Digital Twin-Driven Predictive Maintenance for Space Resource Extraction Facilities

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Digital twin (DT) technology is a transformative tool for space resource extraction, enabling predictive maintenance for facilities on the Moon, Mars, and asteroids. By integrating physics-based models with real-time sensor data and AI, the DT creates a dynamic mirror of equipment health. This framework utilizes lifetime learning and robust data fusion from hard and soft sensors to adapt to evolving conditions and predict component failures. Validated through a simulated lunar mining testbed, this approach significantly reduces unplanned downtime and supports autonomous decision-making in remote, harsh environments.

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Synergistic Synthesis of a Hydrogen-Rich

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Background: Transitioning toward long-duration crewed exploration of the Moon and Mars is compromised by cumulative biological damage from Galactic Cosmic Rays (GCR). Traditional Aluminum shielding is flawed as it triggers nuclear fragmentation, producing hazardous secondary neutrons.

Objectives: This study presents a multi-disciplinary approach by synthesizing a sustainable "Bio-Shield" composite derived from processed human biological waste via In-Situ Resource Utilization (ISRU). The goal is to evaluate the material's efficacy in preserving DNA integrity.

Methods: The composite was engineered as a high-hydrogen organic matrix (52.53% Carbon, 6.77% Hydrogen), stabilized by Epoxidized Soybean Oil (ESO). Radiation attenuation was analyzed using the NIST XCOM database (0.001 to 1000 MeV). "Flight Readiness" was validated via LAMMPS molecular dynamics (MD) simulations under ASTM E595 thermal-vacuum standards at 398.15 K.

Results: The Bio-Shield demonstrated definitive superiority over Aluminum. At 1 MeV, it required approximately 20% less mass thickness for equivalent attenuation. LAMMPS simulations verified thermodynamic stability, with hydrogen atoms remaining chemically anchored within the matrix, preventing outgassing in vacuum conditions.

Conclusions: This research establishes a new paradigm: transforming metabolic waste from a logistical liability into a strategic protective asset. The Bio-Shield fosters a circular space economy, providing a mass-efficient roadmap for safeguarding astronaut health during Artemis missions and beyond.

Unconventional means for space resources extraction and in-space manufacturing - the inadequacy of contemporary space law.

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The conceptual speculations on space mining have preceded similar works regarding space law. Both concepts have been resonating with each other during the initial phase of the early space age, and have remained connected since then. However, while the evolution of international space law was shaped by the circumstances of the Cold War, its further development has been slowed to a near halt. In contrast, the evolution of space resource concepts has carried on, shaped by different factors. This has given rise to numerous proposals for ISRU, in-space manufacturing as well as large scale construction in Earth Orbit. Among them are more novel concepts that introduce the use of microorganisms, lichen or fungi into the extraterrestrial extraction process, along with creating groups of machines forming swarms or “ecosystems”. It is here where the broader understanding of space resource activities resides and where the restrictive legal environment might force space mining and manufacturing regulations to search for its “new habitat” beyond the framework established by corpus iuris spatialis. This presentation aims to showcase selected unconventional space mining technologies and discuss the reason for space mining regulations - which are still shaped by the provisions of International Space Law - migrate towards different legal environments in search for closure.

Harvesting Light Energy in Space and Earth Without Sunlight

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Harvesting light energy in space can open the door to cleaner-lasting,and smarter missions even when sunlight is partially blocked or without sunlight. Reliance on sunlight is one of the quietest weaknesses in current space systems.The research aims to develop a conceptual design for harvesting light energy in space without sunlight.This structure using broadband dielectric optical mirror panels with high reflectivity in the visible range,and solar panels will be established inside in such a way that when artificial light enters the interior,equal amounts of light fall on each solar cell due to reflection.The main purpose of this structure is to ensure that the amount of electricity generated from solar panels is more than the amount of electricity consumed by the artificial light.This innovation significantly enhances with the extension of space mission duration,spacecraft's dependence on the sun will decrease and at the same time a new dimension will be added to energy harvesting on earth and in space.

Solid Earth Tide Residuals as Indicators of the 18.6-Year Lunar Nodal Cycle in GNSS Time Series

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In GNSS time series, Solid Earth tides stand out with high precision model in geodetic signals, the residuals that remain in GNSS time series continue to hint at unresolved long-period dynamics. The small residual that remains even after conventional tidal correction is not just noise-they may contain signatures of long-period geophysical processes hidden within geodetic observations. The 18.6-year lunar nodal cycle is particularly important in this context,as it can affect deformation patterns over long periods of time by changing the pattern of tidal forcing. The present study seeks to determine whether the small residual signals left after standard tidal correction in GNSS time series, this study will extract low-frequency geophysical information that is hidden beneath short-term noise and environmental fluctuations. After correcting for major tidal signals and other known periodic effects, the residual displacement record will be analyzed using spectral analysis and time-series decomposition. One of the main challenges of this research is to separate the potential 18.6-year nodal signal from other low-frequency variations such as hydrological loading and atmospheric effects. Comparative analysis of long-term GNSS stations will show how stable and detectable this nodal signal is in different geodetic environments. By revealing, this study aims to clarify how long-term unresolved tidal effects can affect decadal geodetic observations. If the 18.6-year lunar nodal cycle is detected in residual GNSS signals, it would be strong evidence that these effects need to be explicitly included in precision geodesy.

