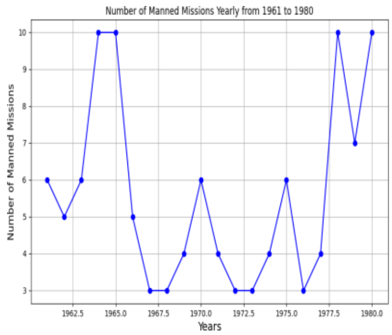
Exploratory endeavors like the Apollo program, undertaken during the 1960s and 1970s, have yielded pivotal technical insights into the lunar environment, surface characteristics, and prospective resources conducive to sustaining human presence. Additionally, missions targeting asteroids and comets, exemplified by NASA's OSIRIS-REx and ESA's Rosetta, have delved into the intricacies of smaller celestial bodies, elucidating their composition, origins, and the potential availability of valuable resources. These studies collectively contribute to our expanding knowledge of celestial bodies, paving the way for future exploration and potentially unlocking valuable resources for scientific and practical applications.

3. A Brief Description on the Background of Human-Crewed Missions

Expanding upon the knowledge derived from unmanned space missions, manned missions have become a focal point of exploration, involving classifications predicated on mission types and execution reliability. A detailed study into the viability of manned missions to particular planets or asteroids, as outlined in [43], constitutes a fundamental leap in the realm of manned exploration. This research lays the groundwork by initiating a framework that begins with the categorization of types of scientific tasks carried out during manned missions, such as:

- Target Science: It comprises a detailed analysis and discussion of a target astronomical body, encompassing examinations about its core nature, mode of origin, historical evolution, and much more.
- Cruise Science: The practice of cruise science involves spacecraft measurements and investigations throughout the transit to a planetary target. This facilitates scientific research by ensuring precise real-time analysis and interpretation of data.

Scientific Background of Manned Mission: The race to space was arguably one of the notable consequences of the Cold War. The Soviet Union emerged as the first nation to launch a manned mission in 1961, with Yuri Gagarin orbiting the Earth aboard Vostok 1. Concurrently, the United States responded with Project Mercury, commenced by NASA in the same year.



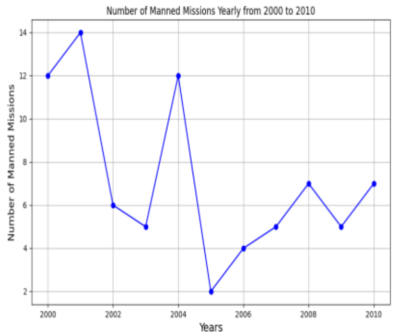


Figure-1 (left) The graph here represents the number of manned missions from the very first human flight to the last Apollo program. **Figure-2** (right) The graph here represents the number of manned missions from 2000 onwards, each assigned to reach the ISS, within LEO.

The graphical representation above showcases some of the successful manned missions encompassing both within Low Earth Orbit (LEO) and beyond LEO. Nevertheless, there have been fatal unsuccessful manned missions that resulted in the loss of various human lives. An example of such a mission failure and human casualties is the STS-51L (Challenger) Space Shuttle explosion in 1986. Considering and mitigating the occurrence of such accidents is one of the aims of this paper, among others.

4. Critical Consideration for Crewed Space Missions: Ensuring Human Safety and Success

Manned space missions represent the pinnacle of human exploration and scientific achievement. Examining possible hazards that can jeopardize human lives during a space mission is a pivotal process. Vehicle design and reliability, environmental conditions, and mechanical durability are some aspects among several other crucial inspections. This section outlines key prerequisites drawn from various studies researched previously **[33, 48]** to ensure the safety and success of these missions.

4.1. Risk Associated with Manned Missions

Some of the major risks that can result in a significant loss of mission objectives, with human casualties being the primary concern, include:

- ***Radiation Exposure:*** Solar radiation, Galactic Cosmic Rays (GCRs), and trapped radiation are types of radiation present in space. Astronauts are highly susceptible to acquiring fatal effective doses of radiation, particularly GCRs, which are ionizing radiations composed of heavy ions.
- ***Equipment Malfunctions:*** Technical devices installed aboard spacecraft may behave differently or fail due to issues such as microgravity, software glitches, radiation, etc. This could lead to signal anomalies, miscommunications, and ultimately mission failure.
- ***Negligence in technical verification of subsystems:*** Inadequate testing, clearance, and design of system-level devices can have catastrophic consequences. Thorough examination of every subsystem is essential to mitigate risks.
- ***Meteorite or Debris Impact on Spacecraft:*** Tiny meteorites, space debris, or objects can pose a threat to spacecraft. These objects typically travel at high velocities and carry significant energy, making impacts potentially damaging to the spacecraft on a critical level.

4.2. Countermeasures to Overcome Counter Risks

Addressing the mentioned concerns, the scientific literature has explored various countermeasures, prominently outlined in the work of **[48]**. Mitigating these risks necessitates strategic planning, including:

- Distinguishing between materials and assessing structural reliability, while simultaneously evaluating the impact of mechanical and environmental behaviors on both, is a critical aspect of scientific investigation.
- Performing a comprehensive risk assessment to identify all potential failure modes. Scheduling missions during periods of lower solar activity can reduce the risk of exposure to solar radiation. Planning trajectories to minimize time in radiation-prone regions is also considered.
- To minimize the potential for single-point failures, assigning backup systems or subsystems. Developing effective radiation shielding is one of the crucial steps to protect astronauts during space travel.
- Designing a comprehensive medical emergency plan for in-flight scenarios is crucial to ensuring the health and well-being of individuals aboard a spacecraft.

An assessment of RAMS (Reliability, Availability, Maintainability, Safety) and requirements for space vehicles with extended on-orbit stays has been conducted **[9]**. Minimum safety deterministic requirements have been established, while other RAMS aspects have been addressed through probabilistic requirements.

5. Potential Celestial Entities Capable to Sustain Humans and their Future Exploration

5.1. Moon – A Premier Destination for Human Settlement and Manned Expeditions

5.1.1. Availability of Water

For a long time, the Moon was considered dry and dusty, but recent in-situ observations revealed water in some samples of its earliest-formed crust. Nonetheless, water is found in some samples of the earliest-formed lunar crust, according to recent in-situ observations of the hydroxyl content and hydrogen isotopic composition in lunar highlands rocks. This discovery provides strong evidence for a shared water source in the Earth-Moon system [6]. Research on lunar samples focused on younger basalts and pyroclastic glasses, indicating that the Moon has multiple water sources, including water ice from meteorites, water formed from solar wind hydrogen reaction with lunar soil, and primordial water.

Radar scans from Earth discovered water on the Moon's surface, with polar conditions resembling those on Mercury [2]. Native water and volatiles altered by planetary impacts have been found in lunar materials, distributed unevenly across the surface. Cold traps in shadowed craters, volcanic glass beads, and apatite in lunar basalts all contain water [47].

