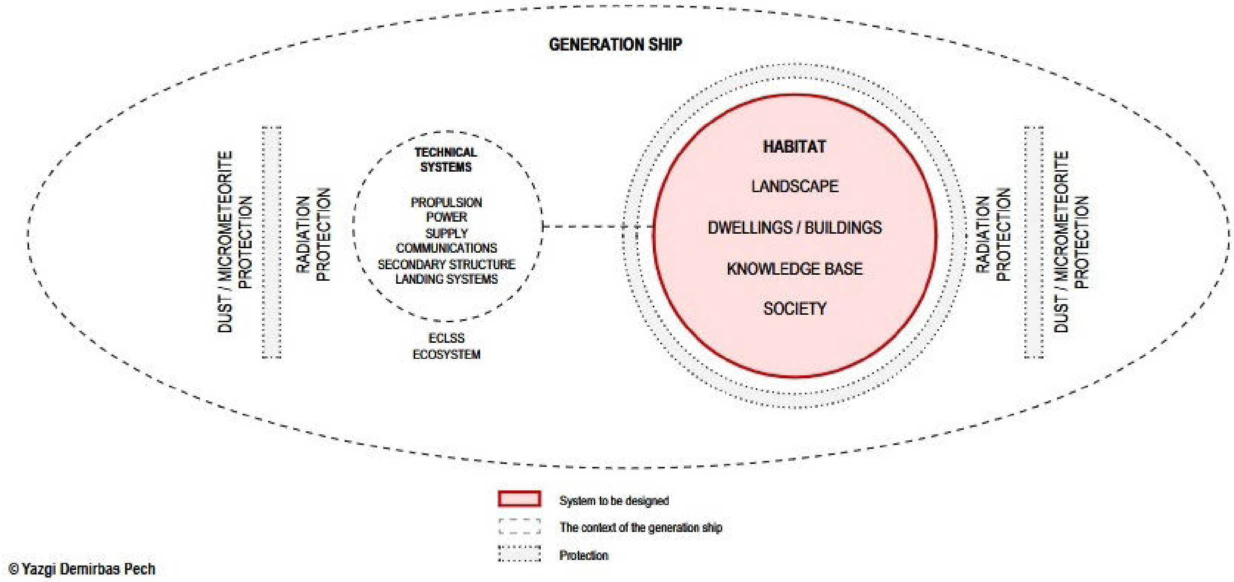
Parnika Singh reports on recent developments in interstellar studies

Project Hyperion Design Competition

The Project Hyperion Design Competition is the first of its kind, exploring the long-term sustainability of a generation ship habitat and society. Registration for the competition to design a generation ship is now over. The registered teams now have until the 9th of March to work on their Phase 1 submissions, involving initial designs and narratives addressing the challenges of a believable society in a generation ship with vernacular architecture and low-tech, knowledge & technology transfer, cultural evolution, environmental and life-support systems. Shortlisted teams will then proceed to Phase 2. Competition results will be announced in June of this year. More about our competition at www.projecthyperion.org.



Electric Propulsion for Interstellar Travel

On 28 October 2024, Nadim Maraqten, Dan Fries and Angelo Genovese (all of whom are i4is researchers) released their International Astronautical Congress paper titled *Advanced Electric Propulsion Systems with Optimal Specific Impulses for Fast Interstellar Precursor Missions* affiliated with i4is (www.researchgate.net/publication/385172298). Interstellar exploration is in its early stages, but its potential scientific and cultural impact is immense. To support upcoming interstellar missions, advanced propulsion systems are critical for achieving the high speeds (delta-V) needed and for allowing larger payloads. However, the best propulsion system depends on the specific mission requirements.

This study uses the non-dimensional Tsiolkovsky equation to optimize the combined payload and structural mass fraction of spacecraft based on factors such as specific impulse (efficiency of propulsion), specific power, thruster efficiency, transfer time, and required delta-V. Three mission scenarios are analyzed under the assumption of an advanced power source with a specific power of 1,000 W/kg and a thruster efficiency of 97%: a round trip to Jupiter, a rendezvous with Pluto, a mission to the solar gravitational lens focal point (beyond 500 AU from the Sun). For each mission, the study identifies the ideal specific impulse to maximize the payload mass fraction, the corresponding transit time, the type of electric propulsion system that could achieve these goals, and the total spacecraft mass assuming a launch with NASA's Space Launch System Block 2. The results show that advanced electric propulsion systems could significantly increase payload capacity and reduce travel times compared to conventional methods, making interstellar precursor missions more feasible.