VERNACULAR ARCHITECTURE AS A BLUEPRINT FOR EXTRATERRESTRIAL HABITATS

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First extraterrestrial habitats will be a new form of vernacular architecture - highly efficient and reliant on local resources. As we prepare for permanent missions to the Moon and Mars, designing sustainable off-world shelters is critical. This paper proposes that Earth's traditional architectures provide powerful inspiration for space infrastructure.

Vernacular builders practice extreme In-Situ Resource Utilization (ISRU) and zero-waste philosophies, extracting materials from seemingly barren environments. Their creations prioritize human-scale prefabrication, efficient spatial planning, climatic performance, and autonomous maintainability.

Crucially, building on the Moon or Mars presents the same fundamental constraints. Though modern space structures are technologically scaled up, environmental pressures are of a comparable magnitude for historical societies navigating their own extremes. This proves that every environment is hostile until adapted to by specific architecture. By examining indigenous constructions from the Arctic to the Amazon, traditional building logic can be categorized into three domains: Materials, Forms, and Performance.

These historical, technical innovations are synthesized into an abstract framework of design principles to inspire space designers, demonstrating that the key to surviving off-world lies in the ancestral wisdom of how humans adapt to extremes on Earth.

Data-Driven and Simplified Crank–Nicolson Model for Heat Distribution in Habitat 1.0

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Efficient thermal control is essential for comfort, safety and energy use inside closed habitats. During the EMMPOL25 analog mission at Habitat 1.0 AATC, temperature data was recorded in two rooms using Netatmo sensors placed at different heights. In this work we develop a simple, data-driven model of heat distribution based on the heat diffusion equation. Physical parameters such as thermal diffusivity, heat transfer coefficient and heater power were estimated from warm-up and cool-down segments of the sensor data. The heat equation was then solved numerically in two dimensions using the Crank-Nicolson method. Simulation results show realistic temperature evolution and spatial heat spreading that agrees with recorded measurements. The approach is lightweight, requires minimal input, and demonstrates that even a simplified model can capture the main thermal behaviour of small habitat rooms. This work provides a practical basis for future improvements toward more advanced habitat thermal control and energy planning.

Numerical Analysis of Structural Alkali-Activated Regolith Partitions in Lunar Lava Tubes

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Lunar lava tubes, naturally occurring subsurface tunnels, are widely recognized as promising locations for future lunar bases due to their inherent protection against cosmic radiation, micrometeoroid impacts, and extreme temperature variations. The establishment of a breathable atmosphere within such structures requires the maintenance of adequate internal pressure; however, the stabilization of large-scale cavities and the mitigation of crack propagation remain critical challenges. This study proposes a conceptual design for a vertical internal partition within a lunar lava tube. The partition is composed of lunar regolith alkali-activated material, in accordance with in-situ resource utilisation (ISRU) principles. The structural performance of the proposed solution is evaluated using finite element method (FEM)-based numerical simulations that incorporate the effects of lunar environmental conditions, including loading induced by internal–external pressure differentials. The results demonstrate that the regolith-based geopolymer partition can effectively isolate a confined section of the lava tube while limiting stress transfer to the surrounding rock mass, thereby reducing the risk of structural instability. The proposed concept enables the formation of controlled habitable zones and supports the maintenance of atmospheric pressure levels suitable for human activity while preserving the structural integrity of the natural formation

Why Is Effective DEM Calibration for Extraterrestrial Regolith Still Out of Reach?

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Space agencies are pursuing sustained lunar and Martian missions, where in-situ resource utilization (ISRU) is essential. In this context, the Discrete Element Method (DEM) is considered a key tool for modeling regolith, as well as regolith–machine and regolith–fluid interactions under extraterrestrial conditions. However, despite recent advances, effective DEM calibration for extraterrestrial regolith remains out of reach.

Current calibration approaches rely primarily on terrestrial laboratory experiments using regolith simulants and simplified tests, which can reproduce selected responses for specific scenarios. While Earth-based facilities can simulate extreme temperatures, vacuum, and radiation, they cannot provide sustained reduced-gravity conditions. Short-duration platforms such as drop towers or parabolic flights also offer only seconds of altered gravity, making them unsuitable for standard geotechnical testing. As a result, key parameters such as cohesion and internal friction angle can be reliably determined only under Earth gravity, while equivalent measurements for reduced-gravity environments remain unavailable. Consequently, DEM calibration lead to non-unique, scenario-dependent solution.

To function as a virtual testing environment, a DEM model must respond consistently across varying gravitational conditions, as real regolith does. However, this is currently not achievable, and a transferable calibration framework across gravity regimes remains unavailable, limiting predictive capability for ISRU system design.

Without gravity-consistent calibration, DEM remains a tool for reproducing experiments rather than predicting regolith behavior in extraterrestrial environments.

Possibilities of applying the constructed wetlands in lunar base conditions

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Future lunar and Martian bases will be essential for long-term space exploration. A key challenge will be securing water resources and closing the water cycle. Constructed wetlands may offer a promising low-energy stage in domestic wastewater treatment, producing effluent suitable for further polishing and reuse. Such systems may also provide secondary functions, including biomass production and possible support for air revitalisation through plant-based CO_2 uptake.

This study assesses the potential use of constructed wetlands for treating domestic wastewater generated by crew members, and selected additional streams, in a lunar or Martian base. The first stage will identify key needs, constraints and technical possibilities. A conceptual model of a constructed wetland module will then be developed. Its primary function will be wastewater treatment as part of water recovery. Additional functions and local conditions, including food production, air purification, substrate availability, space demand, energy use and materials, will also be considered. The model will be compared with selected physicochemical and bioregenerative options.