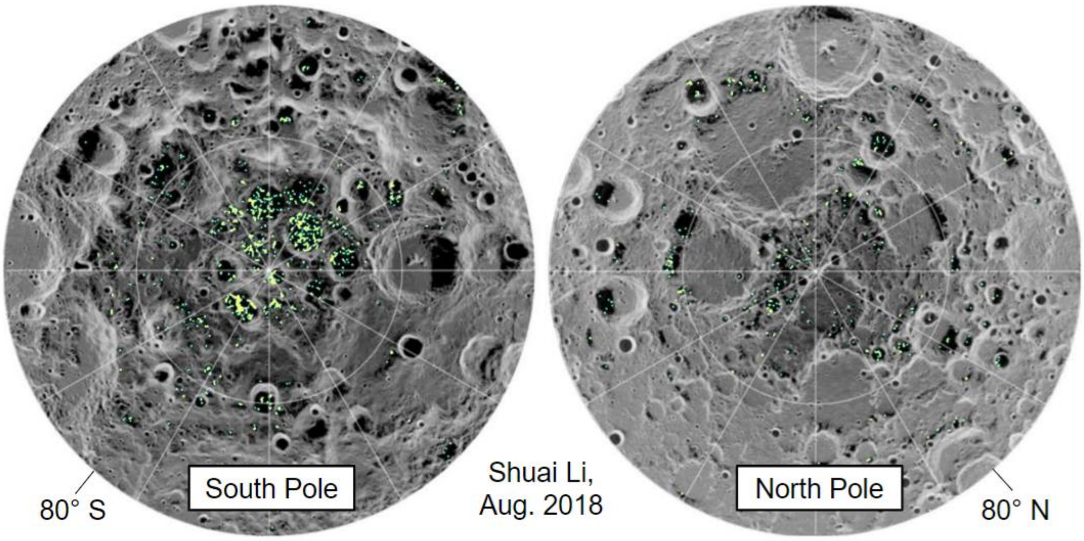


Figure-3 Water Distribution and Confirmation on Both Poles [Image Courtesy: NASA]

A recent scientific study created global maps of lunar surface water, revealing higher content at higher latitudes and a connection with space weathering [31]. While some areas show anomalously high water content, no global correlation with surface composition was observed. Potential water sources include exogenous, endogenous (magmatic), impact delivery, and solar wind implantation. Data from the Moon Mineralogy Mapper (M3) aboard Chandrayaan-1 identified surface water on Mars, focusing on the distinctive water absorption feature in the near-infrared spectral region. The presence of the distinctive water absorption feature in the near-infrared spectral region, at a wavelength of about 2.8 micrometres, was examined in the M3 data. The study [31] identifies water-filled locations on the Moon, such as high-latitude volcanic complexes at Compton-Belkovich and Bullialdus crater, and silicic volcanic deposits at Gruithuisen, Compton-Belkovich, and Maria, with Gruithuisen and Marian domes having higher water volumes.

5.1.2. Mineral and Salt Traces

The lunar regolith, or soil, potentially harbors minerals such as copper, nickel, platinum-group elements, chromite (a chromium ore), and ilmenite (a titanium ore). However, these minerals are expected to exist in lower concentrations compared to Earth [7, 34]. Notably, oxygen, silicon, aluminium, calcium, iron, titanium, and magnesium are prevalent elements on the Moon, presenting valuable mining opportunities. The Moon's significance lies in its proximity to Earth, a relatively shallow gravity well enabling cost-effective space access, and the abundance of crucial raw minerals, particularly oxygen within rocks [7]. This oxygen serves as a vital raw material for fundamental manufacturing processes, including the production of structural materials and silicon for semiconductors. Additionally, lunar oxygen holds potential as a fuel oxidizer for human spaceflight and rocket propulsion [29]. The primary silicate minerals on the Moon, including feldspar, pyroxene, olivine, and ilmenite, are associated with iron and aluminium, constituting the majority of lunar rocks. The Moon contains all of the elements found on Earth, and many useful elements exist in the rocks of the Moon in substantial concentrations. Some of the useful elements that can be obtained from the Moon as byproducts of extracting or processing other materials include iron, titanium, silicon, sodium, and copper. However, there are also elements such as gold, chlorine, and boron on the Moon, which are dispersed and not concentrated like on Earth [15].

5.1.3. Organic Molecules

The proposed model suggests the possibility that volatile compounds, including organic material, remain archived in buried paleoregolith deposits intercalated with lava flows on the Moon. In this study, researchers utilized selected free and polymeric organic materials to assess the hypothesis that organic matter can withstand the effects of heating in the lunar regolith by overlying lava flows. Results indicate that the presence of lunar regolith simulant appears to promote polymerization and therefore preservation of organic matter. Once polymerized, the mineral-hosted newly formed organic network is relatively protected from further thermal degradation. Carbonaceous matter has been identified on black pyroclastic beads collected from Shorty crater during the Apollo 17 mission, representing the first identification of complex organic material associated with any lunar sample. The chemical, physical, and isotopic properties of this organic matter, together with its pre-terrestrial origin, are detailed in the report. The most probable source suggested for this organic matter is through the accretion of exogenous meteoritic kerogen from micrometeorite impacts into the lunar regolith. The LCROSS mission detected organic molecules including C_2H_4, CH_3OH, and CH_4 at the lunar polar regions in 2010 (Colaprete et al., 2010). The origin of these organics on the moon is not yet completely understood, but one suggestion made by Zhang and Paige (2009) is that organic molecules could be deposited on the polar regions by migration of volatiles from cometary or meteoritic impactors. Recent work suggests that Mercury's poles may also contain organics in the form of dark deposits.

5.1.4. Atomospheric Habitability

The essential features of the Moon's atmosphere include its extremely low number density, dominated by neutral species, primarily helium and argon, and its exosphere-like nature. Stoichiometry does not apply, and the missing species remain absent. The relative brightness variation with altitude from four sodium images has been studied, and the results for Na and K have been analyzed. The high-energy solar wind environment creates an interaction between the lunar surface and the space environment that includes sputtering, thermal evolution, and local electric fields. The atmosphere is primarily composed of neutral atoms and molecules, with atomic sodium being the most abundant species **[53].** The argon data from measurements indicate that approximately 8% of the 40Ar produced on the Moon due to decay of 40K is released to the lunar atmosphere and subsequently lost. The source of atmospheric argon is localized, probably in an unfractionated, partially molten core. The radiogenic helium released with the argon amounts to 10% of the atmospheric helium supply. The total rate of helium escape from the Moon accounts for only 60% of the solar wind He particle influx. Lateral dispersal of volatile elements occurs due to the lunar atmosphere, which has condensed on soil grain surfaces. The modern lunar atmosphere primarily acts as a pipeline for escape of virtually all atmospheric gases.

