

JRCentral

Who Said Is Not Important, What Said Is Important

ELECTROMAGNETISM

STRONG FORCE

WEAK FORCE

GRAVITY

$$Z = \int \mathcal{D}(\text{Fields})$$

$$\exp i \int d^4x \sqrt{-g} [R - F_{\mu\nu} F^{\mu\nu} - G_{\mu\nu} G^{\mu\nu} - W_{\mu\nu} W^{\mu\nu}$$

$$+ \sum_i \bar{\psi}_i \mathcal{D} \psi_i + D_\mu H^\dagger D^\mu H - V(H) - \lambda_{ij} \bar{\psi}_i H \psi_j]$$

MATTER

HIGGS BOSON

THE THEORY OF EVERYTHING
(SO FAR)

PLANETARY

SCIENCE

DECEMBER ISSUE



ACKNOWLEDGEMENT

We are deeply grateful to Prof. (Dr.) Balvinder Shukla, Hon'ble Vice Chancellor, Amity University Uttar Pradesh, for giving us the valuable opportunity to share our project and the vision behind this magazine with her. Her kind encouragement and keen interest in our initiative strengthened our confidence and reminded us of the importance of curiosity and collaboration in research. Her words of appreciation and motivation continue to inspire us to carry this endeavor forward with greater enthusiasm.

We extend our sincere thanks to Dr. W. Selvamurthy, President of Amity Science, Technology and Innovation Foundation & Director General of Amity Directorate of Science and Innovation, for giving his precious time to our magazine. His thoughtful feedback and insightful suggestions helped us refine our initial vision, offering new perspectives on how to take this initiative ahead with clarity and purpose. We deeply value the time, encouragement, and guidance he shared with us at this important beginning.

We also express our heartfelt thanks to Dr. Sanjay Singh, Head of Department, for providing the facilities and a supportive environment that made it possible to bring this idea to fruition. Our deepest gratitude goes to Dr. V. R. Sanal Kumar, whose mentorship, knowledge, and constant encouragement have been invaluable throughout this journey. His guidance has not only shaped the essence of this magazine but also inspired us to approach research and creativity with deeper understanding and purpose.

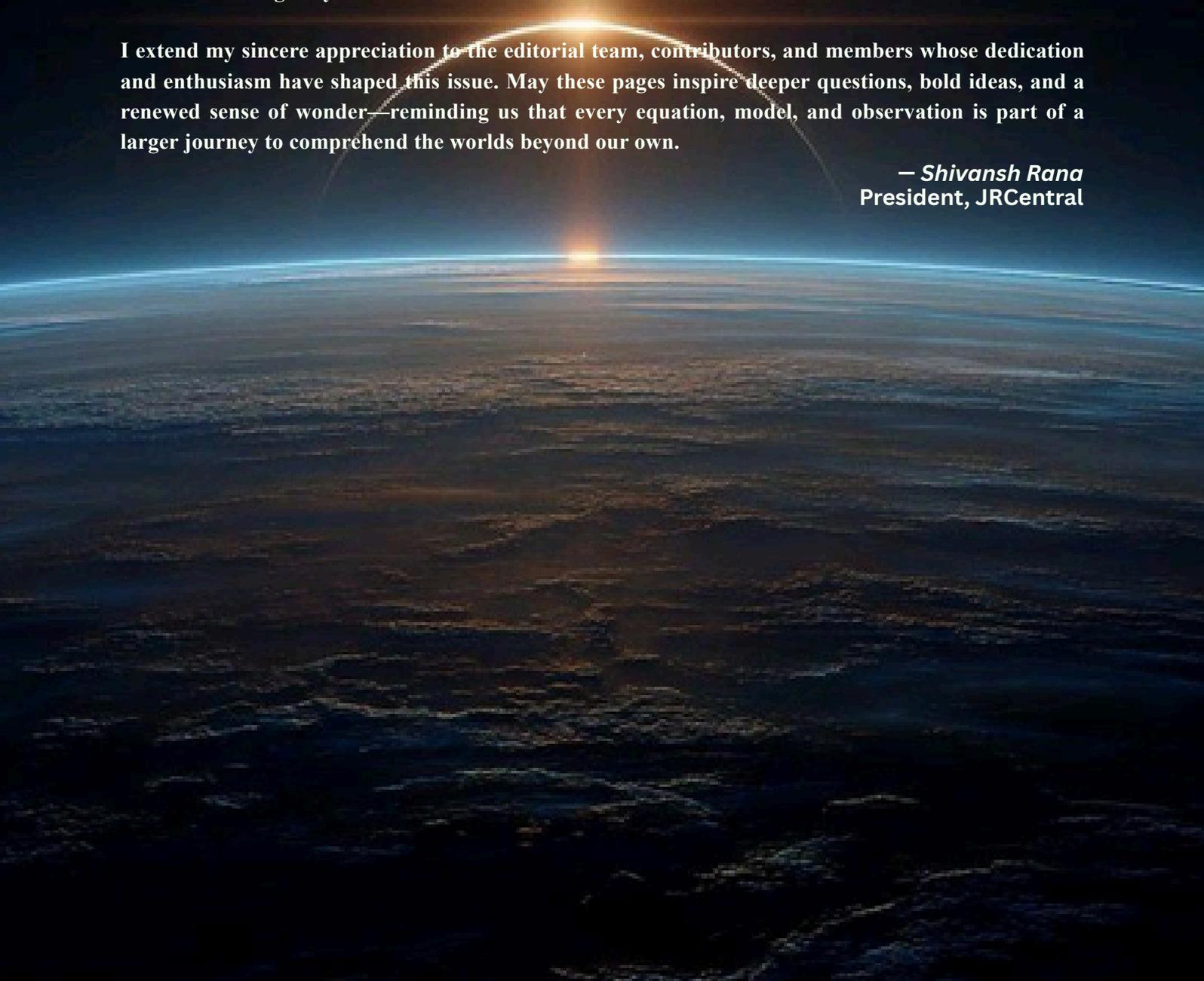
It gives me immense pleasure to present this edition of the Research Club Magazine, dedicated to the fascinating and ever-evolving field of Planetary Sciences. From the silent geology of distant moons to the turbulent atmospheres of gas giants, planetary science represents humanity's enduring quest to understand not only other worlds, but also our own place in the cosmos.

Planetary science sits at a unique crossroads—where physics, chemistry, geology, astronomy, and engineering converge. Each crater, magnetic field, atmospheric plume, or orbital resonance tells a story written over billions of years. As students and researchers of science and engineering, we are inheritors of this grand narrative, using modern tools—space missions, simulations, spectroscopy, and theory—to decode the histories of planets, moons, and planetary systems.

This issue celebrates both curiosity and rigor: the spirit that drives us to ask how planets form, evolve, and sometimes fail—and the discipline required to transform observation into understanding. Whether studying planetary interiors, atmospheric dynamics, magnetospheres, or exoplanetary systems, the work showcased here reflects a shared ambition to push the boundaries of human knowledge beyond Earth.

I extend my sincere appreciation to the editorial team, contributors, and members whose dedication and enthusiasm have shaped this issue. May these pages inspire deeper questions, bold ideas, and a renewed sense of wonder—reminding us that every equation, model, and observation is part of a larger journey to comprehend the worlds beyond our own.

— Shivansh Rana
President, JRCentral



Fire, force, and form—this issue explores the invisible physics that shape worlds, from the Sun's outer atmosphere to the air we breathe on distant planets.

We open with *Solaris: The Promethean Fire*, a journey into the Sun as both creator and disruptor, followed by *The Stalemate: Gravity vs. Pressure*, where equilibrium becomes the quiet architect of stars and planets alike. These ideas come alive in *Touching the Fire: The Parker Era*, which captures humanity's bold attempt to sample the Sun's atmosphere and confront stellar extremes firsthand.

Moving from space to speed, *Taming the Supersonic Inlet* examines how shockwaves and boundary layers govern the performance of high-speed aircraft—reminding us that the same fluid dynamics shaping planetary atmospheres also dictate the limits of human engineering.

Planetary science takes centre stage as we ask: *Why Planets Wear Different Colours?* What appears cosmic and artistic is, in fact, diagnostic—each hue encoding chemistry, temperature, and atmospheric history. This theme continues through *Planetary Volcanism* and *Extreme Planetary Atmospheres*, where internal heat, pressure, and composition define whether a world breathes gently or rages violently.

Our gaze then shifts toward life itself. *Pursuit of Life on Mars* explores how molecular biosignatures preserve whispers of ancient microbial activity, while *Can Planetary Science Influence Human Health?* closes the issue by dissolving boundaries between disciplines—revealing how space science informs medicine, resilience, and survival on Earth.

Together, these stories reveal a unifying truth: the laws governing stars, planets, machines, and biology are deeply interconnected. To understand the universe is not merely to observe it—but to recognize ourselves within its physics.

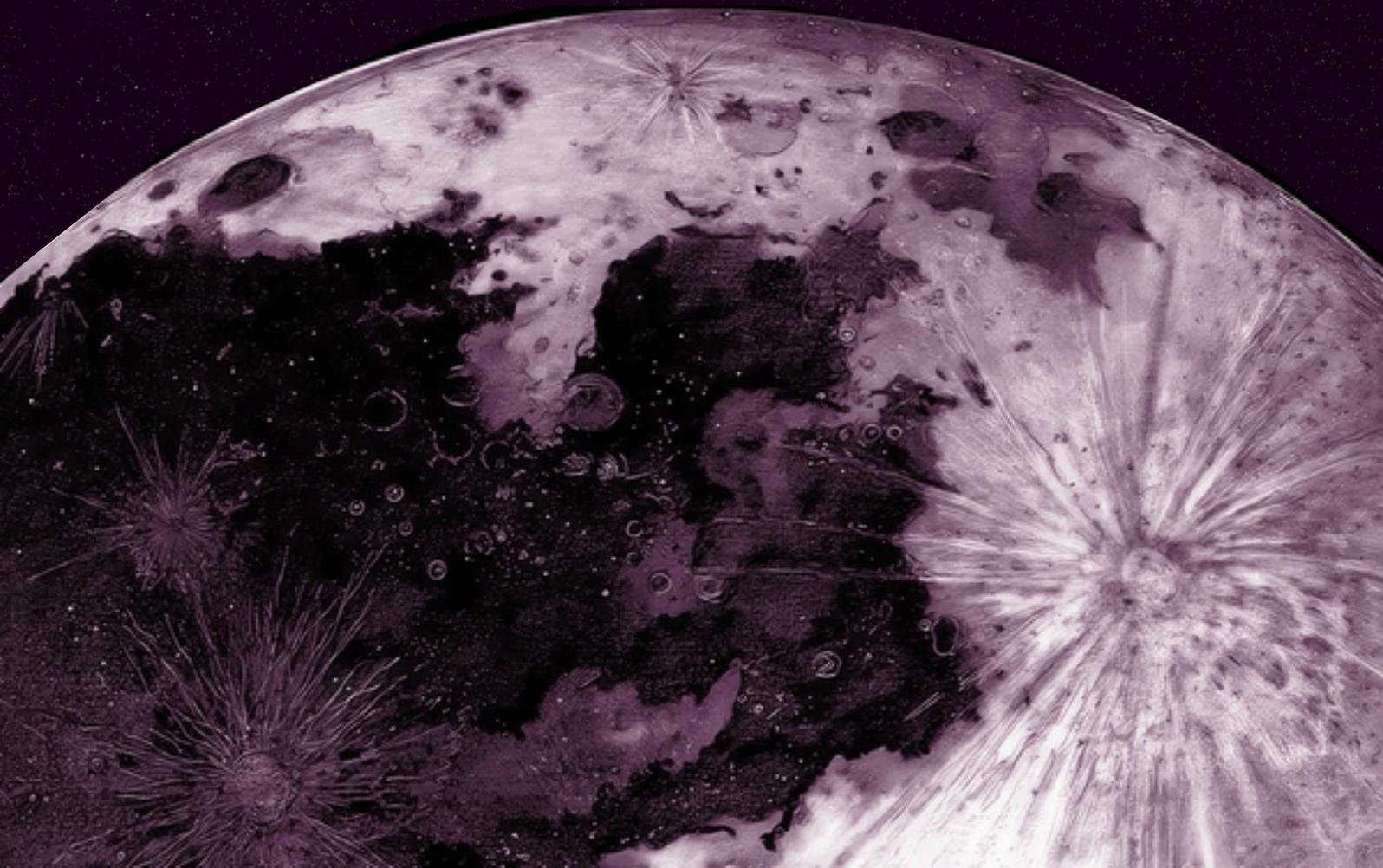
— *Daksha Tuteja*
Editor-in-Chief, JRCentral