The practical stage will include lab and pilot-scale experiments in a bed filled with lunar regolith simulant, with reference to Martian conditions. It will focus on edible plants with edible biomass above the substrate, aiming to combine wastewater treatment with safe biomass production. The results will verify and refine the conceptual model.

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Air Permeability of Alkali-Activated Regolith Based Materials for Lunar Construction

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Establishing a long-term human presence on the Moon requires the development of construction materials capable of ensuring safety under extreme environmental conditions. This study examines the air permeability of alkali-activated materials (AAMs) incorporating a lunar regolith simulant to evaluate their suitability for lunar habitat applications. Experimental tests were performed using a dedicated apparatus to determine the permeability coefficient under simulated extraterrestrial conditions by monitoring air pressure changes as gas flowed from an atmospheric-pressure chamber into a vacuum chamber through the material sample. The results demonstrate that AAMs exhibit low air permeability, comparable to conventional brittle materials, and that the addition of the regolith simulant does not adversely affect this property, supporting their applicability within in-situ resource utilization (ISRU) strategies. Furthermore, the relationship between permeability and internal pressure decay was analyzed to assess operational safety margins. Calculations indicate that AAM-based structures are capable of maintaining safe internal pressure levels for several hours in the event of sealing layer failure, providing a critical time window for leak detection and mitigation. These findings confirm that AAMs represent a promising material for the safe and sustainable construction of lunar habitats, combining adequate mechanical performance with the potential for local resource utilization.

Conceptual Design of an Extraterrestrial Regolith Excavation and Beneficiation Unit System (EREBUS)

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Space resource utilization requires compact and energy-efficient systems capable of operating directly on planetary surfaces. This work presents the conceptual design of EREBUS-an Extraterrestrial Regolith Excavation and Beneficiation Unit System-based on an edge-processing approach, where excavation, transport, and sorting are performed locally within a single integrated machine.

The proposed platform enables continuous regolith harvesting through two main stages: soil loosening using a rotary tiller and collection using a bucket wheel. The bucket wheel simultaneously transports material to an onboard rotary sieve, where particle size separation is performed in situ. Desired fractions are stored in dedicated tanks, while oversized particles are rejected back onto the surface, minimizing unnecessary material handling.

The system operates in two modes: mobility mode, allowing bidirectional movement, and excavation mode, enabling controlled low-speed harvesting in a single direction. The edge-based architecture allows the beneficiation process to continue independently of mobility, improving operational efficiency.

By shifting regolith processing from centralized facilities to an edge-based, in-situ system, EREBUS reduces energy demands and logistical complexity, supporting scalable extraterrestrial mining operations.

Remote Sensing–Based One-Class Classification for National-Scale Tree Species Mapping: Oriental Beech in Türkiye

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One-class classification provides a practical alternative for large-scale species mapping when reliable presence data are available but representative absence samples are limited. This study develops a remote sensing–based one-class classification framework for national-scale tree species mapping, using Oriental beech (*Fagus orientalis* Lipsky) in Türkiye as a case study. Multi-temporal Sentinel-2 imagery was processed in Google Earth Engine to capture seasonal spectral and phenological characteristics of the target species. Spectral bands, vegetation indices, and environmental variables were evaluated to identify the most informative predictor combinations. Presence records of Oriental beech were used to characterize the spectral feature space of the species, while independent presence and background samples supported model evaluation. Alternative seasonal datasets, predictor configurations, and classification thresholds were compared to assess model robustness and transferability. The resulting model identified the major distribution areas of Oriental beech across Türkiye and demonstrated the potential of one-class approaches for species-level mapping over large and environmentally heterogeneous regions. The proposed framework reduces dependence on exhaustive non-target training data and offers a transferable methodology for mapping other tree species with limited reference information.

Beyond Individual Missions: Designing a Cumulative Impact Assessment Framework for Lunar Resource Activities

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Growing interest in lunar resource extraction has raised concerns about the environmental consequences of sustained human activities on the Moon. Existing regulatory approaches assess impacts on a mission-by-mission basis but fail to address the aggregate effects of continuous and overlapping lunar resource activities. Although scholars increasingly recognise the risk of cumulative environmental harm, international space law lacks a framework for assessing impacts that accumulate over time.

This paper asks: How can international space law develop a cumulative impact assessment framework capable of addressing the combined environmental effects of recurring lunar resource activities? To answer this question, the paper undertakes a doctrinal analysis of the Outer Space Treaty and related governance instruments, together with a comparative examination of terrestrial cumulative impact assessment regimes and deep-seabed mining governance under the International Seabed Authority.

The paper argues that mission-specific environmental assessments will be insufficient for future large-scale lunar resource utilisation. It therefore proposes a Lunar Cumulative Impact Assessment (LCIA) framework incorporating staged licensing, continuous monitoring, cumulative environmental data collection, and periodic environmental reviews across multiple missions and operators. By focusing on aggregated environmental effects, the framework seeks to strengthen the long-term sustainability of lunar resource governance.