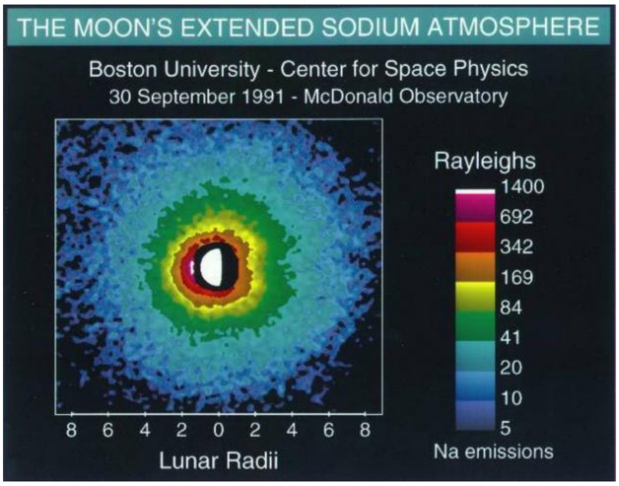


Figure-4 Moon's Extended Sodium Atmosphere [Image Courtesy: NASA]

The exosphere of the Moon primarily consists of minor constituents such as sodium and potassium. Spectra of the bright limb of the Moon show weak emission features that are attributed to resonant scattering of sunlight from sodium and potassium vapor above the subsolar point. The sodium emission extends to the poles, and the zenith column density of sodium above the subsolar point on the bright limb is 8 + 3 x 108 atoms/cm2, while the scale height for the sodium atmosphere is 120 ± 42 km. The zenith column density of potassium above the subsolar point is 1.4 ± 0.3 x 10' atoms/cm2, while the scale height is 90 ± 20 km. The ratio of the density of sodium in the lunar atmosphere to the density of potassium is (6 + 3) to 1, which is close to the sodium to potassium ratio in the lunar surface minerals **[45]**.

5.1.5. Energy Sources

The high-energy solar wind environment creates an interaction between the lunar surface and the space environment that includes sputtering, thermal evolution, and local electric fields **[53]**. Earthshine is the dominant source of natural illumination on the surface of the Moon during lunar night and at some locations within permanently shadowed regions (PSRs) near the poles that never receive direct sunlight. As such, earthshine has the potential to enable the scientific investigation and exploration of conditions in areas of the Moon that are either temporarily or permanently hidden from the Sun. Under certain circumstances, the heat flux from earthshine could also influence the transport and cold-trapping of volatiles present in the very coldest areas within PSRs.

In this study, Earth's spectral irradiance, as it would appear at the Moon in the solar reflectance band (0.3–3.0 µm) and at thermal emission wavelengths (3–50 µm), is examined with a suite of model image cubes and whole-disk spectra created using the Virtual Planetary Laboratory (VPL) three-dimensional (latitude, longitude, and altitude) modeling capability [21]. The lunar surface may be used as a mounting platform for a solar power system from where it could beam power to Earth from the Moon across the 384,000 km distance.

Lunar resources include minerals and volatiles embedded in lunar regolith. Six lunar power stations (LPS) can be built on the nearside residing along the eastern and western limbs of the Moon to collect 130 TW of solar energy for the delivery of 20 TW of electrical energy on Earth (assuming a total end-to-end efficiency of 15%). These power stations can provide the total equivalent of a 174 km diameter solar array area (95,900 km2 area). Conversion to microwave can be accomplished through magnetrons, which is a microwave amplifier vacuum tube. A minimum of three Earth rectenna stations at 120° apart are required due to Earth's spin to ensure continuous power generation. The lunar power station eliminates issues with the structural stability of large structures implied by large SPS.

The use of lunar resources for energy on the Moon is necessary for various lunar development activities, such as science stations, lunar resource processing, and tourism. The presence of water at the poles allows for propellant production; furthermore, the availability of raw materials, such as silicon, for the fabrication of thin film solar cells directly on the surface of the Moon, negates the need for transporting and installing solar cells from Earth. The on-Moon fabrication process would result in an electric power system that is repairable/replaceable through the simple fabrication of more solar cells and allows for the expansive use of the Moon [24].

5.2. Mars – The Next Frontier for Multiplanetary Species

5.2.1. Availability of Water

NASA's Mariner 9 mission observed potential river channels originating in chaotic terrain on Mars [40], flowing northward into the Chryse region, potentially resulting from permafrost melting. Equatorial regions exhibit dendritic channel networks, hinting at rainwater collection, while larger sinuous rivers lack identifiable sources. Potential water sources on Mars include liquid water on or below the surface, water ice in polar caps, and surface or subsurface ice in high-latitude areas [25]. In 2008, the Phoenix Mars Lander discovered subsurface ice in the northern hemisphere. No potential 'Oasis' Regions with water presence have been identified. The "circumpolar region" beyond polar caps may contain ice. The planet may have formerly had liquid water, distributed throughout a chilly, dry climate regime and fed by subterranean sources, according to a number of other geological features and observations [28]. Missions like Mars Odyssey and Mars Reconnaissance Orbiter contribute significant data on water vapor, subsurface ice, and mineral composition, shedding light on Mars' water content [46]. Detailed examinations by rovers like Curiosity and Perseverance identify hydrated minerals, indicating past water activity. Mars undergoes an intricate water cycle, engaging both surface and subterranean reservoirs. The primary means of water transport is through the sublimation of surface ice, followed by condensation and precipitation in polar regions [42]. Mars exhibits characteristics stemming from surface runoff and groundwater seepage, some dating back a million years. Recent observations from orbit and direct measurements suggest that aquifers beneath Mars' surface may play a significant role as a water source [42].

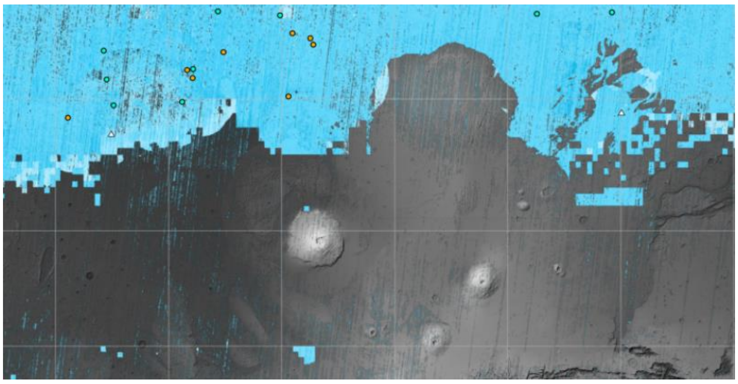


Figure-5 Water Identification on Mars [Image Courtesy: NASA]

5.2.2. Mineral and Salt Traces

Remote sensing and on-site measurements by rovers and landers have revealed minerals on the Martian surface, such as clays, sulfates, and carbonates, suggesting the past presence of liquid water and a more favorable climate. Additional findings include widespread pyroxene and distributed olivine across the Martian crust, as well as abundant silica discovered by the Mars Exploration Rovers (MERs) [17].