In this edition of our Research Club Newsletter, we turn our attention outward — beyond Earth, toward the planets, moons, and systems that quietly hold the history of our universe. Planetary science sits at a beautiful intersection of physics, chemistry, geology, and astronomy, reminding us that every world has a story written in its atmosphere, surface, and motion.

What makes this field so compelling is not just its scale, but its relevance. By studying distant planets and familiar neighbors alike, we learn more about our own origins, climate, and future. Each orbit calculated, each spectrum analyzed, and each mission imagined brings us closer to understanding where we stand in the cosmos.

As always, this magazine reflects the curiosity and dedication of our members — a community unafraid to ask large questions and chase them with rigor and wonder. I'm incredibly proud of the work that went into this edition and excited to see how our shared fascination with the universe continues to grow with every issue we create together.

— *Sameeha Khan*
Head of R&D, JRCentral





ARTICLES

ACHIEVEMENTS

THE ETHICS OF INTERPLANETARY EXPLORATION

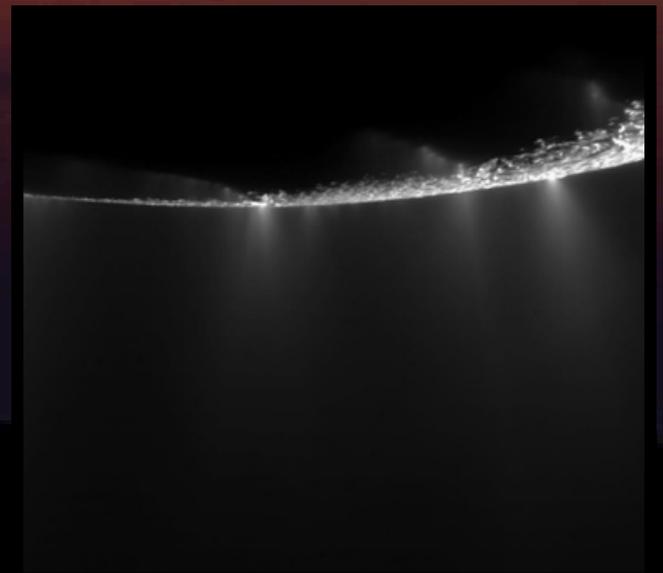
When humanity sends spacecraft to other planets, moons, and asteroids, we carry more than instruments and ambition—we carry ourselves. Invisible hitchhikers such as bacteria, spores, and organic residues from Earth can survive extreme conditions and potentially contaminate alien environments. Preventing this is the goal of planetary protection, a discipline that sits at the intersection of science, ethics, and engineering.

At its core, planetary protection has two purposes. Forward contamination refers to Earth microbes accidentally introduced to another world, which could compromise the search for extraterrestrial life. Backward contamination addresses the opposite concern: protecting Earth from any potentially harmful material returned from space. Together, these safeguards ensure that exploration does not irreversibly alter the very worlds we aim to study.

The rules governing planetary protection are set internationally by the Committee on Space Research (COSPAR), under the Outer Space Treaty of 1967. Planets and moons are classified based on their potential to host life. For example, Mars, Europa, and Enceladus—where liquid water may exist—fall under stricter categories than bodies like the Moon. The higher the chance of habitability, the more rigorous the sterilization requirements.



Panoramic view of Gale Crater on Mars captured by NASA's Curiosity rover, revealing layered terrain formed over billions of years.



Icy water vapor and particles spraying from fractures ("tiger stripes") near the south pole of Enceladus, as imaged by Cassini.

Limits of Sterility and the Future of Planetary Protection

Ethically, planetary protection forces scientists to confront a profound question: Do we have the right to alter another world before understanding it? Introducing Earth life could permanently erase evidence of native biology, if it exists. Even if a planet is lifeless, contaminating it today could mislead future scientists into mistaking earthen microbes for alien ones. Protecting planetary environments is therefore an act of scientific humility as much as caution.

Technologically, keeping spacecraft clean is a major challenge. Space agencies use clean rooms where air is filtered to remove particles and microbes. Spacecraft components are often baked at high temperatures in a process called dry heat microbial reduction, killing resistant bacterial spores. Chemical sterilants, ultraviolet radiation, and plasma cleaning are also used. For especially sensitive missions, engineers carefully select materials that do not harbor microbes easily.

Despite these measures, complete sterility is impossible. Instead, planetary protection aims to reduce contamination to acceptable levels while balancing mission feasibility. As exploration advances toward sample-return missions and human travel to Mars, these challenges will only grow more complex.



Sterilization techniques, including dry heat microbial reduction, plasma cleaning, and UV sterilization, used to keep spacecraft components free of contaminants

SOLARIS: THE PROMETHEAN FIRE

For the greater part of human history, the Sun portrayed itself a divine mystery. It was Apollo's chariot, and Ra's eye. However, by the dawn of the 19th century, it had morphed into a physics problem that threatened the foundations of science. The physicist Lord Kelvin calculated that if the Sun were a burning coal, it would last 5,000 years and if it were collapsing under its own gravity (converting potential energy to heat), it would last around 30 million years. Yet, biologists and geologists remained firm on the notion that the Earth was billions of years old, contrary to the emerging hypotheses. The Sun posed itself a scientific mystery—the solution to which, laid in the newly discovered realm of the atomic nucleus, unearthed in 1939 by Hans Bethe.

The Sun is a fusion and not a fission reactor. It is critical to distinguish the two: A fission reaction works by splitting heavy, unstable atoms like Uranium-235, releasing great amounts of energy and toxic radioactive waste. A fusion reaction, on the other hand—the one that powers the Sun—does the opposite. It takes the lightest element in the universe—hydrogen—and crushes it together to form helium.

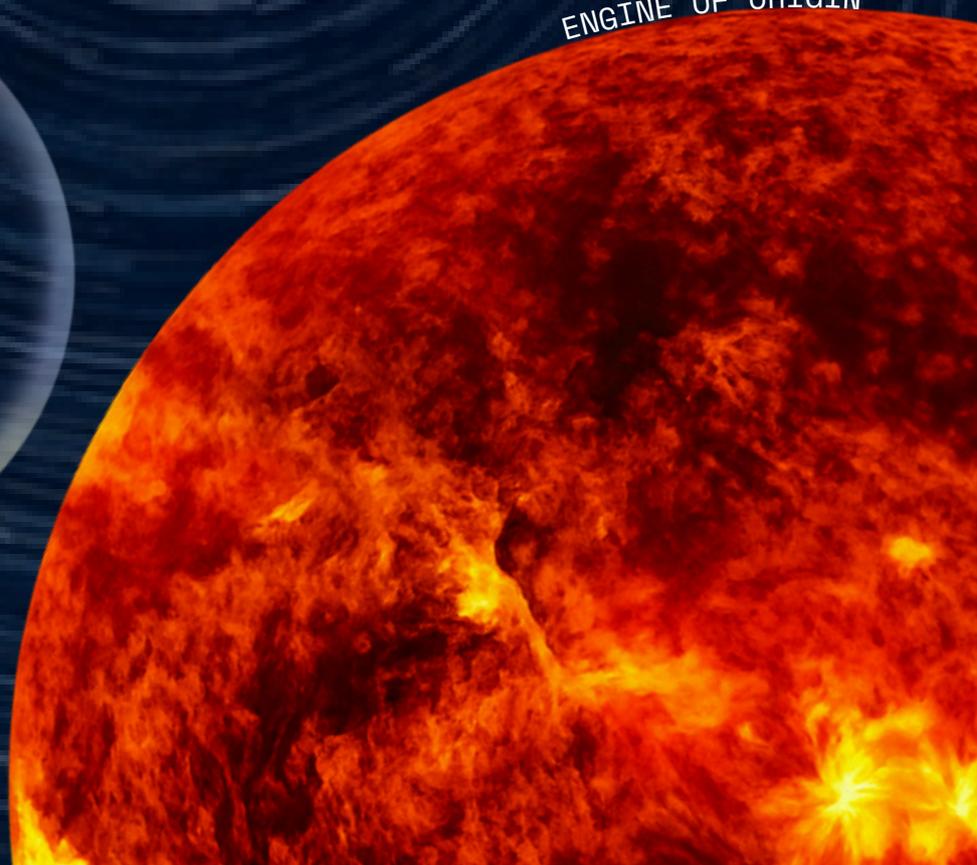
The Proton-Proton Chain :- Deep in the solar core, where temperatures exceed 15.7 million Kelvin and the density is 150 times that of water, hydrogen nuclei (protons) are stripped of their electrons. They move fast enough to overcome the electrostatic repulsion that usually keeps positive charges apart. When they collide, they fuse. This process, known as the p-p chain, converts four protons into one helium nucleus. Crucially, the resulting helium nucleus is 0.7% lighter than the four protons that made it.

Where did the missing mass go? It became pure energy, according to Einstein's famous equation, $E=mc^2$. That tiny 0.7% mass defect is responsible for all the light, heat, and life in the solar system.

The Neutrino Proof

How do we know this is happening? We can't see the core. The proof lies in Neutrinos. These "ghost particles" are a byproduct of fusion. They interact so weakly with matter that they fly instantly out of the Sun and through the Earth. In 2020, the Borexino experiment in Italy detected neutrinos specifically from the Sun's secondary fusion cycle (CNO cycle), confirming Bethe's theory with experimental certainty.

ENGINE OF ORIGIN



THE STALEMATE: GRAVITY VS PRESSURE

To an astrophysicist, a star is not a static object. It is a battlefield locked in a permanent, high-stakes stalemate known as Hydrostatic Equilibrium.