Information Sharing for Space Resource Activities on Celestial Bodies: Adapting the High Seas Treaty Clearing-House Mechanism to Outer Space

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With the expected increase in commercial and scientific activities involving the use of natural resources found on celestial bodies, disseminating and providing access to information and data concerning space resource activities is pivotal for ensuring a safe and peaceful space environment. From an international legal standpoint, the sharing of information on space resource activities on celestial bodies, is primarily regulated by Article XI of the Outer Space Treaty (OST). However, Article XI OST still contains ambiguities and gaps, as well as practical barriers, which effectively render it underused. This paper analyses the current gaps and ambiguities found in Article XI OST and engages in proposed solutions by adapting parts of the regulations of the Clearing-House Mechanism (CHM) established in the High Seas Treaty, also known as the BBNJ. The paper intends to demonstrate how establishing a CHM with similar regulations, tailored to space resource activities on celestial bodies, could help to bridge the gaps found in Article XI OST, facilitate the sharing of information and data on such activities, and support the development of an effective international governance framework for space resources. As such, this paper contributes to the broader discussion on information sharing in the context of space resource activities on celestial bodies, and advocates for the establishment of a 'Space Resources Clearing-House Mechanism' as the informational infrastructure.

Automated Space Weather Monitoring: From Raw Data to Visualization

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Space weather events pose significant risks to satellite operations, communications, and navigation systems. However, monitoring and analysis are often hindered by fragmented access to data products and repetitive manual processing of frequently updated measurements.

This paper presents a fully automated, reproducible pipeline for acquiring, processing, and visualizing space weather parameters from the NOAA Space Weather Prediction Center. The system employs asynchronous Python components for efficient data retrieval, with scheduled execution orchestrated via GitHub Actions to enable regular, automated updates. Processed data are normalized and stored in a serverless PostgreSQL backend, supporting long-term access and efficient querying. An interactive dashboard built with Streamlit enables exploration of key indices such as the Kp index and interplanetary magnetic field parameters.

Beyond archival access, the system supports rapid visual inspection of potential extreme space weather events by highlighting elevated geomagnetic activity and abrupt variations in solar wind parameters. This enables users to track storm evolution within a unified interface.

The pipeline achieves end-to-end update latency under four minutes per cycle, improving the availability of near-real-time space weather data and providing a unified workflow for analysis and visualization of geophysical conditions.

A Governance Framework for Planetary Defense: Leadership, Cooperative Cost Allocation, and Article IX Sustainability Constraints

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Planetary defense represents a paradigmatic global collective action problem, where technical feasibility, political legitimacy, and cost allocation are tightly interlinked. This paper proposes an integrated decision-support framework to address the distribution of financial responsibility and liability in international planetary defense missions. The framework combines a leadership-based financing mechanism inspired by the Stackelberg paradigm with a cooperative Shapley-value allocation process. A tolerability threshold inspired by Article IX of the Outer Space Treaty is introduced to incorporate political and legal sustainability constraints associated with potential collateral damages. Through a simulation-based case study employing Design of Experiments and Latin Hypercube Sampling, the analysis shows that strong leadership commitment alone does not guarantee mission viability or legitimacy. Instead, optimal outcomes emerge from a balanced interaction among financial coverage, expected damage reduction, and internationally acceptable risk thresholds. The results highlight the importance of quantitatively grounded governance frameworks to support cooperative planetary defense decision-making under uncertainty.

From Risk to Resilience: Dynamic Assessment of Complex Aerospace Networks Under Operational Stress Using European Air Transport as a Case Study

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Conventional resilience assessments evaluate aerospace network robustness under average conditions, systematically underestimating vulnerability during elevated stress, a critical gap where resilience depends on interactions between operational performance, structural concentration, and temporal demand cycles. This study develops a dynamic resilience framework integrating trajectory-derived operational metrics, network-theoretic diagnostics, and a composite stress indicator, applied to European air transport as a dual-use case study. ADS-B data (OpenSky Network, 2021–2025) and Eurostat statistics provide the foundation; a Rome Fiumicino-centred subnetwork with unusually concentrated structural dependence serves as context. Three levels are integrated: operationally, excess minutes (median 7.2–8.5 min) and stretch ratios quantify persistent inefficiency across five traffic regimes; structurally, hub removal collapses network efficiency from 0.506 to zero against 15–20% losses for secondary nodes; temporally, Italy's seasonal amplitude (67.7%; peak-to-trough ratio 1.7–2.2) exceeds Germany (~25%) and France (~30%), a recurring stress test on a fragile configuration. Operational inefficiency, structural centrality and temporal amplification jointly amplify systemic vulnerability, producing disproportionate consequences invisible to isolated analyses. The framework extends to space traffic management architectures and satellite constellations under analogous dual-use pressures.

Robustness of swarm consensus under faulty or compromised rovers

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Autonomous robotic teams are becoming a key component of in-situ resource utilization, where rovers will need to concur on a shared map and decide on the prospecting locations in the absence of human supervision. The basis for this concurrence is distributed consensus, which can deteriorate if some rovers fail, get stuck, or are even taken over by a malicious agent. Our model of a multi-rover team is essentially a network of rovers that are all aiming to agree on a single decision, and we have introduced "zealotry": rovers that, due to sensor failure or being fed false information, are stuck on a particular belief.

We looked at two types of behavior. With simple DeGroot averaging a single zealot can, in the long run, influence the whole connected team, meaning that a naive consensus is inherently insecure. By contrast, using bounded-confidence (Hegselmann-Krause) dynamics where rovers disregard beliefs that differ too much from their own, the group is very resilient: even with zealots placed randomly, it manages to reach the correct decision with up to about 10% of agents compromised before it either fails to converge or tilts towards the adversary's target.

However, the critical factor is not how many agents are compromised, but their locations. On scale-free networks, a single zealot positioned on a high-degree hub can influence the entire team, while numerous poorly connected ones have little impact. A third factor is the confidence radius: rovers that listen too broadly are vulnerable to being manipulated, whereas those with very narrow listening ranges become disjointed. We have adapted our findings into prospecting swarm design rules that ensure reliability even when individual rovers are untrustworthy.