The identification of hydrated sulfates like kieserite and gypsum, often in conjunction with hematite, implies the past ubiquity of acidic saline waters on Mars. Carbonate minerals hint at remnants of more temperate temperatures during Mars' Noachian epoch (3.5 billion years ago), requiring liquid water and a moderate level of carbon dioxide. Opaline silica, likely formed through feldspar weathering or volcanic ash diagenesis, indicates a role of neutral or alkaline fluids in modifying basaltic rocks [56].

Research on Mars' evaporating salty waters revealed unique saline mineral assemblages and lower precipitation values for minerals like halite compared to Earth. The presence of halite suggests extremely high salinity and uninhabitable brines. Anion abundances in dilute evaporating liquids significantly influence a H_2O [56]. The ultimate source of main anions in Martian brines is volcanic degassing.

Studies on hygroscopic salts in Martian soils raised the prospect of life [12]. Similar to the Atacama Desert, where enormous halite evaporites provide a habitat, the deliquescence of these minerals on Mars may offer microorganisms a temporary source of liquid water. Modeling environments with evaporites containing chloride salts, research focused on the aw of deliquescence solutions of magnesium chloride, calcium chloride, and sodium chloride, suggesting that hygroscopic minerals like chloride salts could liquefy on the Martian surface, providing microbes a limited source of liquid water. This process mirrors observations in the Atacama Desert where hygroscopic salts create a habitat for microbes exploiting deliquescence at specific relative humidity values.

5.2.3. Organic Molecules

Scientific progress in astrobiology has stemmed from the detection of organic chemicals on Mars, facilitated by the Sample Analysis at Mars (SAM). The unequivocal demonstration of thiophenic, aromatic, and aliphatic compounds in drill samples from Mars' Gale crater has significant implications [55]. The discovery of organic compounds not only fuels the exploration for Martian life but also enhances our comprehension of its geological and environmental history. These organic molecules might have originated abiotically on the Martian surface, arrived from space, or been produced by past or present Martian life.

The significance of organic carbon, considering that all known life is carbon-based, particularly organic carbon, is pivotal in the context of Martian life exploration. Despite Mars harboring a substantial amount of carbon, this carbon is not life-related [17]. It manifests as surface carbonate minerals and atmospheric carbon dioxide. The Mars Chemical Detector (MOD), part of the MOD/MOI instrument suite, searches for specific chemical compounds, including amino acids and polycyclic aromatic hydrocarbons [5]. The instrument is designed to detect trace amounts of particular organic compounds like nucleobases, carboxylic acids, polycyclic aromatic hydrocarbons, and amino acids. Tested under Mars-like conditions, the MOD/MOI package has demonstrated flawless functionality in extreme environments, providing composition and chirality analyses of samples containing 10 parts per billion amino acids, even though concrete evidence of organic molecules on Mars is currently lacking [5].

5.2.4. Atomospheric Habitability

In contrast to Earth, Mars possesses a relatively thin atmosphere primarily composed of carbon dioxide (CO2), significantly less dense than Earth's atmosphere [42]. This thin atmosphere provides minimal shelter from the Sun's radiation, resulting in a much colder Martian surface. While there are limitations to sustaining a complete terrestrial environment on Mars, no insurmountable barrier has been identified. The absence of atmospheric oxygen poses challenges for human habitation, and organisms face lethal levels of UV radiation. However, there is potential for certain anaerobic, cold-adapted bacteria to thrive on Mars [4]. Creating an oxygenated, ozone-rich atmosphere using photosynthetic organisms is conceivable, albeit a process that might span several million years.

The average surface pressure near the equator is around 600 pascals, significantly lower than Earth's 101,325 pascals [1]. Carbon dioxide (CO_2) and nitrogen (N_2) constitute the majority of Mars' atmosphere, with traces of argon, neon, oxygen, and methane. The partial pressures of carbon dioxide (CO_2) and nitrogen (N_2) in

Mars' atmosphere are 20–200 kPa and 0.2–30 kPa, respectively [42]. Methane's presence raises intriguing possibilities for subsurface ecosystems and life sustainability on Mars, suggesting both abiotic and biological sources [60]. Furthermore, the existence of methane raises the prospect of redox gradients sustaining life and habitability on Mars, regardless of the route responsible for producing methane on the planet.

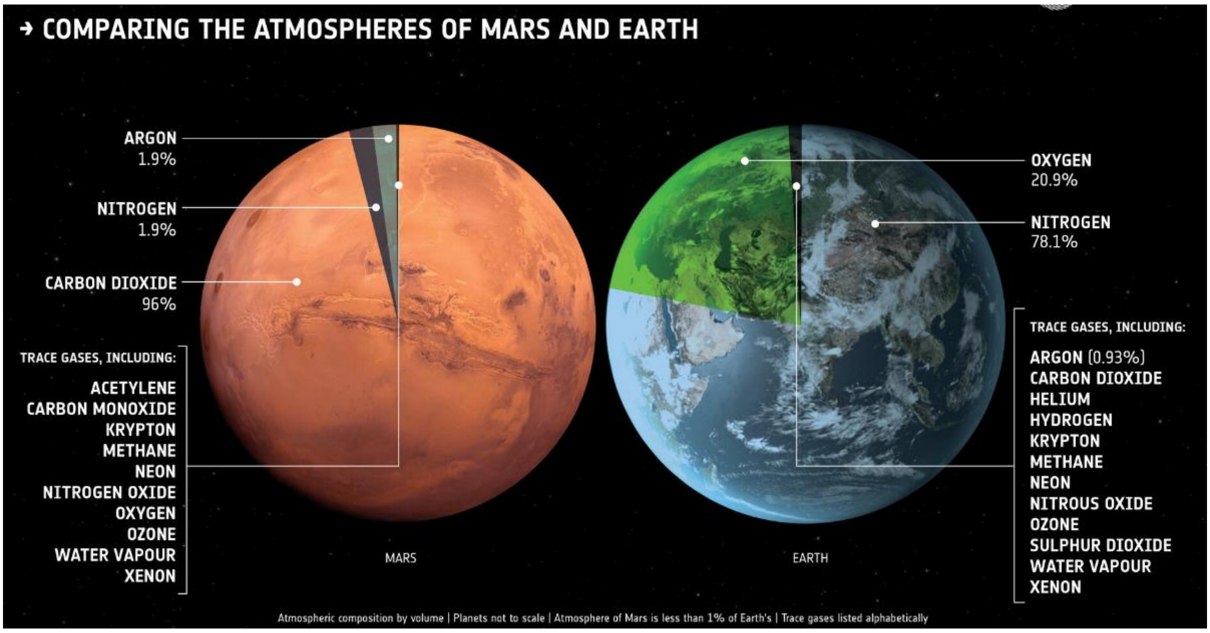


Figure-6 Comparison of Earth and Mars Atmosphere [Image Courtesy: European Space Agency]

5.2.5. Energy Sources

Sunlight serves as the primary and practically sole large-scale energy source on Mars. Despite abundant solar energy during the day, reliance on photosynthesis is limited due to the thin atmosphere, resulting in elevated surface radiation levels [4]. Wind energy emerges as a practical alternative to traditional energy sources on Mars, offering a potential solution for sustained power during extended missions. The thin Martian atmosphere results in significantly higher wind speeds compared to Earth, establishing it as a feasible option for a renewable energy source [1].