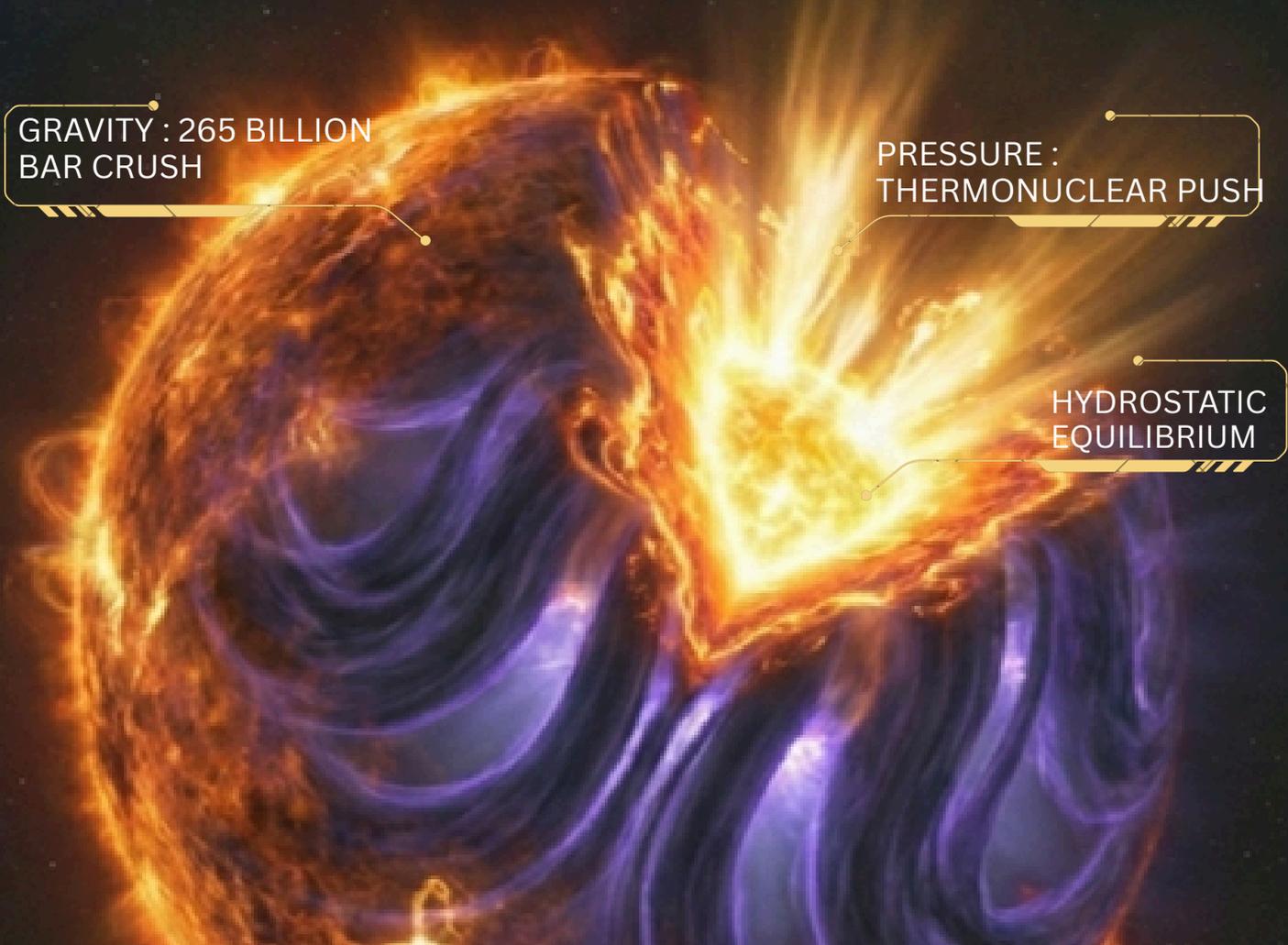
The Aggressor: Gravitational Collapse The Sun contains 99.86% of the total mass of the Solar System. This creates a gravitational field of terrified intensity. Every atom in the Sun is being pulled toward the center. The inward pressure at the core is approximately 265 billion bar (atmospheres). Without a counterforce, this gravity would crush the Sun into a white dwarf in less than an hour.

The Defender: Thermal Pressure The counter-force is the fusion explosion itself. The energy released in the core creates outward Thermal Pressure. The photons (light particles) and the kinetic energy of the gas particles push outward against the crushing weight of the layers above.

The Stability Mechanism: This balance creates a natural thermostat. If the fusion rate drops, the core cools and pressure drops. Gravity wins momentarily, crunching the core tighter. This compression heats the core back up, reigniting the fusion rate. This self-correcting feedback loop ensures the Sun burns at a steady, stable rate for 10 billion years.

THE END OF THE WAR

This war has a time limit. In about 5 billion years, the hydrogen fuel in the core will run exhausted. The outward pressure will falter. Gravity, waiting patiently for eons, will finally win. The core will collapse, heating up enough to fuse helium into carbon, causing the outer layers to swell. The Sun will leave the "Main Sequence" and become a Red Giant, likely consuming the orbit of Earth.



GRAVITY : 265 BILLION
BAR CRUSH

PRESSURE :
THERMONUCLEAR PUSH

HYDROSTATIC
EQUILIBRIUM

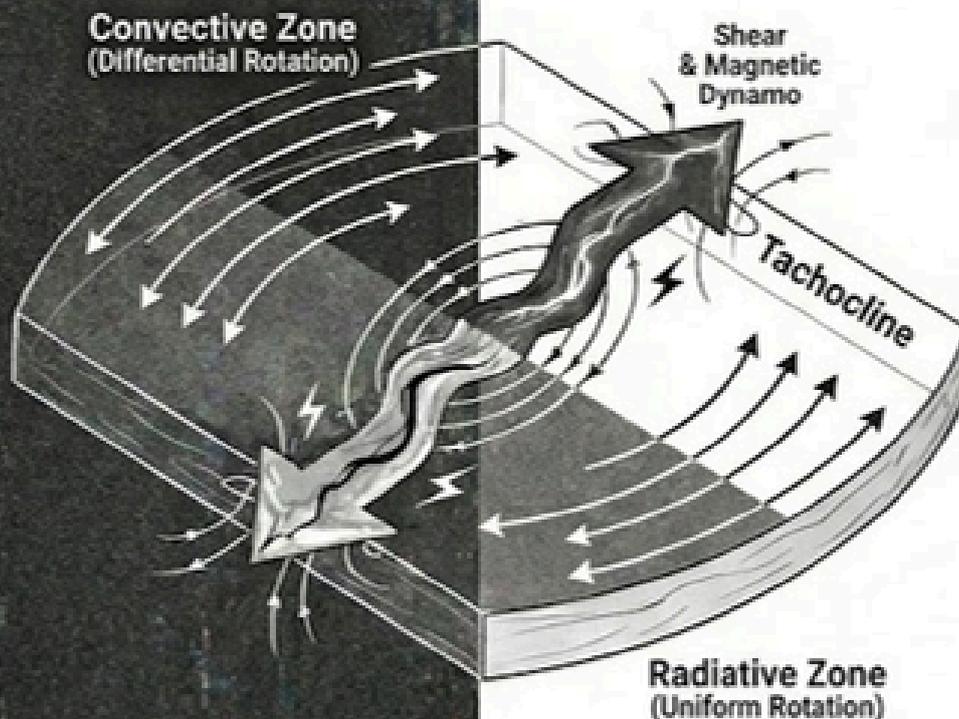
THE TACHOCLINE: WHERE THE DYNAMO SINGS

CONVECTIVE ZONE

The Boiling Pot At 70% of the solar radius, the physics changes. The plasma becomes cool enough to be opaque. Heat can no longer radiate through; it must physically boil upward. Massive columns of hot plasma rise, cool at the surface, and sink back down. This is the Convective Zone.

THE TACHOCLINE: THE SHEAR LAYER

The boundary between these two zones is the most critical engineering feature of the Sun: the Tachocline. The Radiative Zone rotates like a solid body (uniform speed). The Convective Zone rotates differentially (25 days at the equator, 35 days at the poles). The Tachocline is the layer where these two rotation regimes grind against each other. This massive shear force stretches the Sun's magnetic field lines, winding them up like a rubber band ball until they snap. This "Solar Dynamo" is the origin of sunspots, flares, and the space weather that threatens our satellite infrastructure.



Helioseismology—the study of acoustic pressure waves (sound) bouncing inside the Sun—has allowed us to map the solar interior with the precision of a medical MRI.

RADIATIVE ZONE:- THE LONG WALK

Surrounding the core is the Radiative Zone. Here, the plasma is so dense that energy cannot move by convection. Instead, photons must bounce randomly from atom to atom. This "Random Walk" is incredibly inefficient. A photon created in the core takes an average of 170,000 years to stumble its way to the surface. The light hitting your eyes today was generated during the Ice Age.

TOUCHING THE FIRE: THE PARKER ERA

For the entirety of human history, astronomy has been a "remote sensing" science. We could observe the stars, measure their spectra, and calculate their orbits, but we could never touch them. That paradigm shifted forever on December 14, 2021, when NASA officially announced that the Parker Solar Probe (PSP) had successfully "touched the Sun," dipping its sensors beneath the Alfvén critical surface and entering the solar corona.

This was not merely a record-breaking flight; it was a targeted strike against a physics problem that has humiliated scientists for the better part of a century.

The Thermodynamic Paradox: The mission's primary objective was to resolve the "Coronal Heating Mystery." According to the Second Law of Thermodynamics, heat flows from hot objects to cold objects. Therefore, the further you move away from a heat source, the cooler it should get. The Sun, however, defies this law.

The Surface (Photosphere): A relatively cool 5,500°C.

The Atmosphere (Corona): A staggering 1 million degrees Celsius. This is akin to walking away from a campfire and finding that the air suddenly becomes a thousand times hotter than the flames. Physicists knew energy was being transported upward, but the mechanism remained invisible until Parker flew through it.

The Discovery: Magnetic Switchbacks Flying at speeds eventually exceeding 690,000 km/h, the probe discovered the smoking gun: "Switchbacks." identified in Nature as "Alfvénic velocity spikes," these are magnetic field lines that are not straight, but violently kinked in zig-zag shapes. As these magnetic whips propagate through the solar wind, they "snap" back into straight lines via magnetic reconnection. It is this explosive release of kinetic energy that acts as the hidden fuel source, superheating the corona.

Engineering the Impossible:- The spacecraft is a marvel of thermal defense. To survive, it hides behind a Thermal Protection System (TPS)—a 4.5-inch thick shield made of a carbon-carbon composite foam sandwiched between graphite sheets. The engineering stakes are absolute. While the front of the shield roasts at 1,370°C, the instruments in its shadow operate at a comfortable room temperature of 29°C. Because of the communication lag with Earth, the probe uses autonomous limb sensors to constantly adjust its angle; if the shield slips even one degree, the spacecraft would be incinerated in seconds.



SYNCING.....
SCAN TO ACQUIRE
LIVE TRAJECTORY
AND VELOCITY DATA.