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A pilot study on the susceptibility of Staphylococcus aureus to antimicrobial blue light after high-altitude stratospheric flight on the PERUN rocket.

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S. aureus is one of the most medically significant opportunistic pathogens in the context of future long-duration crewed missions. It is well established that exposure to spaceflight-related environmental stressors can alter microbial virulence, physiology, and responses to stress factors. The aim of the present pilot study was to assess the effect of high-altitude stratospheric rocket flight on the sensitivity of *S. aureus* strains to antimicrobial blue light (with 409 and 415 nm), which is considered a promising method for decontamination during future long-distance space missions. Two *S. aureus* strains (MRSA and MSSA) were subjected to stratospheric flight conditions aboard the PERUN rocket. After recovery, the strains underwent four serial passages to stabilize their phenotype. Subsequently, both flight-exposed and ground-control strains were exposed to blue light at wavelengths of 409 nm and 415 nm for either 15 or 45 minutes. The antibacterial efficacy of the light treatment was assessed by determining the reduction in the number of viable cells. *S. aureus* strains exposed to stratospheric flight conditions exhibited significantly reduced susceptibility to blue light inactivation compared to control strains. The observed changes depended on both the bacterial strain and the wavelength applied. The results indicate that exposure to stress factors present in the stratosphere may induce adaptive responses in microorganisms that increase their tolerance to oxidative damage generated during blue light exposure. The observed phenomenon highlights the need for further research on microbial adaptation to extreme environments and its implications for the effectiveness of light-based decontamination strategies.

Development of a Communication Protocol for a Lunar Rover Swarm with a Central Base Hub

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The growing interest in establishing a permanent human presence on the Moon creates a need for autonomous robotic systems capable of operating in harsh and isolated environments. Reliable local communication between such systems is essential for coordination, task execution, fault recovery, and mission safety, yet it has received less attention than spacecraft-to-Earth communication.

This thesis presents the design, implementation, and evaluation of a communication protocol for a swarm of autonomous lunar mobile 3D-printing rovers. The system is based on ESP32-S3 microcontrollers and SX1262 LoRa transceivers and includes mechanisms for synchronization, routing, relay communication, acknowledgments, fault recovery, and network diagnostics.

The protocol was evaluated through experiments measuring communication range, signal quality, latency, routing performance, synchronization accuracy, packet loss, and behavior under simulated failures. The impact of LoRa parameters, including bandwidth, spreading factor, and coding rate, was also analyzed.

The results demonstrate reliable communication on resource-constrained hardware. The routing and recovery mechanisms restored connectivity after failures, while synchronization improved network stability by reducing packet collisions. The study also identifies limitations related to payload size, scalability, and clock drift, suggesting directions for future work.

Hillfort as an archaeoastronomical instrument – case study in Carpathian mountains

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For centuries, or even millennia, humans have conducted complex archaeoastronomical measurements and specific looking at the Sky. Natural landscapes served various archaeological cultures and communities for both agricultural and ritual purposes. This study focuses on the Polish Carpathians and examines nearly 44 early medieval hillforts, only some of which held significance for such measurements. The Horodyszcze hillfort in Trepcza (near Sanok) exhibited such characteristics, with origins dating back to the Celtic period before passing into Slavic control. Data from the National Geoportal and EU-DEM were used for the analysis. A four-class "archaeoastronomical factor" was developed to characterize these geoarchaeological sites. Modern GIS techniques and astronomical software (Stellarium) were applied. The study's primary outcome confirms the hypothesis regarding the use of the terrain surrounding specific hillforts for complex analysis; additionally, the study determined the orientation and spatial layout of the hillforts relative to the cardinal directions.

Human Footprints in Extreme Environments: Microbial Dispersion Around an Arctic Research Station in the Context of Future Space Habitats

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Human activity alters microbial communities even in remote environments. Understanding the spread of human-associated microorganisms is important for monitoring isolated ecosystems and developing contamination control strategies for future space habitats. The aim of this study was to determine the spatial extent of human-associated microorganisms around an Arctic research station. Approximately 20 soil samples were collected along a gradient of anthropogenic influence (research station, 1 m, 100 m, 1 km, and a virgin site) and analysed in three replicates. Serial dilutions (up to 10^{-3}) were cultured under conditions selective for mesophilic bacteria, psychrophilic bacteria, and fungi. Representative isolates were identified using MALDI-TOF MS. Microbial abundance and diversity decreased with increasing distance from the research station. Human-associated microorganisms remained detectable beyond the immediate vicinity of the station, whereas cold-adapted environmental taxa became dominant at more distant sites. Environmental bacteria, mainly *Bacillus*, *Peribacillus*, and *Pseudarthrobacter*, predominated, while opportunistic taxa, including *Bacillus cereus*, *Serratia marcescens*, *Enterococcus faecium*, and *Staphylococcus epidermidis*, were detected at low abundance. The most remote samples contained fewer culturable microorganisms and numerous dematiaceous fungi, such as *Ulocladium.* These results demonstrate that even limited human presence can influence microbial dispersion in extreme environments. The observed presence of opportunistic taxa highlights the need for further investigation of microbial dynamics in analogue settings relevant to future space habitats.