5.3. Europa

5.3.1. Availability of Water

The subsurface ocean may contain twice the volume of Earth's oceans combined. Additionally, evidence indicates that the moon's ice shell may be composed of a mixture of water ice and magnesium sulfate [39]. The potential impact of tidal heating on Europa's ice shell is the generation and transport of liquid water through the ice shell, which may result in the formation of water reservoirs and transient water lenses at shallow depths. However, the thermal/gravitational stability of these water reservoirs is uncertain. The presence of liquid water within the ice shell a few kilometers below the surface may result from enhanced tidal heating [27]. The formation of lenticulae on Europa may provide insights into heat and mass transport processes within Europa's ice shell because it could include possible liquid water transport from the underlying ocean to the surface and near-surface of the ice shell [37].

5.3.2. Mineral and Salt Traces

The presence of endogenous sodium chloride on the surface of Europa suggests that there may be an interior source for this material, which has important implications for our understanding of its subsurface chemistry [57]. Certain minerals or molecules, such as hydrated salt minerals rich in magnesium and sodium sulfates or mixtures of hydrated salts and sulfuric acid, which may include sulfate hydrates, are present on Europa's surface. These substances may be crucial to the makeup of the oceanic water beneath the surface or may solidify at the base of the crust [13]. When solutions of high pH freeze, brucite ($Mg(OH)_2$) is expected to precipitate out as Mg^{2+} is consumed to form $Mg(OH)_2$. The remaining Na^+, Cl^-, and $SO4^{2-}$ form either mirabilite ($Na_2SO_4 \cdot 10H_2O$), if Na^+ is the limiting ion, or epsomite/meridianiite ($MgSO_4 \cdot nH_2O$), if SO_4^{2-} is the limiting ion, or a combination of these salts in different ratios, depending on the solution's initial concentrations [26]. On the other hand, when solutions of low pH (< 8.4) freeze, only mirabilite or a mixture of mirabilite and epsomite/meridianiite are expected to form because there is no Mg^{2+} to form brucite as all the Mg^{2+} had already precipitated out in a higher pH environment. Cl^- ions form $NaCl \cdot 2H_2O$, which is not expected to be detectable by Raman spectroscopy. $H_2SO_4 \cdot 8H_2O$ is formed when H^+ ions uptake SO_4^{2-},and $HCl \cdot 6H_2O$ can be formed when H^+ ions uptake Cl^- ions **[26]**.

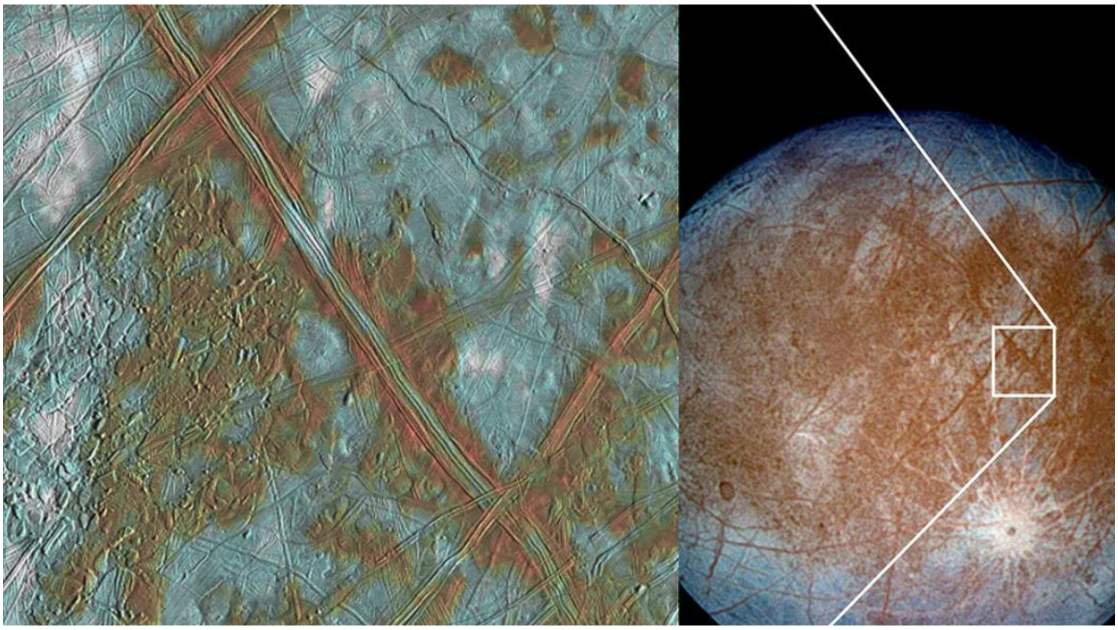


Figure-7 Water Ice on Europa discovered by Galileo Spacecraft [Image Courtesy: NASA]

5.3.3. Organic Molecules

The results of numerical modeling suggest that hydrogen peroxide and other oxidants can be formed through the radiolysis of ice by high-energy electrons and ions. The paper also mentions that the oxidants and reductants that can affect Europa's oceanic redox conditions are incompletely constrained **[20]**. The subsurface ocean is believed to be in contact with its rocky mantle, which would provide dissolved salts and inorganic material including phosphates and nitrites. The availability of phosphates is important for the formation of organic molecules such as nucleic acids, whereas the availability of nitrites may be used as a source of metabolic energy for organisms. In addition, salts, which are ubiquitous in the oceans of Earth, are considered fundamental for the existence of life. Salts stabilize biological macromolecules and provide other critical functions, including the maintenance of osmotic balance and the regulation of ion concentrations. Organic matter with molecular masses above 200 u and smaller reactive nitrogen- and oxygen-bearing molecules were found in the plumes of Enceladus by the Cassini-Huygens mission. Europa is thought to have similar plumes containing organic molecules, which will be studied by the upcoming Europa Clipper mission **[49]**.

5.3.4. Atomospheric Habitability

Jupiter's hazardous radiation environment may be somewhat shielded from Europa's powerful magnetic field. The existence of oxygen and hydrogen on Europa may provide crucial hints in the hunt for extraterrestrial life. Microbes may be able to obtain energy from hydrogen, and one of the main results of photosynthesis is thought to be oxygen **[58]**.

Large CO_2 and SO_2 absorption bands, as well as lesser H_2O_2 bands, were found by the Galileo spacecraft observations of Europa's anti-Jovian and trailing sides. The computed band depth distribution revealed that although SO_2 has a similar sparse distribution to CO_2, it is not always connected with the latter. Instead, CO_2 is strongly related to dark patches on the surface. The correlation between CO_2 and the hydrates could point to a CO_2-rich ocean, which would be a favorable habitat for creatures that would flourish close to the rock-ocean interface and resemble the planet's primordial life **[19]**.