Hot Traversable Wormholes

On 21 January 2025, Remo Garattini and Mir Faizal of the Canadian Quantum research center published a paper in the Journal of Cosmology and Astroparticle Physics titled *Hot Casimir wormholes* (arxiv.org/abs/2403.15174). The paper explores an innovative approach to constructing traversable wormholes using the thermal Casimir effect. Wormholes, theoretical tunnels in spacetime, allow shortcuts between distant points. Traditional wormholes require exotic matter—materials that violate energy conditions in general relativity. The Casimir effect, a quantum phenomenon that generates negative energy between closely spaced metallic plates, offers a promising candidate for such exotic matter.

This study extends the Casimir effect to finite temperatures, examining how thermal fluctuations impact wormhole size and stability. By analyzing both low- and high-temperature regimes, the researchers model scenarios with plates at fixed distances and radially varying configurations. At low temperatures, thermal corrections minimally influence the wormhole's properties, while at high temperatures, they significantly alter the wormhole's throat size and energy density.

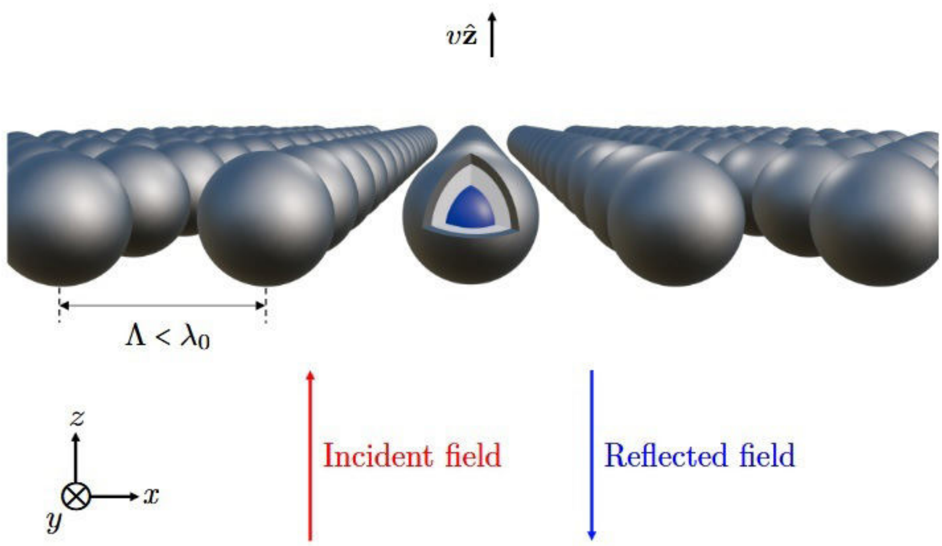
The findings highlight that thermal effects do not disrupt the traversability of Casimir wormholes, though creating a practical wormhole would require temperatures and configurations beyond current technological capabilities. The research also suggests that incorporating superconducting materials or quantum corrections could further refine wormhole designs. Overall, this study deepens our understanding of quantum phenomena in spacetime geometry, opening new possibilities for theoretical physics and futuristic space travel concepts.

Metasurface Materials for Light Sails

On 17 October 2024, Cornell's preprint server arXiv released a paper titled *Analyzing the acceleration time and reflectance of light sails made from homogeneous and core-shell spheres* by Mitchell R Whittam et al of Karlsruhe Institute of Technology (https://arxiv.org/abs/2410.13494). Selecting appropriate materials and designs for light sails, such as those envisioned in the Breakthrough Starshot Initiative, is a critical and complex challenge. This study proposes a potential solution using "metasurfaces" composed of periodically arranged microscopic spheres. These spheres are made from materials like aluminum, silicon, and silicon dioxide.