Astrometallurgy: The Challenges of Extraterrestrial Metal Processing

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Astrometallurgy: The Challenges of Extraterrestrial Metal Processing

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As terrestrial mining faces depleting resources and growing ecological challenges, the dawn of space exploration has birthed astrometallurgy—the science of processing metals in extraterrestrial environments. This paper examines the fundamental technological barriers of manufacturing metals beyond Earth, focusing on how microgravity alters basic fluid physics, eliminating buoyancy and sedimentation while promoting surface tension dominance. It highlights the harsh operational constraints of vacuum environments, such as radiative-only cooling, extreme thermal shifts, and abrasive lunar regolith. Finally, the overview explores cutting-edge In-Situ Resource Utilization (ISRU) prototypes, including molten regolith electrolysis, which extract life-supporting oxygen while producing high-purity metallic powders as a byproduct. These powders serve as essential feedstock for space-based 3D printing, laying the foundation for autonomous, off-world infrastructure despite current limitations in energy demand and component degradation.

World Model Discovery by Coordinated Autonomous Robots Exploring Unknown Space Environments

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This paper is devoted to the study of a novel world model (WM) learning approach that can support the exploration of icy moon and dwarf planet surfaces by coordinated teams of anticipatory robots. The presented procedures constitute key components of the AI/ML/Control software framework MoonEx for autonomous multi-robot space missions. First, we discuss state-of-the-art artificial intelligence and Machine Learning (ML) techniques for autonomous planetary surface robots, including our recent research on WMs and anticipatory coordination. We then present new concepts for multi-level robot decision-making and learning autonomy, featuring coordinated transfer- and federated learning within exploratory robot teams. Furthermore, we demonstrate how multicriteria multi-agent reinforcement learning can be integrated with complementary learning approaches, including self-supervised and semi-supervised learning. The proposed procedures enable the effective application of proactive robot swarm capabilities for multi-agent task allocation and path planning, while accounting for cumulative risks, mission duration, and the expected scientific value of exploration, focusing on potential near-surface liquid water reservoirs. In conclusion, we argue that the proposed approach effectively integrates anticipatory coordination with multi-agent ML methods to enhance the efficiency, reliability, and resilience of autonomous multi-robot missions operating in unknown and hostile environments

Smoldering coal-waste dumps as polyextreme habitats: a metagenomic characterization of their microbiomes

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Smoldering coal-waste dumps are anthropogenic polyextreme, highly heterogeneous environments characterized by elevated temperatures, extreme pH and salinity, high concentrations of heavy elements, and complex toxic organic compounds, creating steep geochemical gradients. Microorganisms, especially prokaryotes, can thrive under such conditions. Studying these extremophiles can provide insight into adaptations to harsh environments, which is relevant to multiple aspects of astrobiology, from the search for life beyond Earth, through planetary protection, to future biotechnological applications in space exploration. In this study, we investigated microbiomes from two smoldering coal-waste dumps in the Upper Silesia region of Poland using next-generation sequencing. For each dump, several environmentally distinct sites were analyzed. Shotgun metagenomic data were used to reconstruct metagenome-assembled genomes (MAGs), followed by phylogenetic placement, genome annotation, and metabolic potential analysis. The results revealed thriving and diverse microbiomes, including over 160 putative new species of *Bacteria* and *Archaea*. The study also resulted in high-quality MAGs representing previously poorly characterized taxa, allowing us to better understand their adaptations to extreme environments. Altogether, this study provides insights into microbial adaptation, habitability, and biogeochemical cycling under extreme, astrobiology-relevant conditions.

Leverage points, sustainability, and resilience for the lunar water-ice in-situ resource utilisation process

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In order to establish a long-term permanent human lunar presence, *in-situ* resource utilisation of lunar resources will be essential. The use of lunar water-ice will be particularly important for numerous systems that will comprise a future lunar base including: base operations (*i.e.,* life support), agriculture, and transport. Following a literature review of lunar water-ice deposits, and extraction and processing methods, this paper identifies areas of future use of lunar water-ice for a long-term human lunar presence and uses a system dynamics approach to model water use across the system. The system dynamics approach facilitates the identification of leverage points in the system (*i.e.,* areas in the system where a small change results in a big impact). The results of the system dynamics simulation and the subsequently identified leverage points enable for the development of recommendations for lunar infrastructure development, and the high-level design of the lunar water-ice extraction process chain. Considering the system dynamics results, leverage points, and recommendations, it is discussed how sustainability and resilience can be achieved throughout the system.

DEM Model Calibration of Regolith Simulant Using the Dynamic Angle of Repose

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The Discrete Element Method (DEM) is commonly applied in numerical simulations of granular media, but its accuracy depends strongly on the proper selection of model parameters. Therefore, calibration against experimental data is an essential step in DEM modelling. This work focuses on the use of the dynamic angle of repose as a reference quantity for calibrating a DEM model of granular flow in a rotating drum. The calibration is based on experiments performed under terrestrial gravity conditions. The obtained results provide a basis for evaluating and adjusting the numerical model parameters.

Psychophysiological Monitoring of Analog Astronauts During a One-Week Habitat Mission: A Pilot Study

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Space analog habitats provide unique opportunities to investigate adaptation to isolated and confined environments. This pilot study aimed to identify psychophysiological characteristics associated with task performance and adherence during a one-week analog habitat mission.

Five analog astronauts (Mage = 20.4 years; three females) completed a seven-day mission involving scientific experiments, operational tasks, prescribed physical training, and mindfulness practice. Baseline assessment included temperament (FCZ-KT), action control (ACS-90), body composition, and aerobic fitness. Individualized recommendations for physical training and mindfulness were developed based on psychological and physiological assessment.