The formation of brines **[26]** in the ocean, the existence of which is linked to the availability of Na^+, Cl^-, Mg^{2+}, and $SO4^{2-}$, can potentially support life through various metabolic pathways such as methanogenesis or sulfate reduction. Additionally, the presence of brines on Europa's ocean floor could create a more stable environment for life, which can be shielded from radiation and other environmental stresses.

5.3.5. Energy Sources

The habitability of Europa's subsurface ocean increases greatly if there is thermal activity, such as volcanism, occurring at the underlying rock-water interface. The addition of tidal heating in the silicate interior caused by the resonance with Io and Ganymede increases the potential for volcanic activity, and hence habitability, with its implications for life. Europa's silicate interior is supposed to have a heat source in the form of radiogenic nuclides, but depths to silicate solidus temperatures would be hundreds of kilometers deep if it is the only heat source. Constraining the heat flow from the silicate interior can be used as a proxy for habitability by discriminating heat flow regimes [14].

5.4. Titan

5.4.1. Availability of Water

Titan is internally differentiated, with a subterranean ocean of liquid water, a high-pressure layer of water ice underneath the ocean, and a solid outer ice shell or crust, according to observations made by the Cassini-Huygens mission. The solid core, which consists of rock or a mix of rock and ice, is separated from the other layers. Particularly at shallow levels, the outer ice shell is primarily made up of Ih water ice, which is probably combined with methane hydrate [11]. Titan's ocean is located beneath its organic-covered ice crust and is likely made up of water and various dissolved salts and other materials. The thickness of the crust above the ocean is estimated to be 50-200 km, and the oceanic depth is estimated to be 500-700 km. The presence of salts or ammonia may explain the ocean's high density, but magnesium sulfate is also a potential solution. It is unknown whether there is direct contact between the ocean and the silicate core, or if a layer of high-pressure ice separates them, but recent research suggests that convection can move material through the ice layer, including salts and volatiles [35].

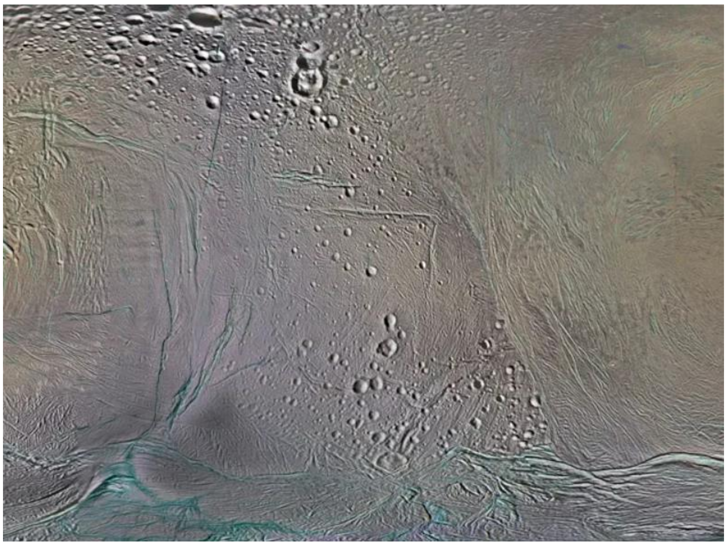


Figure-8 Surface of Titan showing the traces of water and organic molecules [Image Courtesy: NASA]

5.4.2. Mineral and Salt Traces

Titan's ocean is possibly made up of water and various dissolved salts and other materials, such as ammonia, sulfates, and nitrates. However, the specific minerals or salts present in the ocean are still unknown [35]. Acetonitrile, an industrially useful mineral expected to be found on Titan, can persist in its high-temperature form at low temperatures, making it a viable mineral species for Titan's surface [10].

5.4.3. Organic Molecules

Titan's deep subterranean ocean receives and expels a significant amount of biological matter. Rivers and other geological formations are created by liquid and solid hydrocarbons [11]. Similar to Earth, Titan has an active hydrological cycle that involves substances like ethane and methane. The molecules condense out in Titan's nitrogen-dominated atmosphere, rising to the surface as precipitation and flowing as liquids or depositing as sediments. In Titan's polar regions, the liquid organics create rivers, which eventually lead to the formation of liquid bodies like lakes and seas. For thousands to hundreds of millennia, these lakes and oceans have remained constant. Nitrogen and methane in the atmosphere are converted into more complex molecules through a series of chemical reactions that are driven by energy from the Sun and Saturn's magnetic field. These chemical processes lead to the formation of a wide range of organic molecules, including tholins, amino acids, and other complex organic compounds. Tholins are thought to be important building blocks of life, as they contain carbon, hydrogen, nitrogen, and oxygen, which are essential elements for life as we know it **[44]**. Recent studies indicate that Titan's global subsurface ocean may also be in contact with the rock core, potentially providing further elements critical for a habitable environment. Therefore, there is a possibility that the organic molecules on Titan could lead to even greater molecular complexity and potentially the most complex organic building blocks of life.

Considering the ubiquity of methane on Titan, reductants and carbon compounds could be available in the ocean. The bigger question is whether there are sufficient sources of oxidants in the ocean. Moreover, the presence of radiogenic 40Ar in the atmosphere shows that transport from the subsurface has occurred, and geophysical data suggest the presence of a salty water ocean in the interior. On the other hand, regarding the source of nitrogen and methane, nitrogen comes from two sources: ammonia and primordial C-H-O-N-S organic matter, materials that would have been accreted if Titan formed from comet-like icy planetesimals at temperatures of 70-100 K. Ammonia could have been converted to N_2 via early atmospheric photochemistry, shock chemistry from comet impacts, and heating of ammonium-bearing minerals in Titan's core. Regarding the source of methane on Titan, it is still uncertain whether it is primordial or produced internally **[20]**.

5.4.4. Atomospheric Habitability

Hydrogen cyanide, ethane, methane, and other organic molecules were observed in Titan's atmosphere, which are important for understanding the moon's habitability potential **[54]**. Titan's atmosphere is mostly composed of nitrogen and contains a small percentage of methane. Its surface conditions, with a pressure of 0.15 MPa and a temperature of 94 K, are such that methane and ethane exist in liquid form, forming lakes and seas predominantly located at the north pole **[51]**. The study suggests that proteins originating from Earth can potentially retain their structural stability even under extreme environmental conditions similar to those found in Titan's subsurface ocean, where the presence of ammonia might make survival feasible. However, it is important to note that these are simulated results, and further research is needed to determine if this could be the actual case **[38]**.