The research applies Mie theory, a method used to understand how light interacts with small structures, to evaluate the metasurfaces' ability to reflect light, absorb heat, and enable efficient acceleration. The findings highlight the effectiveness of metasurfaces made from silicon spheres combined with an added silicon dioxide layer. This design demonstrates strong broadband reflectance due to the constructive interference of light waves while maintaining low absorption. Furthermore, the study shows that the metasurfaces retain over 90% reflectance even when placed in embedding materials with refractive indices up to 1.13, without requiring significant re-optimization.

A light sail infinitely spanning the x-y plane moving along the +z-axis at speed v illuminated by a linearly polarized incident plane wave reflected in the -z direction. The sail comprises spheres (which we depict here as having a core and two shells) arranged in a square lattice characterized by a lattice constant Λ, which is always smaller than the wavelength λ_0 of the incident field as observed on Earth.
Credit: Whittam fig1.



Market Feasibility of Nuclear Electric Propulsion

On 29 November 2024, i4is Executive Director Andreas Hein et al published a paper titled *Market Study on Nuclear Electric Propulsion for Space Applications* (hal.science/hal-04811171/document). Presented at IAC24 by a colleague from the University of Luxembourg, the paper explores its potential in advanced space missions and logistics. NEP offers a balance between high efficiency and significant power output, making it a promising alternative to chemical and solar electric propulsion for long-duration missions. Unlike solar electric propulsion, NEP can operate in shadowed regions and deep space, enabling continuous functionality.

The study, part of the European Space Agency's RocketRoll project, evaluates NEP's viability for missions like transporting satellites from low Earth orbit (LEO) to geostationary orbit (GEO) and delivering cargo to lunar orbit. NEP is compared with existing propulsion methods, focusing on cost, efficiency, and mission duration. The results indicate that NEP can reduce costs and increase payload capacity, particularly for missions requiring large-scale logistics or extended operations. In addition to traditional applications, the paper explores emerging markets that NEP could enable, such as on-orbit satellite servicing, lunar mining, and deep-space exploration. NEP's ability to provide sustained thrust and power positions it as a critical technology for the future development of lunar bases, interplanetary travel, and space resource utilization.

A Trifecta of Approaches to Interstellar Travel

On 18 November 2024, the Systems Assessment and Engineering Management journal published an article by Victor Christianto and Florentin Smarandache of the University of New Mexico titled *Three Novel Approaches to Deep Space: Interstellar Travel that Transcend the Limitations Imposed by the Rocket Equation* (sciencesforce.com/index.php/saem/article/view/427/593). The paper explores three innovative approaches to interstellar travel that overcome the Tsiolkovsky rocket equation's limitations by leveraging quantum mechanics, superconductivity, and cosmic structures to enable efficient, long-distance space travel.

The first approach, macroquantum tunneling, theorizes macroscopic objects could "tunnel" through energy barriers, bypassing traditional propulsion. Drawing from superfluid and superconductor phenomena, this method could enable spacecraft to travel vast distances without consuming propellant. The second method, non-orientable wormholes, inspired by Möbius strips and superconductors, proposes spacetime curvature through materials like crystals, potentially facilitating faster-than-light travel and revolutionizing propulsion. The third approach examines neuron-like galaxy cluster structures, proposing the cosmic web's interconnected nature could inspire advanced navigation systems or warp drives. These quantum-based ideas promise breakthroughs in interstellar exploration despite significant technical challenges.

Re-estimating the Drake Equation Terms

On 1 December 2024, Cornell's preprint server arXiv released a paper by Lukasz Lamza of Jagiellonian University titled *Chemical Complexity and Prevalence of Life in the Universe: A New Method for the Estimation of Key Terms of Drake Equation* (arxiv.org/abs/2412.01001#). The paper introduces a novel approach to estimating the prevalence of life in the universe by correlating chemical complexity with abundance across cosmic environments. The study proposes that environments with greater chemical complexity, defined by the diversity of molecules present, are less abundant. Using this inverse relationship, the paper quantifies the fraction of the universe's baryonic mass that reaches the minimum chemical complexity required for life. Combining this with statistical models of planetary systems, it predicts the number of planets in a Milky Way-sized galaxy capable of supporting life.