Rhythmicity and endurance were associated with differences in task performance, time management, and adherence to prescribed training and mindfulness. Action Control profiles revealed consistently high performance-related action orientation but individual differences in planning, task initiation, and ruminating on setbacks. Engagement in scientific tasks appeared to depend primarily on self-regulatory competences, whereas adherence to routine mission tasks was associated with both psychological and physiological characteristics.

These findings suggest that psychophysiological profiling and monitoring may support personalized pre-mission preparation and the identification of crew members requiring additional behavioral support.

KGK2026 Abstract 0032

Beyond Licensing: From Regulatory Control to Fostering Innovation

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KGK2026 Abstract 0033

Radiation Resistant P-Topcon-Perovskite Tandem Solar Cells for Energy Harvesting in Space

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KGK2026 Abstract 0034

From Population Models to Personalized Physiological Intelligence in Human Space Exploration

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The Use of Satellite Technologies in Mapping Flood Extent and Analysis of Its Impact on the Availability of Ambulances in Flood Areas

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Climate-induced floods increasingly threaten crisis management systems, yet their cascading impacts on emergency medical services (EMS) remain understudied. This study presents a novel framework for assessing EMS operational disruption, utilizing the catastrophic September 2024 flood in southeastern Poland as a case study.

The methodology employs a multi-sensor remote sensing approach, integrating SAR and optical satellite imagery to delineate maximum flood extent. To quantify disruption, these flood vectors were combined with spatial road networks and a big-data repository of over 800 million ambulance GPS telemetry logs. This enabled granular velocity models separating "signals-on" versus "signals-off" modes while accounting for temporal variations. By algorithmically adjusting road parameters to reflect complete or partial inundation, we simulated altered routing behaviors and recalculated optimal paths to emergency calls. The modular architecture also allows integration with real-time UAV imagery and multi-agency dispatch feeds.

The spatial analysis generated a high-fidelity EMS Accessibility Map, explicitly identifying structural blind spots and isolated communities. Findings demonstrate that beyond physical network degradation, the flood caused a systemic reduction in asset distribution efficiency, bottlenecking broader rescue coordination. This scalable framework can be leveraged to optimize future ambulance station positioning and integrate real-time flood parameters into predictive emergency routing.

Remarks on Regulation of Space Mining Activity in Light of the Polish Act on Space Activity in the European Context

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In February 2026, the Polish Sejm passed the Act on Space Activity, constituting a long-awaited response by the Polish legislature to Poland's obligations arising from the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies of 1967. In keeping with the letter of the Treaty, the new Act seeks to comprehensively encompass the entirety of potential — or even merely hypothetical — activity in outer space, which is warranted in an era of technological and programmatic decentralization and privatization of the global exploration and use of outer space. Accordingly, although this Act does not refer to the subject of space mining, does not treat this field of legislation as an instrument of regulatory marketing, and does not expressly address other activity on the surface of other celestial bodies, it nonetheless not only unambiguously regulates such activity — as yet another field of activity in outer space — but expressly equips the national regulator with tools for delineating the framework of activity in outer space, such as the establishment of safety zones. This article analyzes the potential practical realities of applying the Polish Act to mining activity in space and to activity on the surfaces of other celestial bodies, in the context of global and European regulatory trends and proposals concerning the protection of activities conducted in deep space, the prevention of conflicts, and the sustainable use of that space, as well as the regulatory decisions of other states, including in particular European states.

Biological Service Layers for Lunar Habitats: A Systems Engineering Framework for Assessing Pioneer Organisms in Future Life-Support Architectures

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Future lunar habitats will require life-support architectures that are resilient, resource-efficient, and capable of operating with limited resupply. While current habitat concepts rely primarily on physicochemical and mechanical systems, biological components may offer complementary functions if they can be translated from survival studies into validated engineering services. This paper proposes a systems engineering framework to assess pioneer organisms as potential biological service layers in controlled lunar habitat environments.

The framework does not assume near-term operational readiness. Instead, it identifies candidate functions that require staged validation across five service layers: Atmosphere Management; Resource Cycling; Surface and Environmental Conditioning; System Resilience and Redundancy; and Ecological Succession.

By mapping these service layers against environmental control and life-support system requirements, the framework identifies candidate integration points where biological systems may complement physicochemical hardware, subject to laboratory, analog, and lunar demonstration testing. Particular attention is given to containment, reliability, maintainability, failure modes, and interface requirements. The paper argues that pioneer organisms should not be evaluated only by their ability to survive extreme conditions, but by their capacity to provide measurable, controllable, and mission-relevant services within habitat architectures.

This approach positions biological systems as a research pathway for future hybrid life-support concepts, rather than as replacements for established engineering solutions.

KGK2026 Abstract 0038

Deep Sintering of Lunar Regolith Simulants

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Sustainable lunar surface operations will require locally produced infrastructure such as landing pads, roads and foundations to reduce dust, improve mobility and limit transported mass. This contribution investigates Deep Viscous Sintering (DVS), an in-situ resource utilization approach in which lunar regolith is heated internally under vacuum to consolidate material below the surface instead of forming only a thin top layer.

The project uses mare-type lunar regolith simulants and mixtures with different basaltic glass fractions to represent glass-rich and agglutinate-like components of lunar soil. A ceramic heater is deployed into a regolith bed, while thermocouples record heat propagation and local heating rates. The influence of glass content, compaction and heating program on sintering onset, densification and sample integrity is evaluated. Hot-stage microscopy and furnace tests identify softening, deformation and flow temperatures and link these transitions to the deep-sintering response.