MISSION TIMER - T MINUS 5 BILLION YEARS

Inside the Planetary Dynamo: The Role of Magnetostrophic Waves, Core–Mantle Interaction, and Universal Scaling Laws

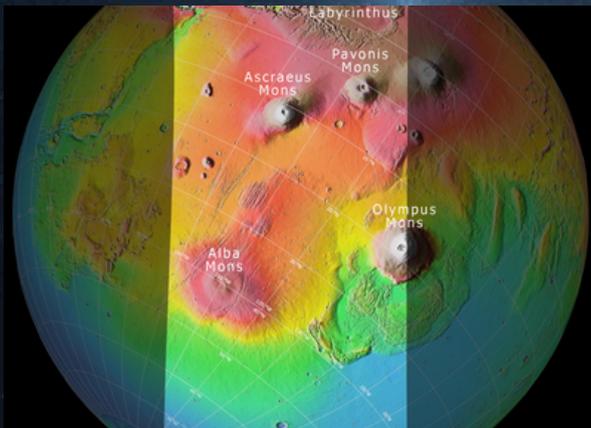


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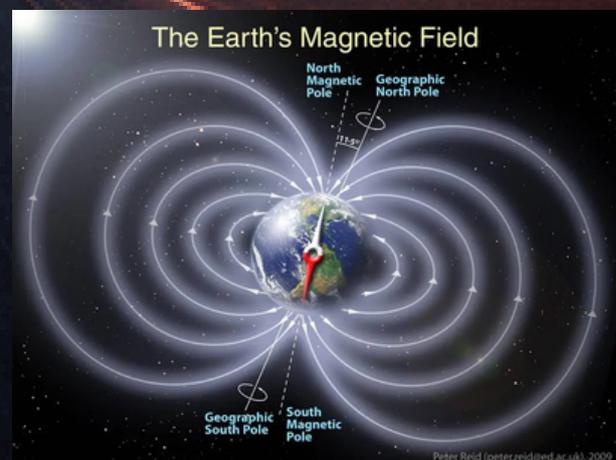
Binod Sreenivasan's research addresses the fundamental problem of how planetary magnetic fields, such as the Earth's, are generated and structured within turbulent, rapidly rotating fluid cores. His work integrates three complementary approaches: laboratory experiments, high-resolution numerical simulations, and asymptotic theory, to dissect the controlling physics of dynamo action.



Topographic view of Mars' Tharsis province
(ESA/NASA MGS/MOLA Science Team, FU Berlin
via ESA multimedia and NASA/JPL data)

His most recent and synthesizing contributions advance a unifying magnetostrophic wave theory. Sreenivasan and collaborators argue that slow, large-scale magnetostrophic waves—not turbulence alone—act as the principal agent for the inverse energy cascade that builds and sustains the axial dipole (Varma & Sreenivasan, PEPI 2022). This culminates in the discovery of a self-similar scaling law for the dipole-multipole transition, suggesting a universal principle for classifying dynamo regimes (Majumder et al., JFM 2024).

A central thread of his investigation focuses on core-mantle interaction, demonstrating through dynamo models how lateral variations in mantle heat flux organize convection and leave lasting imprints on the geomagnetic field (Sahoo & Sreenivasan, EPSL 2020). This framework also provided a geophysically grounded explanation for the cessation of the Martian dynamo, linked to the Tharsis volcanic province (Sreenivasan & Jellinek, EPSL 2012).

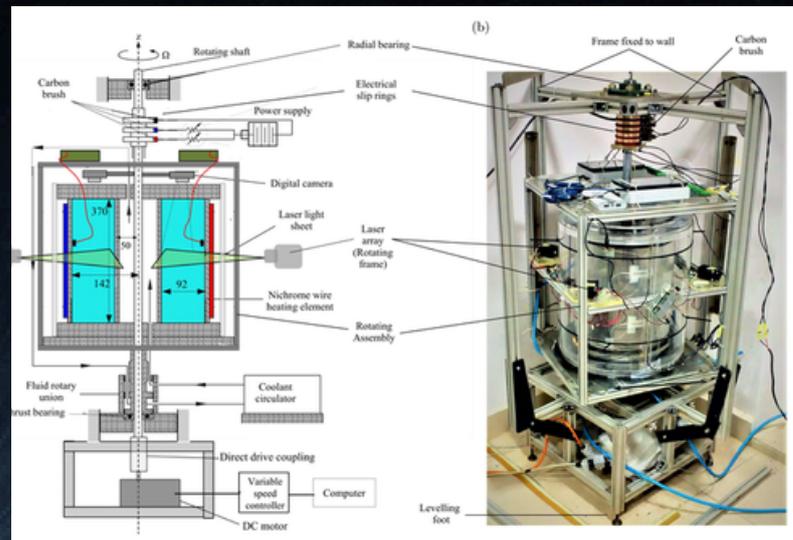


Earth's magnetic field and poles
Peter Reid, University of Edinburgh, 2009

Complementing the theoretical and numerical investigations, these concepts are further examined through precision laboratory experiments designed to emulate the essential dynamics of planetary cores.

The rotating convection facility illustrated here enables controlled studies of rapidly rotating, thermally driven flow in an electrically conducting fluid under well-defined boundary conditions. By independently regulating rotation rate, heat flux, and mechanical forcing, the experiment provides a systematic platform to investigate the influence of boundary heterogeneity,

wave-mediated dynamics, and large-scale flow organization. Advanced optical diagnostics, including laser-sheet illumination and synchronized imaging in the rotating frame, allow detailed measurement of flow structures and coherent modes. Such laboratory studies form a critical link between asymptotic theory and numerical models, offering direct physical validation of scaling laws and dynamical mechanisms relevant to planetary dynamo action.



Schematic and photograph of the Little Earth Experiment (LEE), IISc Bangalore.



PURSUIT OF LIFE ON MARS: ROLE OF MOLECULAR BIOSIGNATURES OF ANCIENT MICROBIAL

The pursuit of evidence of primitive life on Mars represents one of the most curious questions in modern astrobiology. The way discoveries are revealing that Mars once had rivers, lakes, and a dynamic climate, fundamentally reshaping our understanding of the planet's past. Identifying the biological signatures of microbial life is central to confirming life on Mars. The harsh surface environment, such as intense radiation, oxidising soils, and extreme cold, degrades organic matter rapidly; any surviving molecular signatures would likely be ancient, preserved in sedimentary rocks from habitable periods around 3-4 billion years ago.

Instruments like the Sample Analysis at Mars (SAM) on the Curiosity Rover and Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) on the Perseverance Rover have detected organics, but distinguishing biological from abiotic origins remains challenging. Abiotic processes, such as meteoritic delivery or hydrothermal synthesis, can also produce similar compounds, posing false positive signs of such signatures.

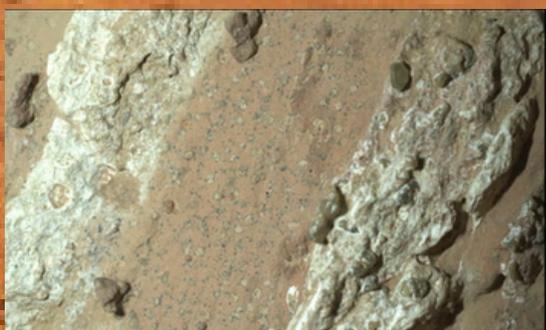


Fig: sedimentary rock formations on Mars



Fig: Curiosity Rover

Indian space agency ISRO also placed a spacecraft, Mangalyaan (Mars Orbiter Mission, 2013), in Martian orbit and gathered enough data on the planet's atmosphere, surface morphology, and mineral composition, which also lays foundational knowledge relevant to understanding Mars' habitability. Building on this, ISRO has also established the Himalayan Outpost for Planetary Exploration (HOPE) in Ladakh to simulate Mars-like conditions and test life-support systems and human responses in extreme environments, advancing preparation for future interplanetary missions.



Fig: Mangalyaan
(Mars Orbiter
Mission, 2013)

Organic Molecules as Primary Indicators

Organic molecules, isotopic fractionations, and specific mineral-organic associations that, on Earth, are often linked to microbial activity, if found on Mars, could be a decisive discovery confirming the presence of life. Recent investigations by NASA's Perseverance rover in Jezero Crater have revealed mineralogical and geochemical features interpreted as potential biosignatures, though no definitive evidence of past life on Mars has yet been confirmed. These findings include organic-bearing mudstones and distinctive iron-rich mineral textures within the Bright Angel formation, which formed in an ancient lake-river environment considered favourable for microbial life.

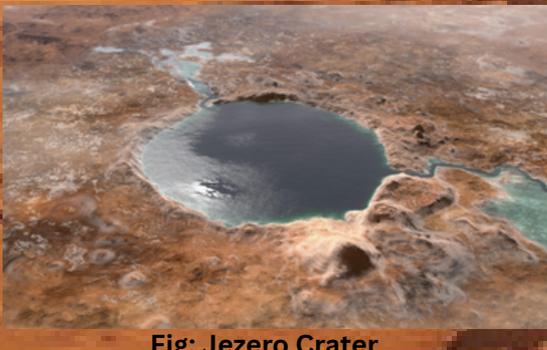


Fig: Jezero Crater



Fig: Perseverance Rover

NASA's Curiosity rover, operating in Gale Crater since 2012, used its SAM instrument to detect a range of organics. Early findings included chlorinated hydrocarbons, initially attributed to instrument reactions, but later confirmed as indigenous with carbon from Mars. More complex molecules, such as thiophenes, aromatics, and aliphatics, were identified in mudstones, resembling degradation products of biological precursors.



Fig: Curiosity Rover

On Earth, organic enrichment in fine-grained sediments like clays often signals biological input, as microbes thrive in such settings. Martian clays in Jezero and Gale preserve organics better than surface regolith due to shielding from radiation. Pigments like carotenoids or chlorophyll derivatives, resistant to degradation, are promising; however, to date, no such compounds have been identified on Mars.

Perseverance, exploring Jezero Crater (an ancient lake-delta system) has Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC), which has detected polycyclic aromatic hydrocarbons (PAHs) preserved in sulfates, and broader surveys revealed organic carbon in sedimentary rocks.

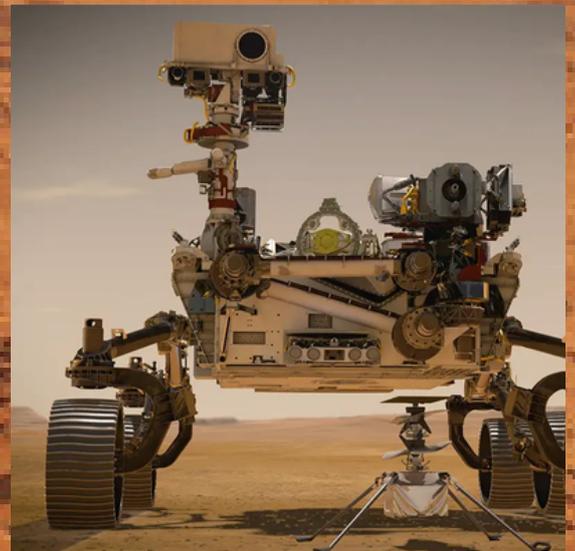


Fig: Perseverance Rover

Lipid Biomarkers: Robust Records of Cellular Life

Lipids, which are fundamental components of cellular membranes, are among the most informative biosignatures because their distinctive hydrocarbon structures can retain biological source information over geological timescales. On Earth, lipid-derived hydrocarbons have been shown to preserve analytical molecular and isotopic signatures for hundreds of millions to billions of years, making them particularly suitable targets in the search for evidence of ancient life on Mars.