Two models are used: one assumes life forms across planetary systems, while the other focuses on individual planets ("planemos") with the necessary conditions for life. Results suggest a range of possibilities, from a few planets hosting life to thousands, depending on assumptions about chemical complexity and environmental conditions. The study refines the parameters of the Drake Equation and provides a new perspective on estimating the likelihood of extraterrestrial life by focusing on measurable chemical and astrophysical properties.

Technosignatures and Biosignatures

On 16 January 2025, Vinicio Pelino released a preprint titled *Exploring the Entanglement of Biosignatures and Technosignatures: A Quantum Perspective* (www.researchgate.net/publication/387960793). The paper explores a novel framework for searching for extraterrestrial life by combining biosignatures (evidence of biological processes) and technosignatures (evidence of technology) through the lens of quantum mechanics. It proposes that these indicators can be conceptualized as quantum states, providing a unified approach to understanding their relationship and detectability. Biosignatures, such as oxygen or methane, represent biological activity, while technosignatures, like artificial electromagnetic signals, point to intelligent life. The study introduces the idea that these phenomena may be "entangled," suggesting that the presence of one could increase the likelihood of detecting the other.

By modeling biosignatures and technosignatures as quantum states, the paper examines their co-evolution and interdependence, using concepts like superposition and entanglement to describe their relationships. For example, a Dyson sphere—a massive structure built to harness a star's energy—might simultaneously exhibit technosignatures (infrared emissions) and engineered biosignatures (atmospheric changes). The framework allows for new ways to interpret data from astrobiology and SETI (Search for Extraterrestrial Intelligence), emphasizing interdisciplinary methods that combine biology, technology, and quantum physics. The paper concludes that this approach offers deeper insights into the emergence of life and intelligence, potentially transforming how humanity searches for extraterrestrial civilizations and understands its own place in the universe.

Achieving Antimatter Abundance

On 13 December 2024, Douglas C Youvan released a preprint titled "Pathways to Antimatter Abundance" (www.researchgate.net/publication/387029365). The paper explores the potential of antimatter, one of the most energy-dense substances, for transformative applications in energy production, space propulsion, and scientific research. When antimatter annihilates upon contact with matter, it releases massive amounts of energy as described by $E=mc^2$, with just 1 gram producing energy equivalent to 43 kilotons of TNT. This makes antimatter a promising candidate for interstellar travel, clean energy, and medical advancements.

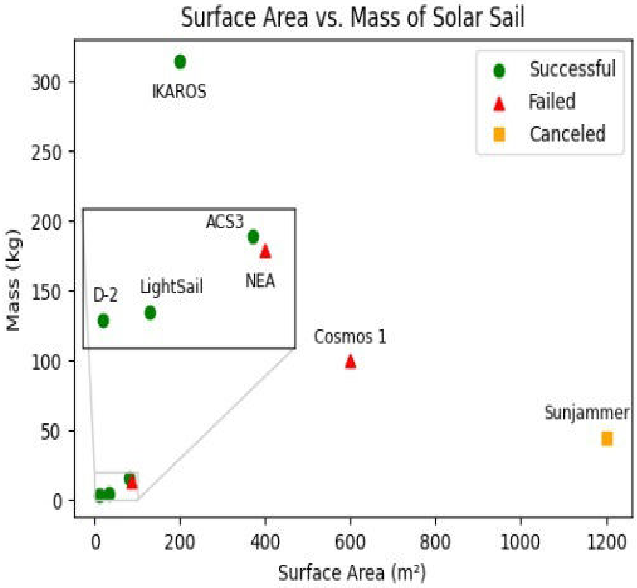
In space exploration, antimatter could power spacecraft to relativistic speeds, significantly reducing travel times. However, the challenges of large-scale production and storage are immense. Current methods, such as particle collisions in facilities like CERN, produce antimatter in minuscule amounts at exorbitant costs—approximately $62.5 trillion per gram. Safely storing antimatter also requires advanced magnetic traps to prevent annihilation. The paper highlights emerging technologies, including laser-based generation and advanced magnetic-optical containment systems, which could improve efficiency and scalability. Antimatter's explosive potential raises ethical and safety concerns, particularly regarding weaponization. The paper stresses the importance of international regulations and collaborative research to responsibly develop antimatter, unlocking its benefits while mitigating risks for future applications.