The atmosphere of Titan, Saturn's largest moon, primarily consists of nitrogen (N_2) and methane (CH_4). Methane is a key molecule in Titan's atmosphere as it acts as a precursor to the production of more complex organic molecules and aerosols. Sunlight and energetic particles in the region lead to methane photolysis, which initiates a series of chemical reactions that eventually lead to the formation of a wide range of hydrocarbons and other organic molecules. The abundance of various molecules, including those involved in the production of complex organic molecules, can be used to understand the photochemical processes that occur in the atmosphere of Titan. For example, the paper discusses the abundances of several molecules such as HC_3N, C_6H_6, C_4H_2, C_3H_4, HCN, C_2H_2, C_2H_6, and C_3H_8 and their distributions. The study provides a comparison of the abundance profiles of these molecules in different latitudes of Titan, indicating the influence of photochemical production and destruction mechanisms. The abundance of these molecules also varies with time, indicating the seasonal changes in the atmosphere of Titan. This suggests that the photochemistry in the outer solar system can be complex and dynamic, and understanding it is essential to determine how organic molecules form and evolve in Titan's atmosphere over time **[41]**. The distribution of these features near its polar regions suggests their dependence on specific factors, such as temperature, precipitation, and subsurface processes. The interactions between hydrocarbon bodies and regolith play a significant role in the moon's geology, chemistry, and climate. Ultimately, the study provides valuable insights into the unique and complex characteristics of Titan **[22]**.

Titan is an ocean world, an icy world, and an organic world. It is the only natural satellite in the solar system with a significant atmosphere and has an active hydrological cycle similar to Earth. Compounds such as methane and ethane condense out of Titan's nitrogen-dominated atmosphere, together with trace amounts of other organics, reaching the surface as rainfall and flowing as liquids or depositing as sediments. The liquid organics form rivers and eventually liquid bodies such as lakes and seas, while the solid hydrocarbon deposits form geological constructs such as dunes, mesas, and evaporite deposits **[11]**.

5.4.5. Energy Sources

Titan is known to have liquid hydrocarbon lakes and seas on its surface, including ethane and methane. These hydrocarbon oceans may provide fuel or energy for upcoming space research missions, according to some scientists. Additionally, the atmospheric composition of Titan is of significant interest, as it contains a complex mixture of molecules, including nitrogen, methane, and other organic compounds that could shed light on the origin of life in the outer solar system [39].

Titan's geological activity is mainly driven by the tidal interaction between Titan and Saturn, as well as internal heat sources within the moon, including radiogenic heating, core differentiation, and exothermic chemical reactions such as methane clathrate dissociation. Geological processes such as cryovolcanism, tectonism, and erosion have been observed on Titan's surface in the form of features such as mountains, channels, dune fields, and impact craters [51]. The large seas Kraken and Ligeia have the potential for being effective sources of hydropower. Wind power, particularly at altitudes of 40 km, is expected to be productive. Despite the distance from the sun and the absorbing atmosphere, solar power is (as on Earth) an extremely efficient source of power on Titan. Nuclear power sources brought to Titan from Earth would last several decades, and material can be extracted from silicate rocks. It is estimated that about 50% of Titan's mass is silicates. Radiogenic argon (Ar) in Titan's atmosphere, likely a product of decay of potassium-40 in the interior, has also been observed by the Huygens GCMS and the Cassini Orbiter Ion and Neutral Mass Spectrometer. However, such materials are likely to be deep in the interior, and extraction of radioactive materials would require significant effort and energy [23].

Below is the tabular description of the temperature, pressure, and density of each celestial body that has been mentioned and discussed.

Table-1 Description of Temperature, Pressure, and Density of Selected Entities

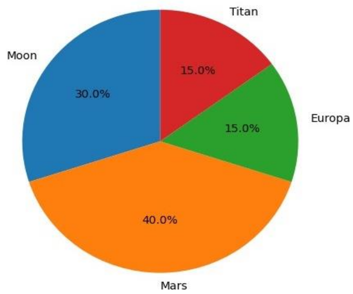
Celestial Body	Temperature	Pressure	Density
Moon	Temperatures at the equator and mid-latitudes of the Moon exhibit wide variations, ranging from -298 degrees Fahrenheit (-183 degrees Celsius) at night to 224 degrees Fahrenheit (106 degrees Celsius) during the day [36].	On the Moon, the atmospheric pressure is approximately $3x10^{-15}$ bar or $2.96x10^{-15}$ atmospheres (atm). In comparison, Earth's average atmospheric pressure at sea level is 1 atm or 1.013 bar. Therefore, the Moon's atmosphere has a surface pressure roughly 14 orders of magnitude lower than Earth's [30].	The highest surface number density of the lunar atmosphere is slightly less than 10^6 particles per cubic centimeter. At night, the surface number density is around $2x10^5$ particles per cubic centimeter, and during the day, it is approximately 10^4 particles per cubic centimeter [30].
Mars	Mars exhibits an average temperature of -80°F (-62°C), with equatorial highs reaching 70°F (20°C) and nighttime lows dropping to -100°F (-73°C). Seasonal variations can be extreme, reaching -378°F (-228°C) in certain latitudes [4,42].	Mars has an atmospheric pressure primarily consisting of carbon dioxide, which is only 1/100th of Earth's. The average surface pressure near the equator is approximately 600 pascals, significantly lower than Earth's standard pressure of 101,325 pascals [1, 4].	Mars' atmospheric density is 1/200th that of Earth, with an average surface pressure of about 6 to 7 millibars, less than 1% of Earth's at sea level [4].
Europa	Europa exhibits global and mean annual surface temperatures of approximately 90 K, 46 K, and 96 K at the pole and equator, respectively [3]. Galileo's thermal emission observations indicate diurnal brightness temperatures between 86 and 132 kelvin at low latitudes [52].	Europa's sparse atmosphere, consisting mainly of molecular oxygen (O_2), was identified by the Galileo spacecraft in 1995. Europa's atmosphere measures at 0.1 micro Pascals, which is approximately 10^{12} times Earth's surface pressure [59].	Compared to the other Galilean moons, Europa has a slightly lower mean density of 3.01 ± 0.005 g/cm³ [59].
Titan	The temperature range is notably extensive between 500 km and 1,020 km, reaching a minimum of 152 K at 490 km altitude and rising to 186 K at the stratopause at 250 km. In the region between the upper and lower portions of the stratosphere and mesosphere, temperatures range from 5 to 10 K [18].	Titan's pressure changes with altitude. The Huygens probe measured a pressure of 1,496 ± 20 mbar at Titan's surface, which is roughly 1.5 times Earth's average sea level pressure [32].	Titan's average density is 1.881 ± 0.002 g/cm³ [32].

Table-2 Comparison of Rotational, Revolution Period, Gravity, Escape Velocity, and Surface Pressure

Celestial Body	Rotation Period	Revolution Period	Gravity	Escape Velocity	Surface Pressure
Moon	27.3 Days	27 Days	1.62 m/s	2.38 km/s	1 picobar
Mars	24.6 Hours	687 Days	3.71 m/s	5.02 km/s	0.0062 atm
Europa	3.5 Days	4333 Days	1.31 m/s	2.02 km/s	0.1 micro pascal
Titan	16 Days	10755 Days	1.35 m/s	2.64 km/s	1.45 atm

6. Discussions and Limitations

Based on the researched and assembled data, an estimation has been made to assess the feasibility of manned missions to various celestial bodies. Several crucial factors were considered in this analysis, including temperature, atmospheric density and pressure, gravity, distance, and others.