Key lipid biomarkers include fatty acids, hopanes, steranes, and archaeal isoprenoid hydrocarbons such as squalane, which derive from cellular membrane lipids and can retain taxonomic and metabolic information. The presence of branched lipid isoforms provides additional biological specificity; for example, iso- and anteiso-branched fatty acids are characteristic of many bacteria and are commonly associated with physiological adaptation to environmental stress, including temperature, salinity, and nutrient limitation.

In terrestrial Mars analogues such as hydrothermal systems, acidic iron-rich waters, and sulfate-rich hypersaline lakes, microbial lipids can persist when rapidly trapped in protective matrices such as silica sinters or evaporitic salts. Icelandic hot-spring sinters preserve lipid biomarkers associated with microbial communities, supporting siliceous deposits as high-value biosignature targets.

In the Río Tinto system (Spain), lipid biomarker studies and drilling/ground-truth campaigns demonstrate that iron-sulfur-rich acidic settings can retain molecular biosignatures, while Mg-SO₄-rich hypersaline lakes in British Columbia (Canada) preserve diverse lipid biosignatures in brines, salts, and sediments—highlighting sulfate-rich deposits as priority targets.

Isotopic Signatures: Evidence of Metabolic Fractionation

Microbial metabolic processes preferentially incorporate lighter isotopes (e.g., ^{12}C , ^{32}S , ^{14}N) producing characteristic isotopic fractionations that are widely regarded as strong indicators of biological activity. Carbon-13 depletion (low $\delta^{13}\text{C}$) in organics signals photosynthesis or methanogenesis; similar patterns for nitrogen, sulfur, and hydrogen. On Earth, ancient rocks show $\delta^{13}\text{C} \sim -20$ to -30‰ for biological carbon versus near 0‰ abiotic. Martian organics from Curiosity show variable isotopes, some consistent with biology but ambiguous due to atmospheric or meteoritic influences.

Sulfur isotopes in sulfates/sulfides could indicate microbial sulfate reduction, producing light $\delta^{34}\text{S}$ in sulfides. Gale Crater data suggest dynamic sulfur cycling, but Mg-sulfate lakes which are common on Mars, may reveal biological signals. Similarly, methane detections, with variable $\delta^{13}\text{C}$, hint at possible biology, though geological sources dominate. Mars mission with sample return will enable precise isotope ratios in organics, potentially revealing fractionation.

Mineral-Organic Associations:

Biosignatures often involve minerals formed or altered by microbes. Redox gradients from metabolism create distinctive assemblages. The 2025 breakthrough: Perseverance "Cheyava Falls" rock in Bright Angel formation shows "leopard spots" of millimetre-scale features with organic carbon, ferrous phosphates (vivianite-like), and iron sulphides (greigite-like). On Earth, such low-temperature redox reactions in mudstones are driven by microbial degradation of organics, using iron/sulphur for energy.

Such spots, in ancient river-bed sediments, co-occur with organics, qualifying as potential biosignatures. Similar to Earth reduction spots or hydrothermal precipitates, these textures suggest energy sources for chemotrophs. Clays and sulfates preserve organics; Jezero's deltaic deposits are ideal. Abiotic explanations (geochemical) exist, but biological parallels are striking. The "Sapphire Canyon" core, sampled by the Perseverance Rover for return, is the mission's strongest candidate yet.

As of late 2025, Perseverance has collected over 20 samples, including Sapphire Canyon, for Mars Sample Return, which is planned 2030s. Advanced analytical analysis of those samples could confirm lipids, isotopes, and chirality. The ExoMars rover mission, which was planned to drill deeper for protected organics, has been delayed, but future missions target subsurface ice or caves, which can also open a significant dimension of possibilities for finding biosignatures.

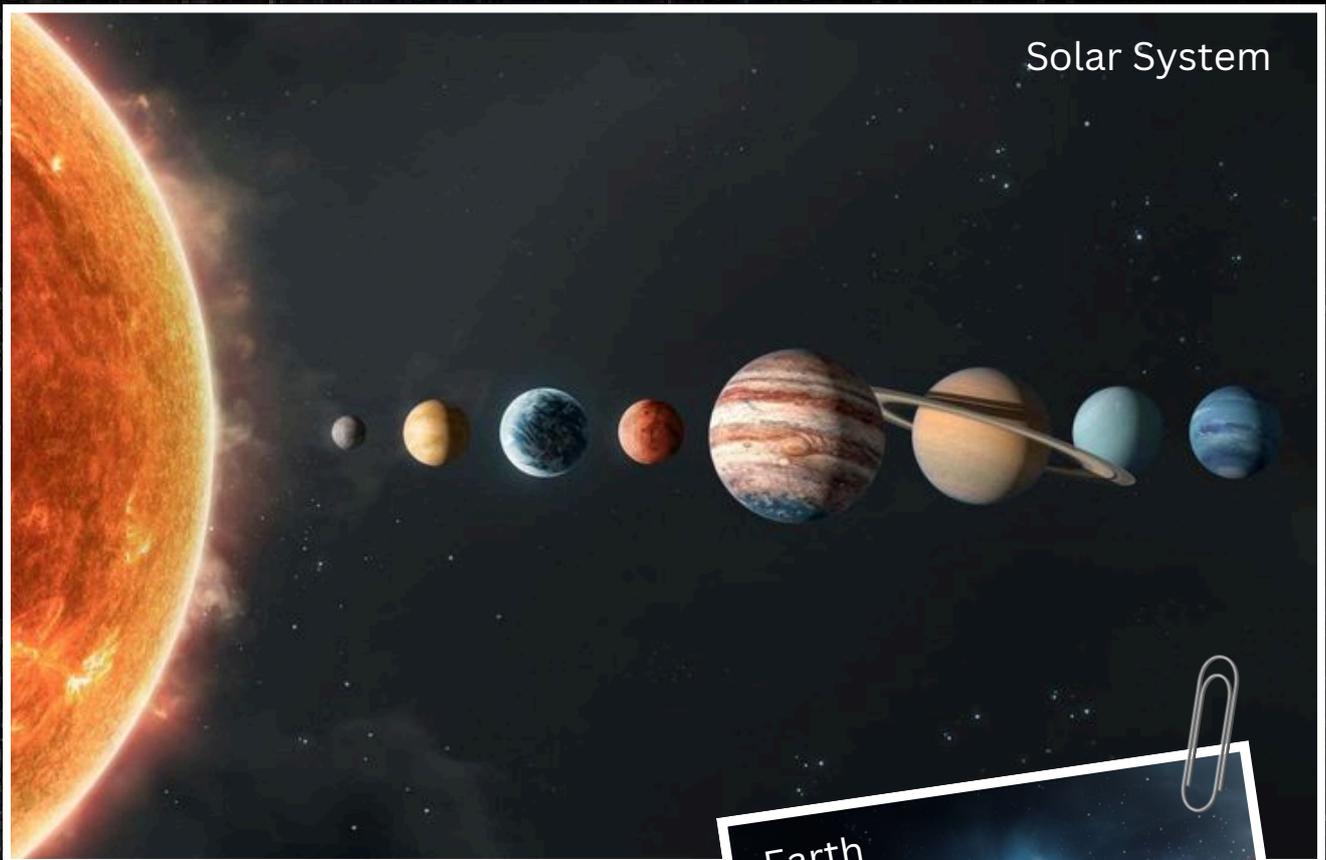
No conclusive life evidence yet, but accumulating organics in habitable contexts, especially Cheyava Falls and Jezero Crater, mark the closest approach to potential biosignatures, strongly suggesting Mars was once biocompatible. Microbial life, simple chemotrophs in groundwater or lakes, remains plausible. Extraordinary claims demand extraordinary evidence. Sample return will provide it, potentially rewriting life's cosmic story. Until then, these signatures fuel hope that Mars may hold whispers of ancient life, awaiting our listening. The quest continues, blending caution with wonder, as we probe whether Earth is alone in advancing lifeforms.



Fig: Cheyava Falls



Fig: Jezero Crater



Why Planets Wear Different Colours: A Scientific Diagnostic, Not a Cosmic Coincidence

Images of planets often feel like postcards from space — Mercury’s dull grey, Venus glowing softly in yellow, Earth painted in blue and white, and Mars standing out in red. In reality, planetary colour is one of the most powerful clues scientists have to understand what a planet is made of, how its atmosphere behaves, and how it has evolved over time. Colour, in planetary science, is not decoration; it is information reflective of planetary habitation.

Mercury’s dark grey appearance is a direct result of exposure. With almost no atmosphere to protect it, sunlight strikes the surface unfiltered. Over billions of years, impacts from tiny meteoroids and constant solar radiation have altered the surface — a process known as space weathering — gradually darkening it and reducing its ability to reflect light.





fig - Jupiter(Hubble space telescope)

Venus presents the opposite situation. Its surface is permanently hidden beneath an extremely thick blanket of clouds. The pale yellow or cream colour we see comes entirely from the way these clouds scatter sunlight.

Earth's colour is the most complex and dynamic in the Solar System. Blue tones arise mainly from the scattering of sunlight in the atmosphere, while oceans absorb red wavelengths, reinforcing the blue appearance. White clouds reflect large amounts of sunlight, constantly reshaping Earth's look. Because Earth's colour depends on liquid water, weather systems, and life itself, scientists consider it an important reference when searching for habitable planets beyond our Solar System.

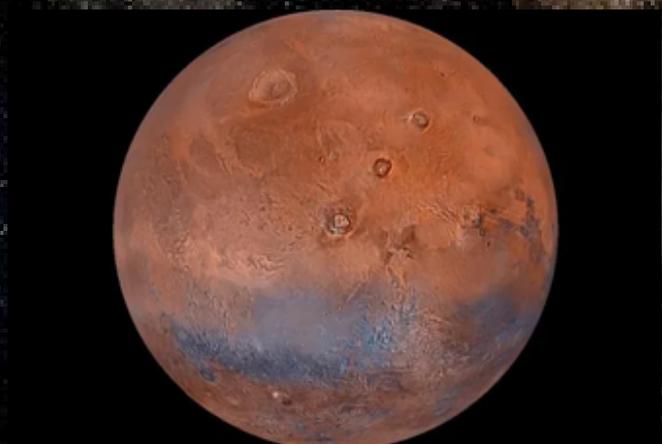


fig - Mars(NASA Gallery)

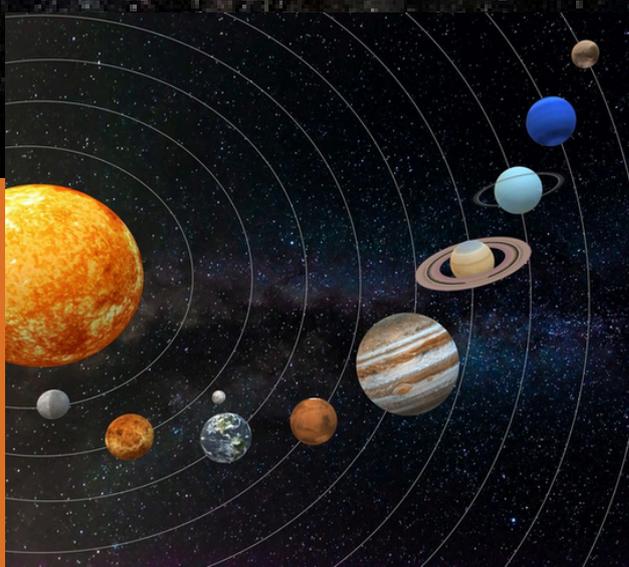


fig - Venus(Magellan spacecraft)

Jupiter and Saturn display striking bands of yellows, browns, and reds. Uranus and Neptune owe their blue tones to methane gas, which absorbs red light. Saturn's moon Titan glows orange due to thick organic smog formed by reactions between methane and nitrogen high in its atmosphere.