Automating Interstellar Object Classification

On 26 November 2024, Richard Cloete et al of Harvard published a paper in the Astronomy and Astrophysics journal titled *Machine learning methods for automated interstellar object classification with LSST* (www.aanda.org/articles/aa/full_html/2024/11/aa51118-24/aa51118-24.html). The paper explores the application of machine learning (ML) algorithms to identify and classify interstellar objects (ISOs) using data from the upcoming Vera C Rubin Observatory's Legacy Survey of Space and Time (LSST). ISOs, such as `Oumuamua and Borisov, could provide unique insights into other planetary systems, but their detection is challenging due to their rarity and brief observation windows. The LSST's vast datasets require automated methods to efficiently detect and classify ISOs among millions of celestial objects. The authors tested various ML algorithms, including Gradient Boosting Machines (GBM), Random Forests (RF), Stochastic Gradient Descent (SGD), and Neural Networks (NN). Among these, GBM and RF performed best. The models were validated using simulated LSST datasets and real-world ISO examples, such as `Oumuamua and Borisov, demonstrating promising results. However, challenges remain, such as minimizing false positives and improving performance with limited data. The paper emphasizes the need for more comprehensive observations and continuous model updates as new ISOs are discovered.

Advances in Solar Sailing

On 23 November 2024, Cornell's preprint server arXiv released a paper by Elena Ancona and Roman Ya Kezerashvili of New York City College of Technology titled *Recent advances in space sailing missions and technology: a review of the 6th International Symposium on Space Sailing (ISSS 2023)* (arxiv.org/pdf/2411.12492). The paper provides an overview of ISSS 2023, which gathered experts from 14 countries to discuss recent advances and challenges in solar sailing technology. Solar sails, which harness sunlight for propulsion without requiring fuel, have progressed significantly since the first successful deployment of Japan's IKAROS in 2010. The symposium highlighted innovative concepts, including advanced solar sail materials, trajectory designs for interstellar and deep-space missions, and cutting-edge control systems.
Key missions discussed included NASA's ACS3 and the Solar Cruiser, showcasing the practical applications of solar sails in space exploration. New materials and techniques, such as thermal desorption coatings and diffractive solar sails, were presented to enhance propulsion and durability. Concepts like electric sails and hybrid propulsion systems were also explored to improve performance for future missions. The symposium emphasized the interdisciplinary collaboration required to overcome engineering challenges, including precise attitude control and material degradation. Presentations addressed novel uses of solar sails, from asteroid exploration to orbital debris removal. This gathering underscored the potential of solar sailing to enable long-term, sustainable space exploration, and deep-space missions, setting the stage for continued innovation in this transformative technology.



Sail area and mass (including the sail and its associated hardware) for some missions of the past decades.
Credit: Ancona and Kezerashvili; Figure 1

Space Nanotechnology

Salaheldin Elabiad of Girne American University published a paper on 9 January 2025 titled *Nanotechnology for Space Exploration* in SSRN (papers.ssrn.com/sol3/papers.cfm?abstract_id=5080329). The paper examines how nanotechnology is revolutionizing space exploration by addressing critical challenges like weight reduction, energy efficiency, radiation protection, and system durability. Nanotechnology enables the development of advanced materials and systems that are lightweight yet robust, such as carbon nanotubes (CNTs), graphene, and boron nitride nanotubes (BNNTs). These materials enhance spacecraft performance by providing superior strength-to-weight ratios, thermal stability, and radiation resistance, making them ideal for extreme space environments. Nanotechnology also advances sensors and instruments, enabling highly sensitive, compact, and multifunctional devices for monitoring spacecraft environments and conducting planetary research. Innovations in energy systems, including quantum dot-based solar cells and thermoelectric materials, improve energy efficiency for long-duration missions. Similarly, nanotechnology contributes to life support systems through water purification, air filtration, and radiation shielding, ensuring sustainable human presence in space. In propulsion, nano-thrusters and nanomaterials in ion propulsion systems enhance fuel efficiency and enable precise maneuvering, which is critical for interplanetary and interstellar missions. However, the paper also highlights ethical concerns, such as the environmental risks of deploying nanomaterials in extraterrestrial settings and the need for international regulations.