Figrue-9 Potentiality of Celestial Bodies for Possible Exploration in (%)

According to the graph, Mars emerges as the leading candidate for a manned mission due to its relatively more supportive environment compared to other options, such as the Moon. Mars boasts a combination of factors, including pressure, density, gravity, and temperature, which make it more conducive to human presence. However, the Moon holds an advantage in terms of proximity and cost-effectiveness.

Europa and Titan, while sharing some similarities in convenience, differ significantly across various categories. Titan falls behind Europa in terms of distance, temperature, and overall environmental conditions. However, Europa exhibits lower values in terms of gravity, density, and pressure compared to Titan.

It is essential to acknowledge that ongoing research is continuously being conducted on Titan, Europa, and various other celestial bodies. The provided chart offers a rough estimate based on current experimental data, simulations, and information gathered from unmanned space missions. However, our understanding of bodies like Europa remains limited, underscoring the necessity for further studies and upcoming space missions to deepen our knowledge.

7. Limitations

7.1. Mars

Mission constraints encompass factors such as velocity requirements, Earth-to-planet transfer time, stay durations on the planet, human activities during the stay, and propellant loss during the voyage **[33]**. Realistic trajectories must consider these elements. The absence of Earth's magnetic field in the Martian environment leads to significantly higher radiation dosages compared to Earth **[16]**. Without Earth's magnetic protection, there's no refuge or return option in the event of a deadly solar flare. The limited human presence on other planetary bodies makes extended stays on Mars challenging, advocating for the establishment of a lunar base before a manned Mars expedition. With a mission duration of two to three years, ensuring continuous operation of Mars lander and transfer vehicle subsystems is crucial.

Ongoing research in interplanetary transport explores areas like developing propulsion systems for faster interplanetary travel, analyzing space radiation, and designing fuel-efficient trajectories. The need for further study and development, particularly in photonics, optoelectronics, and aeronautical electronics, is emphasized **[33]**. Ensuring systems with measurable and predictable failure probabilities is crucial, necessitating a comprehensive review and re-evaluation of the strategy for mission safety. The study underscores the need for a fresh approach to address methodological and challenging issues arising during such missions **[48]**.

7.2. Europa

NASA desires that a Europa mission be able to characterize hazards for a potential future lander mission. This is desirable because current data does not provide sufficient information to identify hazards to such a mission or to design a landing system capable of safely reaching the surface. The reconnaissance objectives recommended by the SDT are twofold, emphasizing engineering and science respectively: Assess the distribution of surface hazards, the load-bearing capacity of the surface, the structure of the subsurface, and the regolith thickness. Assess the composition of surface materials, the geologic context of the surface, the potential for geologic activity, the proximity of near-surface water, and the potential for active upwelling of ocean material. The Europa Clipper mission will address these challenges through its payload that helps fulfill the science objectives.

Gravity measurements will provide valuable information for determining the habitability potential of Europa's subsurface ocean. A global gravity model from a future Europa orbiter would be ideal, but a multiple-flyby mission could still contribute significantly. Small gravity anomalies less than 250 mGal may point to higher heat flows from Europa's silicate interior, increasing the potential for habitability within Europa's ocean. Conversely, measurements of strong anomalies in excess of 250 mGal would imply low heat flows, reducing the potential for habitability, but a future orbiter would be required to confirm these conclusions. Thus, gravity measurements of Europa should be given high priority in future mission planning.

Future spacecraft investigation of Europa, including any manned trips, will benefit from the measurements of the surface topography, which may be affected by the research of water generation beneath Europa's faults. Our understanding of how water and melt are produced and carried beneath Europa's faults may be improved by the spacecraft's comprehensive mapping of the surface topography and fresh, high-quality observations of the moon's interior and surface. Planning a manned expedition and deciding where to land on the moon's icy surface to increase the likelihood of discovering signs of life beneath the ice might benefit from this knowledge.

8. Conclusion

A comprehensive review was conducted by incorporating several studies to highlight celestial bodies offering unique features for manned space exploration. The paper provided a concise yet significant explanation, emphasizing the declining trend in manned missions to specific astronomical bodies. Despite a substantial increase in unmanned missions and their ongoing progress to gain deeper insights into various celestial bodies, planning for human exploration on these bodies is still in progress. The importance of human life safety in manned missions was briefly touched upon.

The available data from unmanned missions painted a picture of potential celestial bodies, some of which were detailed in this paper as the best fit for the trend. The primary goal has been to study and compile a list of possible celestial bodies that could enhance human space exploration. The paper outlined notable celestial bodies, classifying them based on environmental factors, resource availability, feasibility, and more. Numerous possibilities still exist for planets or moons that may contribute to exploration, aiding in our understanding of the solar system and utilizing resources for manned missions in the near future **[62-66]**.

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10. Biography

Kritik, an individual with a strong passion for astrophysics and particle physics, has demonstrated a profound dedication to his field of interest. Originating from Bangalore, Karnataka, India, Kritik showcased his commitment through a notable accomplishment - the successful completion of an internship at Acceleron Aerospace. During this internship, he conducted pioneering research on "Interplanetary Spacecraft Failure Study: Analyzing Trends and Patterns." Kritik's research article displayed his dedication, analytical prowess, and meticulous attention to detail. His work is poised to make a substantial contribution to the realm of space exploration, reflecting his intellectual curiosity and potential for future advancements.

Nikhil Pratap Singh Bharti, a student at Gautam Buddha University, is a diligent individual with a passion for research and exploration. During his tenure as a Research Intern and Trainee at Ethical Edufabrica Pvt. Ltd, he contributed to various projects, showcasing his dedication and skills. Additionally, Nikhil completed the "AstroTech: The Science and Technology behind Astronomical Discovery" certification program from The University of Edinburgh, further enhancing his understanding of astronomy. He also gained practical experience as an intern at Acceleron Aerospace, where he applied his knowledge to real-world aerospace projects. With his enthusiasm and diverse experiences, Nikhil is poised for a successful academic and professional journey.

M. Anto Moses Alexander, a scholar driven by an innate fascination for the cosmos, embarked on his academic journey at St. Columba's School, New Delhi, laying the groundwork for his profound passion for physics. Graduating with distinction in B.Sc. Physics (Honors) with a remarkable CGPA of 7.74, he is currently pursuing M.Sc. in Physics, specializing in astrophysics, at Amity University, Noida. His academic pursuits reflect an unwavering commitment to exploring the intricacies of astrophysical phenomena. With aspirations to obtain a Ph.D. in astrophysics, he aims to contribute meaningfully to the field while nurturing a desire to inspire others to delve into the wonders of the cosmos, thus embodying a relentless pursuit of knowledge and a steadfast dedication to unraveling the mysteries of the universe.

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12. Conflict of Interest

The author declare no competing conflict of interest.

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14. Paper Information

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