Mars is famous for its red hue, long associated with rust. The planet is coated in fine dust rich in iron oxides, formed through chemical interactions involving iron, oxygen, and small amounts of water in Mars's past.

Despite decades of exploration, planetary colour remains an active area of research. A larger question emerges: how much of a planet's history, chemistry, and even potential habitability can be decoded from colour alone?

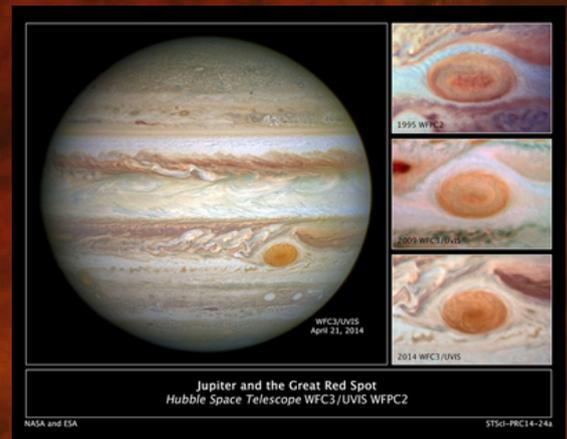


EXTREME PLANETARY ATMOSPHERES

On Earth, weather feels intuitive. Warm air rises, winds respond to pressure differences, and storms evolve over days. Yet across the Solar System, atmospheres exist in conditions so extreme that these familiar ideas entertain scrutiny. Pressures can exceed those at the bottom of the Earth's oceans, temperatures can melt lead, and storms can persist for centuries. (Yadav et al. 2024) Studying such atmospheres is not just an exercise of curiosity, but rather it is central to understanding planetary evolution, climate stability, and the environments of worlds beyond Earth. (Read & Lebonnois)



NASA JPL – Jupiter's Great Red Spot (enhanced color from Juno)



NASA Hubble full-disk storm view

JUPITER: WEATHER WITHOUT A SURFACE:

Jupiter's atmosphere is a striking example of atmospheric physics. (Ingersoll et al.) Composed primarily of hydrogen and helium, it lacks a solid surface and extends deep into the planet, transitioning from cold upper layers to hot, dense regions thousands of kilometres below. Unlike Earth, Jupiter emits more energy than it receives from the Sun, and this internal heat drives vigorous convection throughout the atmosphere. This energy sustains powerful east-west jet streams and massive vortices, including the Great Red Spot, which has persisted for centuries. (Yadav et al. 2024)

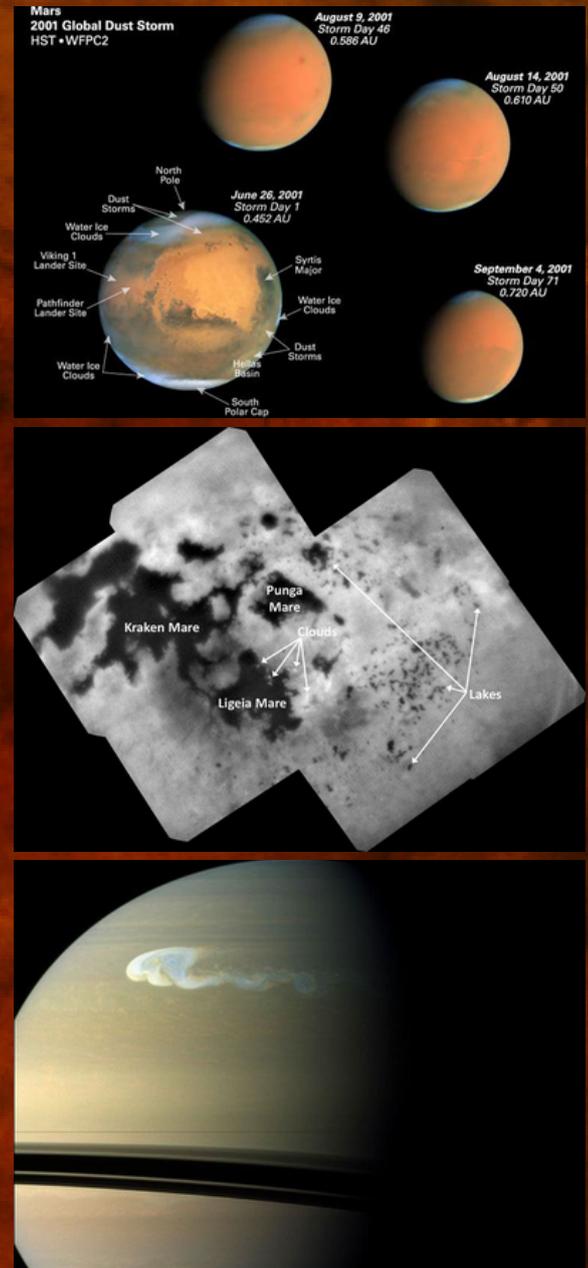
Modern models of Jupiter's atmosphere treat it as a fully compressible system, coupling fluid motion with radiative transfer and chemistry across pressures spanning many orders of magnitude. (Yadav et al. 2024) These studies show that vertical momentum transport and wave-mean flow interactions allow storms to remain stable far longer than terrestrial weather systems — a reminder that “weather” behaves very differently when gravity, rotation, and energy input are pushed to extremes.

OTHER WORLDS, OTHER EXTREMES

Mars, however, presents an opposite case. (Haberle et al.) Its thin carbon-dioxide atmosphere has little thermal inertia, allowing rapid temperature swings and planet-encircling dust storms. Anyone who has felt dust lifted easily on a windy day can appreciate how, on Mars, even weak winds can mobilize fine particles and reshape the climate.

Titan, Saturn's largest moon, feels strangely familiar yet alien. Its dense nitrogen atmosphere supports clouds, rain, and lakes — not of water, but of methane. (Lorenz et al.) The same physical principles that govern Earth's hydrological cycle operate here, simply with different working fluids and temperatures.

Saturn's atmosphere, though similar in composition to Jupiter's, is colder and less massive. (Ingersoll et al.) It still hosts deep convection, strong zonal winds, and episodic global storms, highlighting how internal heat and rotation continue to shape atmospheric behaviour across gas giants.



BEYOND THE SOLAR SYSTEM

Observations and models of hot Jupiter exoplanets show that intense stellar radiation can heat upper atmospheres enough to drive large-scale atmospheric escape. (Khodachenko et al. 2024)

These extreme cases extend the lessons learned from our Solar System and provide context for interpreting the growing diversity of planetary atmospheres detected around other stars.

CAN PLANETARY SCIENCE INFLUENCE HUMAN HEALTH?

Planetary science, traditionally concerned with the study of planets, moons, and planetary systems, has increasing relevance to human health on Earth. Through its overlap with Earth system sciences, planetary science provides critical insights into the physical, chemical, and biological processes that govern planetary environments. These insights form the foundation of the emerging field of planetary health, which examines the relationships between human health and the integrity of Earth's natural systems.

Planetary Health uses knowledge from Earth sciences (part of Planetary Science) to understand environmental impacts. It is a solutions-oriented, transdisciplinary field and social movement focused on analyzing and addressing the impacts of human disruptions to Earth's natural systems on human health and all life on Earth. By examining changes in climate, land use, atmospheric composition, and biodiversity, planetary health research seeks to understand how environmental degradation translates into adverse health outcomes for human populations and other forms of life.

Planetary science contributes to this framework by enabling a systems-level understanding of Earth as a dynamic planet. Planetary health scientists have also characterized long-term risks to humans from the degradation of natural systems and identified opportunities to mitigate adverse health impacts, drawing from public health and epidemiologic research. These observations allow scientists to model environmental change and predict its consequences and directly influence health determinants such as air quality, water availability, food security, and exposure to extreme weather events.

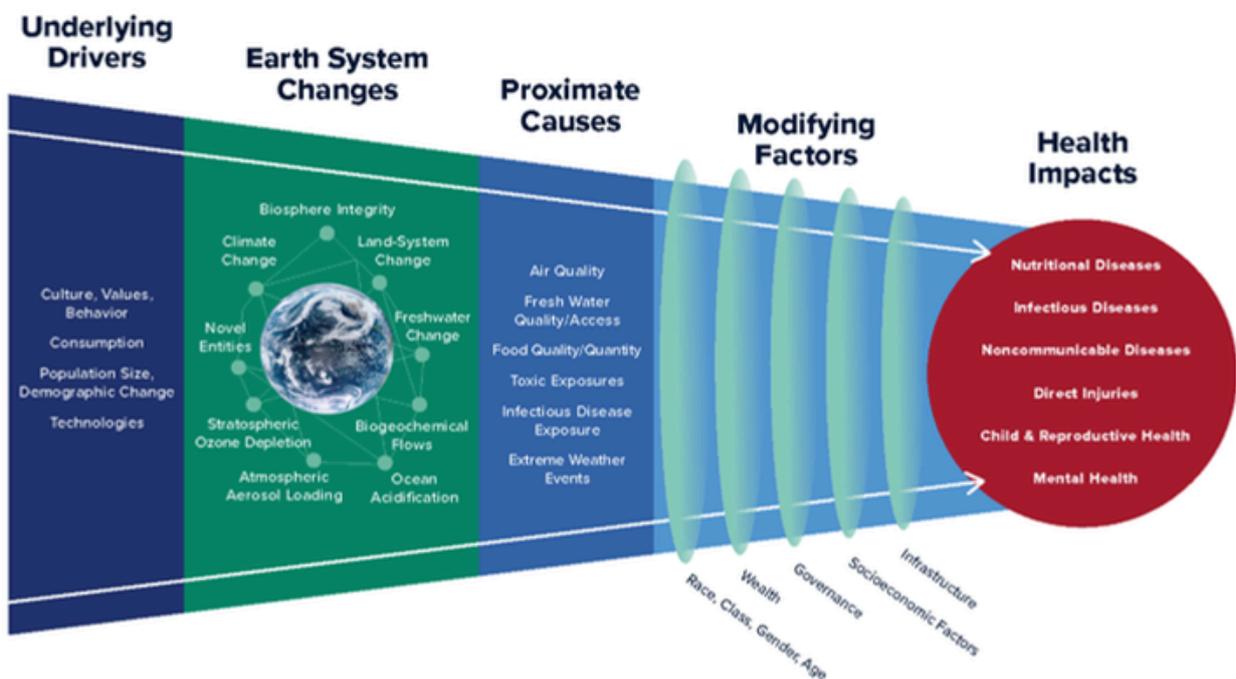


Fig- concept of ecological determinants of health, depicting how environmental changes (shown in the outer globe) affect human health.