Studying Interstellar Objects

Cornell's preprint server arXiv published a paper titled *Information-Optimal Multi-Spacecraft Positioning for Interstellar Object Exploration* by Arna Bhardwaj et al of University of Illinois at Urbana-Champaign on 14 November 2024 (arxiv.org/abs/2411.09110). Interstellar objects (ISOs) are astronomical objects that travel through space without being bound to the Sun's gravity. These objects offer valuable insights into the formation and composition of the universe. However, detecting and studying them is challenging because their appearances are unpredictable, and their positions and movements are uncertain.

This paper introduces a new framework that uses multiple spacecraft to study ISOs more effectively. The method ensures that information collected during ISO encounters is maximized, even with large uncertainties about the object's location. The approach relies on a mathematical system that predicts where an ISO is likely to be, represented as a three-dimensional ellipsoid. It ensures this uncertainty is managed efficiently using advanced probabilistic techniques. The proposed framework determines the best positions for multiple spacecraft around the predicted ISO location to capture the most useful data, such as visual images, while considering factors like spacecraft camera capabilities and the uncertainty of the ISO's position. Simulations using hypothetical ISOs show that this method effectively allows each spacecraft to decide where to go and how many areas of interest to study, maximizing the scientific return while minimizing resource use.

The Future of Antimatter Propulsion

The International Journal of Thermofluids published a preprint on 7 December 2024, titled *Future of Antimatter Production, Storage, Control, and Annihilation Applications in Propulsion Technologies* by Sawsan Ammar Omira et al of United Arab Emirates University (www.sciencedirect.com/science/article/pii/S2666202724004518). The paper explores the potential of antimatter as a propulsion technology for space exploration, emphasizing its unparalleled energy density and efficiency compared to conventional and nuclear propulsion methods. Antimatter-matter annihilation releases energy at an extraordinary rate, with up to 70% of the energy being harnessed for propulsion. This technology could make interstellar travel feasible within a human lifetime, enabling missions to distant stars in weeks or months instead of decades.

The study addresses the challenges of antimatter production, storage, and control, which are significant barriers to its practical application. Current technologies allow for the production and trapping of small amounts of antimatter, but scaling this for propulsion remains a challenge due to the immense energy costs and technological limitations. Proposed solutions include advanced magnetic and cryogenic traps for stable storage and innovative propulsion system designs like beamed-core and plasma-core engines.

Self-Sustaining Space Habitats

R Wordsworth and C Cockell of Harvard released a paper on arXiv on 5 December 2024 titled *Self-sustaining living habitats in extraterrestrial environments* (arxiv.org/abs/2409.14477). The paper explores the concept of creating biologically self-sustaining habitats in extraterrestrial environments, challenging the traditional assumption that life requires Earth-like planetary conditions. The authors propose that ecosystems capable of generating and maintaining their own habitable conditions are theoretically feasible, even in harsh environments like space or planets with thin atmospheres.

Key challenges to life in such environments—pressure, temperature, volatile loss, radiation, and nutrient availability—are analyzed, with potential solutions rooted in biological materials and processes. For example, biologically generated barriers could regulate temperature and pressure, prevent volatile loss, and shield against harmful radiation while allowing sufficient light for photosynthesis. The study also highlights the potential for using bioplastics and biominerals to construct habitat walls, drawing parallels to naturally occurring biological structures. These self-contained habitats have implications not only for astrobiology but also for human space exploration. The research also considers the detectability of such systems on other planets, offering a new perspective on biosignatures in the search for extraterrestrial life.

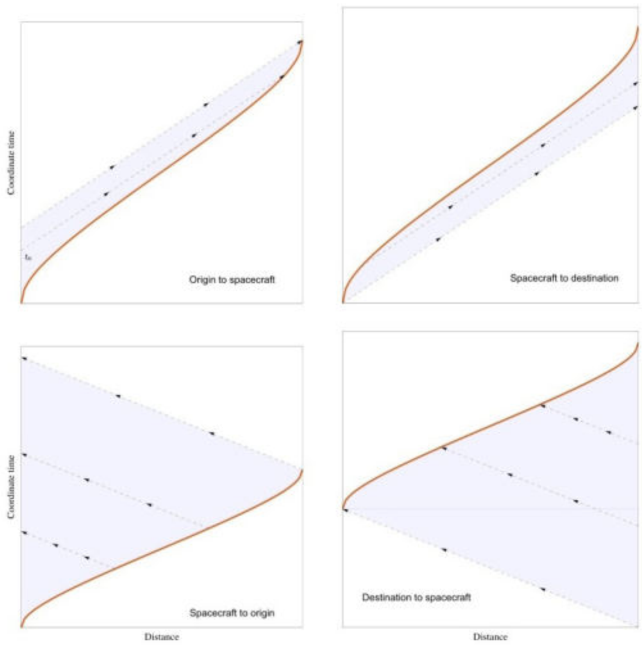
Prototyping a Plasma Thruster

Yuxuan Huang et al of the Chinese Academy of Sciences published a paper on 26 December 2024 in IOP's Plasma Science and Technology Journal titled *Design and experimental study of a field-reversed configuration plasma thruster prototype* (iopscience.iop.org/article/10.1088/2058-6272/ada376/meta). The study introduces the design and experimental testing of a prototype Field-Reversed Configuration (FRC) plasma thruster powered by a rotating magnetic field (RMF). This advanced propulsion system is intended for deep-space exploration, promising higher efficiency, longer operational lifespans, and higher specific impulses compared to traditional chemical and electric thrusters. The RMF-FRC thruster works by ionizing a propellant to create plasma, which is then driven by RMF to form a reversed magnetic field configuration, propelling the spacecraft through electromagnetic forces.

The research involved building a prototype with a 210 kHz RMF and a peak current of 2 kA. Experimental tests achieved a plasma density increase from $5*10^{17}$ m^{-3} to $2.2*10^{15}$ m^{-3} and a plasma current peak of 1.9 kA, confirming successful FRC formation. Optimizing the magnetic field bias to 100 Gauss resulted in the best plasma performance. The prototype demonstrated an RMF coupling efficiency of 53%, surpassing existing FRC thruster designs.

While promising, challenges such as low initial plasma density and energy losses during ionization remain. Future improvements will focus on enhancing the RMF strength and pre-ionization techniques to maximize efficiency. The study highlights the RMF-FRC thruster's potential as a cutting-edge propulsion solution for future space missions.

hindered by safety risks, regulatory challenges, and high development costs. Chemical rockets, the most mature technology, remain indispensable for launch phases due to their high thrust but are less efficient and unsuitable for prolonged missions. Ion Thrusters and Plasma Propulsion Systems excel in efficiency, achieving exceptionally high specific impulses, which reduce propellant needs for long-duration missions. However, their low thrust levels and high energy demands limit their use in deep-space propulsion. NEP offers a balanced approach with moderate thrust and efficiency, but its complexity and high costs present significant challenges. The paper concludes that the optimal propulsion technology depends on mission-specific requirements, and further research into hybrid systems is necessary.



Communications Challenges in Interstellar Travel

Illustration of the time constraints on communication during a spacecraft's travel from launch to landing for the canonical mission. The spacecraft trajectory is the solid line, and photon trajectories to and from the spacecraft and to and from the origin and destination are shown as dashed lines. Each shaded region represents the ensemble of all feasible photon trajectories which intersect the spacecraft trajectory during its cruise phase. The most significant influence on this ensemble shape is the direction of photon propagation.
Credit: Messerschmitt et al Figure 4

Comparing Propulsion Technologies

Aun Abbas released a preprint on engrXiv titled *Comparative Analysis of Rocket Engine Technologies for Long-Term Space Exploration* on 26 December 2024 (engrxiv.org/preprint/view/4258). The paper provides a comparative analysis of five major rocket engine technologies–Nuclear Thermal Propulsion (NTP), Chemical Rocket Engines, Ion Thrusters, Nuclear Electric Propulsion (NEP), and Plasma Propulsion Systems–evaluating their suitability for long-term space exploration. The study examines these technologies across several criteria, including efficiency, thrust, energy consumption, safety, cost, scalability, environmental impact, reliability, and technological readiness.