These observations allow scientists to model environmental change and predict its consequences and directly influence health determinants such as air quality, water availability, food security, and exposure to extreme weather events. Increasingly, advanced computational tools, including artificial intelligence and Earth observation technologies, are employed to monitor planetary changes and assess their implications for population health.

The health impacts of planetary-scale disruptions are not confined to specific regions or socioeconomic groups. The growing frequency and intensity of climate-related disasters such as heatwaves, floods, wildfires, and storms affect both low and high-income countries. As planetary systems approach critical thresholds, the capacity of health systems to respond effectively may be compromised.

Planetary science plays a crucial role in informing strategies to protect human health by identifying environmental risks. This can also help in guiding policy decisions and supporting sustainable development goals. Understanding Earth as a planetary system is therefore essential for advancing planetary science and for safeguarding the health and well-being of present and future generations.





PLANETARY VOLCANISM

LAVA OR ICE?

Volcanism is often imagined as a surface phenomenon—an eruption, a flow of lava, a temporary spectacle. Across the Solar System, however, volcanism is something far more unsettling. It is a sign of internal unrest, a reminder that planets and moons are not inert objects but bodies under constant pressure.

Among the most extreme examples is Io, a moon trapped in a cycle of gravitational stress. Continuous internal heating forces molten rock upward, tearing open the surface through violent eruptions. The landscape is painted in sulphur and ash, an emblem of a world trapped in an endless cycle of creation and annihilation. Venus, however, hides its violence behind a dense veil of clouds. Beneath this shroud lie immense volcanic plains and colossal structures formed by eruptions so vast they appear planetary in scale.

Farther from the Sun, volcanism takes on a colder form. Enceladus ejects jets of water vapor and ice through fractures in its frozen crust, driven by heat generated deep below the surface. Europa shows signs of similar activity, suggesting vast subsurface oceans in perpetual darkness.

Taken together, these volcanic worlds expose a stark reality: geological activity is not gentle or purposeful. Whether expressed through molten rock or icy plumes, volcanism reshapes worlds without pause.

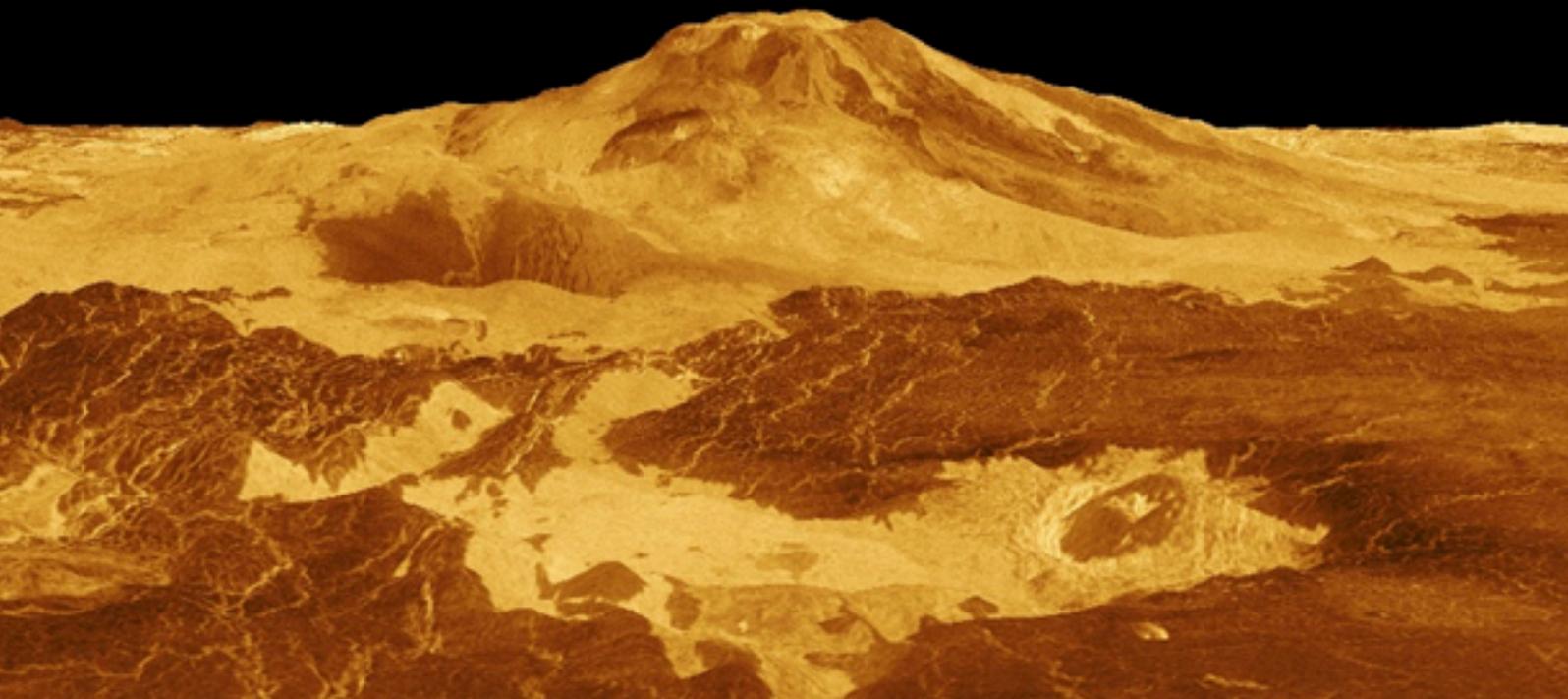




Fig 1 - Eruption on Io - NASA



Fig 2 - Enceladus - NASA Science

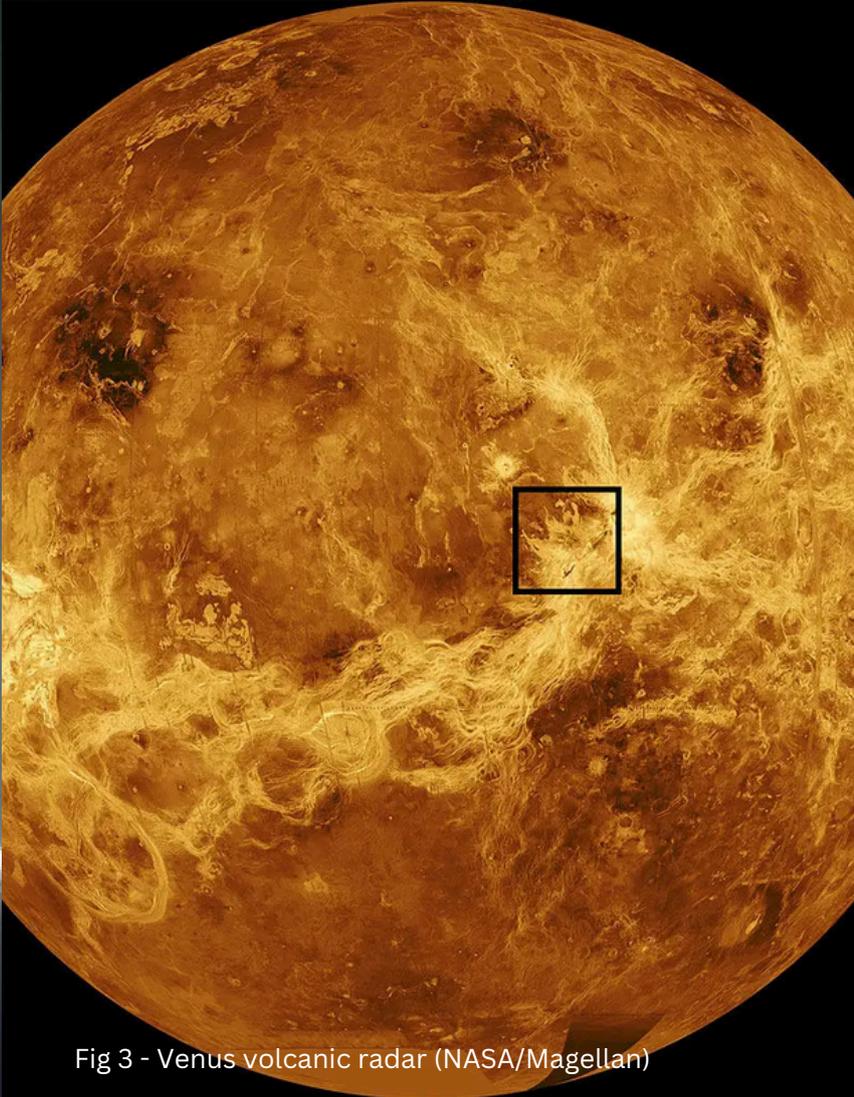


Fig 3 - Venus volcanic radar (NASA/Magellan)



TAMING THE SUPERSONIC INLET

Neeraj Kumar Gahlot
Assistant Professor-III, AIAE

Supersonic inlets are a crucial part of any high-speed aircraft, and their purpose is to slow down the incoming air and bring it to a suitable pressure and temperature for combustion. This is done by deliberately producing a series of oblique shockwaves followed by a normal shock. However, a major aerodynamic problem that comes up in this system is the shockwave and boundary layer interaction that can lead to many opposing effects.

RESEARCH-ARTICLE

Numerical Study of Supersonic Mixed Compression Air Intake With an Array of Air Jets

N. K. Gahlot, N. K. Singh

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J. Fluids Eng. Apr 2021, 143(4): 041206 (10 pages)

Paper No: FE-20-1604 <https://doi.org/10.1115/1.4049370>

HEAT TRANSFER

RESEARCH ARTICLE | Free to Read

Control of shock-induced separation inside air intake by vortex generators

Neeraj Kumar Gahlot | Nirmal Kant Singh

First published: 15 September 2021 | <https://doi.org/10.1002/htj.22329> | VIEW METRICS

WHEN SHOCKS MEET THE BOUNDARY LAYER

The boundary layer is a thin region of relatively slower-moving fluid adjacent to the intake wall, and when a shock wave interacts with this region, it causes adverse effect. The low-momentum fluid in the boundary layer is unable to overcome this adverse pressure gradient, leading to flow separation. This shock-induced separation results in loss of total pressure, flow distortion, unsteady shock motion, and, in the most extreme cases, intake unstart. Therefore, controlling this interaction is critical for stability and efficiency in a supersonic inlet and is the central focus of this paper. There are two broad control methods, active and passive. Active methods are those which need to be controlled after their installation, whereas passive methods rely purely on geometry and structure and cannot be controlled afterwards.

Control of shock-induced separation inside air intake by vortex generators

In this study, a passive flow-control technique called vortex generators was used to suppress the shock-induced flow separation. Vortex generators are small protrusions mounted on the intake surface. They mix the outer flow with the near-wall low-momentum fluid, and energise the near-wall flow. The boundary layer fluid is now less prone to flow separation, making it more capable of handling adverse pressure gradients. The study focuses on micro-vortex generators, whose height is smaller than the boundary layer thickness, minimising additional drag while maintaining effectiveness.