NTP systems are highlighted for their high efficiency and moderate thrust, making them suitable for missions requiring rapid acceleration and significant payload capacity, such as crewed Mars missions. However, their implementation is

Communications Challenges in Interstellar Travel

David Messerschmitt et al of the University of California at Berkeley recently released a preprint on arXiv titled *Timing relationships and resulting communications challenges in relativistic travel* (arxiv.org/abs/2311.14039). The paper explores the challenges and timing intricacies involved in communication during interstellar travel, specifically for spacecraft travelling near the speed of light. It investigates how classical and relativistic effects, such as large photon propagation delays and time dilation, impact the transmission and reception of messages between a spacecraft and entities at its origin and destination. Two mission profiles are considered: one involving indefinite constant acceleration and another with a cruise phase featuring acceleration followed by deceleration. These scenarios highlight the difficulties of maintaining real-time communication due to effects like clock inconsistency and communication blackouts.

The study emphasizes key issues, such as query-response latencies, which can severely delay two-way interactions, and the warping of time experienced during one-way message streaming. For example, photons traveling in the same direction as the spacecraft may not reach their target until much later in the journey, leading to significant delays in communication. The findings underline the necessity for autonomous spacecraft operations during most of the mission and demonstrate that maintaining continuous communication with the spacecraft, while theoretically beneficial, faces profound practical challenges. The study concludes by suggesting that interstellar communication systems must account for these effects to ensure mission success and data integrity.

Gravitational Communication

Cornell's preprint server arXiv released a preprint by Houtianfu Wang on 26 December 2024. titled *Gravitational Communication: Fundamentals, State-of-the-Art, and Future Vision* (arxiv.org/abs/2501.03251). The paper explores the emerging field of gravitational communication, examining the fundamental principles, challenges, and future possibilities of using gravitational waves as a medium for information transmission. Gravitational waves, ripples in spacetime caused by massive accelerating objects like merging black holes, have unique propagation characteristics that allow them to penetrate dense materials and travel across vast cosmic distances with minimal signal loss. This makes them a promising alternative to traditional electromagnetic communication, particularly in extreme or shielded environments.

The paper reviews methods for generating gravitational waves in laboratory conditions, including mechanical resonance, superconducting materials, and particle collisions, although practical generation remains a significant hurdle. Detection technologies, such as laser interferometry and emerging techniques leveraging deep learning, have improved sensitivity but are primarily optimized for astrophysical signals rather than engineered communication systems. Modulation techniques are also explored, highlighting the potential to encode and transmit information through gravitational waves. Despite its promise, the field faces challenges such as weak signal generation, low detection sensitivity, and the impact of cosmic environments on wave propagation. The paper calls for interdisciplinary research to address these barriers, envisioning gravitational communication as a revolutionary advancement in both physics and information technology.

High-Frequency Radio SETI Searches

The Royal Astronomical Society published a paper by Louisa A Mason et al of University of Manchester on 10 December 2024, titled *Conducting high-frequency radio SETI searches using ALMA* (academic.oup.com/mnras/advance-article/doi/10.1093/mnras/stae2714/7920797?login=false). The paper presents the first search for technosignatures—signals potentially from extraterrestrial intelligence—using the Atacama Large Millimeter/Submillimeter Array (ALMA). The study focuses on high-frequency radio observations, exploring ALMA's unique capability to detect narrowband signals in the millimeter and submillimeter wavelength ranges, an area largely unexplored in previous SETI (Search for Extraterrestrial Intelligence) research.

The researchers analyzed archival ALMA data targeting 28 stars identified in the Gaia DR3 catalog. The search specifically looked for narrowband signals with high signal-to-noise ratios, which could indicate artificial transmitters. Despite the high sensitivity of ALMA, no technosignatures were detected at the analyzed frequencies. The study highlights ALMA's potential for SETI research, emphasizing its sensitivity, ability to reduce interference, and capability to explore new frequency ranges. However, challenges like signal drift due to relative motion and spectral confusion from natural astrophysical emissions were noted. The authors propose future improvements, including dedicated SETI backends and advanced signal processing techniques, to enhance ALMA's effectiveness for detecting extraterrestrial signals.