Using computational fluid dynamics (CFD), the authors simulate a supersonic air intake operating at a design Mach number of 2.2. The flow is modelled using the Reynolds-Averaged Navier–Stokes equations with a $k-\omega$ turbulence model, which is well suited for predicting adverse pressure gradients and separation. Several VG configurations are examined by varying their height, spacing, and placement relative to the shock impingement point.

Overall, this paper demonstrates that shock-induced separation is fundamentally a boundary-layer problem, and reinforcing the boundary layer before shock interaction is an effective solution. Strengthening the boundary layer is often more effective than weakening the shock. The findings offer valuable guidance for designing stable, high-performance supersonic air intakes that utilise simple and reliable passive control techniques.

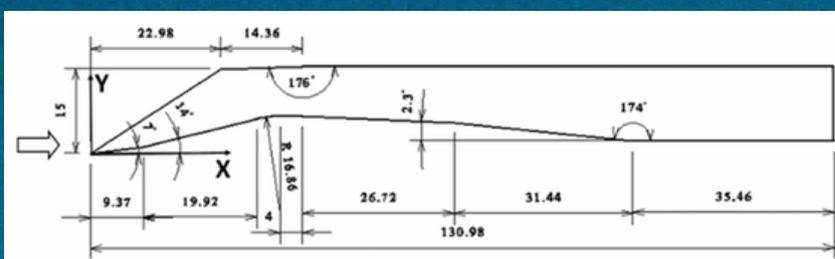


Fig 1 - Air Intake model

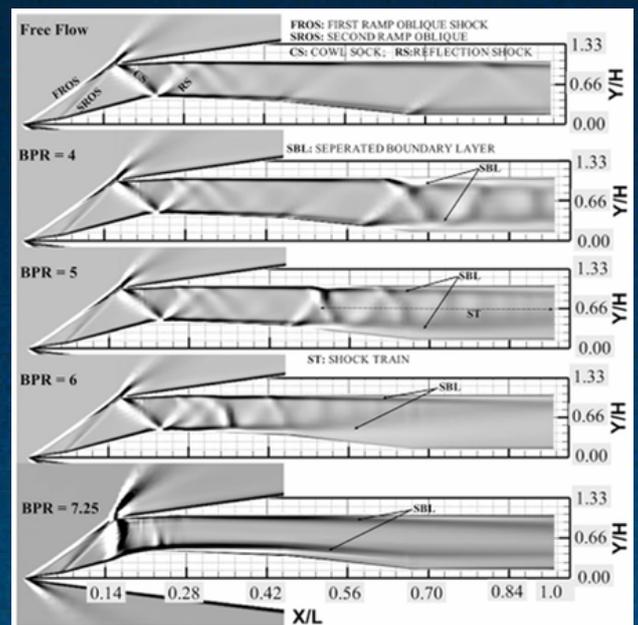
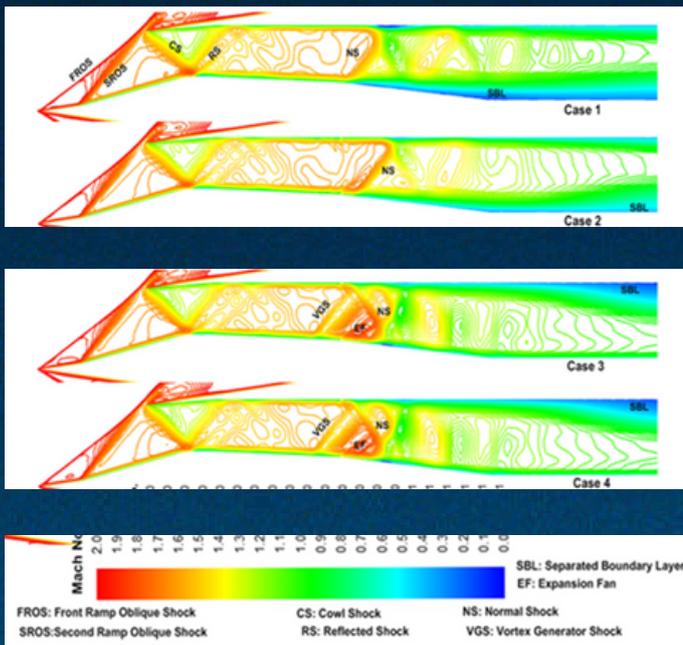


Numerical Study of Supersonic Mixed Compression Air Intake With an Array of Air Jets

While passive techniques such as vortex generators improve intake performance by strengthening the boundary layer, their effect is fixed once installed and is most effective near the design operating condition. To address intake instability under off-design conditions, the second study explores an active flow-control approach using an array of air jets in a supersonic mixed-compression air intake.

In this work, high-momentum air is injected through discrete jets placed near regions of strong shock–boundary layer interaction. Unlike passive devices, air jets allow direct and adjustable momentum addition to the flow. By locally energizing the near-wall region and modifying the pressure field, the jets influence both boundary layer behaviour and shock positioning. This makes them particularly effective in controlling the terminal normal shock, whose upstream movement is a key precursor to intake unstart.

The study uses computational fluid dynamics (CFD) simulations of a mixed-compression intake operating at a design Mach number of 2.2. The flow is modelled using the Reynolds-Averaged Navier–Stokes equations with a turbulence model suitable for capturing separation and adverse pressure gradients. Various jet configurations are examined by changing jet location, injection pressure, and mass flow rate to evaluate their effect on separation size, shock stability, and pressure recovery. Author(s) examined Mach number and pressure contours, shock position stability, separation behaviour, and total pressure recovery to assess the effectiveness of active air-jet control in a supersonic mixed-compression intake



The results show that air-jet injection significantly reduces the separation region downstream of shock impingement and improves total pressure recovery compared to the uncontrolled intake. More importantly, the jets actively stabilise the terminal shock, preventing its upstream displacement under increased back pressure. This enhances the inlet's resistance to unstart and extends its stable operating range beyond what passive control alone can achieve.

However, the study also highlights the trade-off inherent to active control. While air jets provide greater adaptability and control authority, they require additional energy input and increase system complexity. As a result, active methods are best suited for applications where wide operating envelopes and real-time flow control are critical.

Together with passive vortex-based control, this study demonstrates that combining boundary-layer strengthening with active shock management offers a comprehensive strategy for improving the stability and performance of supersonic air intakes.

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***CAN PLANETARY SCIENCE INFLUENCE
HUMAN HEALTH***

- ✦ <https://doi.org/10.1016/j.ssmph.2021.100844>
- ✦ <https://planetaryhealthalliance.org/what-is-planetary-health/>
- ✦ <https://planetaryhealthalliance.org/planetary-health-schematic/>

Research article is published in The International Journal of Machining and Machinability of Materials



A truly proud and joyful moment for Amity Institute of Aerospace Engineering as **Tanishka Verma**, B.Tech. (Aerospace Engineering), 2025 Batch, secured a fully funded **Ph.D. position at the University of Southampton, United Kingdom.**

Ranked among the world's leading institutions for aerospace and engineering research, the university's offer—featuring an impressive £47,000 annual stipend—is a testament to her dedication, academic excellence, and passion for research. This remarkable achievement brings great pride to the entire AIAE community.



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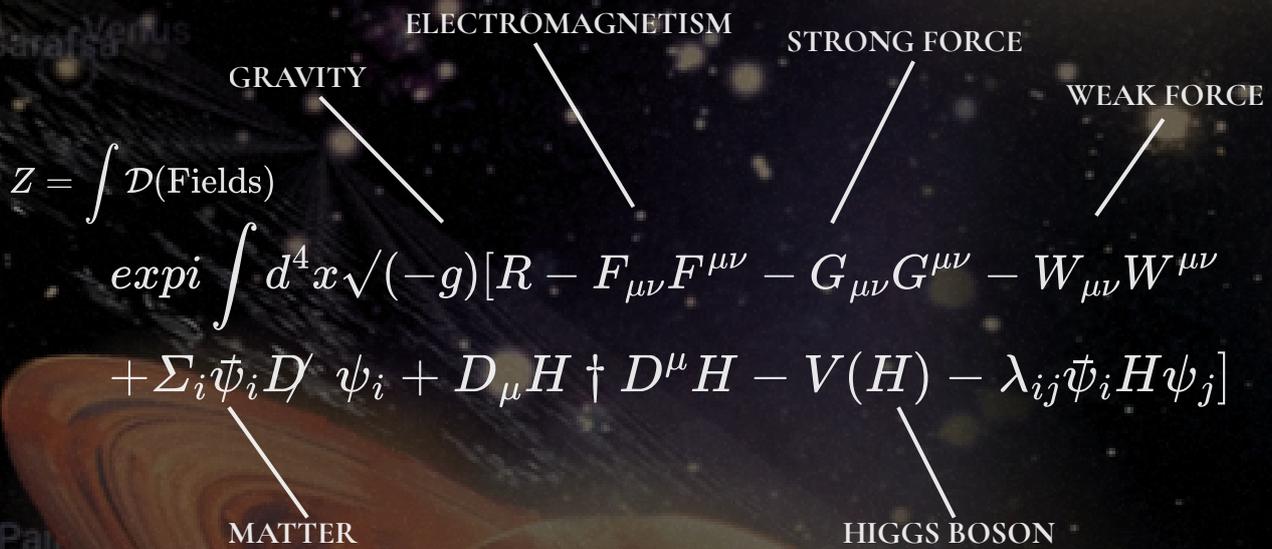
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35 The Theory of Everything (so far)



The Theory of Everything: Unifying Matter, Forces, and the Universe

Modern physics has achieved remarkable success in explaining nature and yet it remains incomplete. Scientists today describe the universe using different equations for different scales. One set explains the motion of planets, stars, and galaxies, while another governs atoms and subatomic particles. The Theory of Everything (ToE) is the search for a single framework that unifies all these laws into one consistent description of reality (Kaku, 2008; Greene, 2011).

At the heart of the universe lies matter, composed of fundamental particles such as quarks and electrons. These particles interact through four fundamental forces. Gravity governs the structure of the cosmos, shaping planets, stars, black holes, and even the expansion of space itself (Einstein, 1916). Electromagnetism controls light, electricity, magnetism, and chemical bonding, making both life and technology possible (Feynman, 1964). The strong nuclear force binds protons and neutrons inside atomic nuclei, while the weak nuclear force enables radioactive decay and fuels stellar reactions (Quigg, 2013). These forces act through exchange particles known as force carriers, such as photons and gluons.

Yet another crucial ingredient of the universe is mass. Particles acquire mass through their interaction with the Higgs field, an invisible field that fills all space. The discovery of the Higgs boson in 2012 confirmed this mechanism and completed a key part of modern particle physics (ATLAS Collaboration, 2012; CMS Collaboration, 2012).

Despite these advances, current theories fail when gravity and quantum physics are required to be applied together, such as at the birth of the universe or inside black holes. A true Theory of Everything would unite matter, forces, the Higgs field, space, and time into a single elegant equation (Witten, 1995; Smolin, 2006).

Although this ultimate theory remains undiscovered, its pursuit continues to drive fundamental research. Its discovery would reshape our understanding of the universe and reveal the deep simplicity underlying nature's complexity.

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