Initial results show that glass additions affect early neck formation, viscous bonding and the transition from fragile consolidation to coherent solid bodies. However, temperature gradients, cracking and heater adhesion remain key challenges for process control and scalability. Overall, the work develops Deep Viscous Sintering as a subsurface ISRU construction technology for producing mechanically stable, load-bearing lunar infrastructure directly from local regolith.

Compatibility of Struvite Crystallization and Microalgae in Nutrient-Concentrated Wastewater: Toward Bioregenerative Life Support

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Recovering nitrogen, phosphorus and magnesium from wastewater is a shared challenge for municipal wastewater management and bioregenerative life support systems (BLSS) in long-duration space habitats. Struvite (MgNH4PO4) crystallization offers an effective route to nutrient recovery, yielding a low-solubility, slow-release fertilizer suited to plant cultivation in resource-constrained habitats. In a closed-loop habitat, microalgae cultivation for oxygen and biomass production may need to be integrated with nutrient-recovery processes, so we tested whether struvite precipitation and microalgae can coexist in a single reactor without compromising nutrient recovery. Precipitation was performed using two parallel nutrient sources, a nanofiltration concentrate and an ion-exchange concentrate (both decalcified), combined with nitrogen-rich leachate obtained from excess-sludge dewatering and KH2PO4 at an Mg:NH_4:PO_4 molar ratio of 1:1:1 (pH 8.0–9.0, 25°C, 2–120 h). Microalgae were added directly (1–2% v/v), alongside an algae-free control. Under matched conditions (pH 8.5, 120 h), the algae-containing run outperformed the control for NH_4 (81.8% vs 62.1%), Mg (89.1% vs 84.4%) and Ca (9.5% vs 0%), while PO_4 removal was comparable (72.8% vs 75.8%). Precipitate mass likewise increased in the presence of microalgae (0.513 vs 0.458 g/0.25 L). These findings demonstrate that struvite crystallization and microalgae can coexist in a single reactor without compromising nutrient recovery, supporting more compact and resource-efficient BLSS for future lunar and Martian habitats.

Bio-derived oral-care materials for long-duration space missions: evaluation of in situ-produced toothpaste formulations

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Long-duration space missions require sustainable oral healthcare to maintain crew health. During rigorous medical screenings, potential astronauts must demonstrate perfect dental health prior to flight. Current space missions rely on terrestrial toothpastes, highlighting the need for formulations specifically designed for long-duration habitation. The experimental toothpastes were designed for in situ production using a cultivated fungal-bacterial consortium, reducing dependence on Earth-supplied consumables. This approach may reduce payload mass and improve the sustainability of future exploration missions. A series of three experiments was conducted on two experimental formulations, differing only in the presence of fluoride, and five commercially available toothpastes. The study compared their effects on demineralisation and remineralisation of synthetic hydroxyapatite and on the release kinetics of remineralising components. The analyses were performed using ICP-OES, SEM-EDS, and XRD. The experimental formulations supported hydroxyapatite remineralisation as effectively as the commercial formulations, demonstrating the potential of biologically derived oral-care materials for future long-duration space missions.

Towards a Computational Architecture for Behavioral Regulation in Embodied Autonomous Systems

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Understanding how adaptive behavior emerges from interactions between internal state and environmental context remains one of the fundamental challenges of computational cognitive science. Integrating explicit computational models of internal behavioral regulation with conventional robotic control architectures remains an open research challenge. This work presents an experimental framework for implementing and evaluating a computational architecture for behavioral regulation, using a computational model of personality as its first functional module. The framework is implemented in MATLAB/Simulink using a differential-drive mobile robot performing a line-following task. A conventional PID controller provides low-level motion control, while a decision layer implementing the computational personality model evaluates internal state variables together with environmental affordances and selects behavioral modes that dynamically modulate controller parameters. The proposed architecture is evaluated through a comparative experiment against a conventional PID-based solution, focusing on task completion, trajectory stability, disturbance recovery, behavioral variability, and tracking performance. Beyond the robotic implementation, the proposed architecture provides a foundation for investigating computational mechanisms
of behavioral regulation across embodied systems, supporting future research in computational cognitive science and autonomous robotics.

Astronaut Cognitive Efficiency Under Multi-Stressor Habitat Conditions: Noise, Stress, and Fatigue

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Introduction: Cognitive performance is critical for astronaut safety, yet isolation, cumulative fatigue, stress, and continuous habitat noise during space missions can severely impair it. This study investigates changes in sequential memory among a crew confined in an isolated analog space habitat under these multi-stressor conditions.
Materials and methods: The study involved 11 crew members during a 7-day international analog mission at AATC (Space_Ready program). Sequential memory was assessed using a custom-built Arduino system featuring a sound sensor, LEDs, and color-coded buttons (Simon-style test). Measured variables included maximum levels reached, reaction times, ambient noise, and subjective fatigue and stress levels (scales 1–10) analyzed on Days 1 and 7.
Results: Day 7 stressors—including confinement isolation, elevated stress, fatigue, and noise (58–72 dB)—triggered a universal increase in reaction times, fatigue, and stress across all crew members compared to Day 1. Communication Officer 2 exhibited the worst drop, with their fastest reaction time rising from 0.201 s to 1.294 s. Day 7 correlations showed that while ambient noise drove baseline task difficulty (r=0.6636 with Max Lvl), stress and fatigue directly degraded overall capability, showing strong negative correlations with the maximum level reached (r=-0.5196 and r=-0.3113, respectively).
Conclusion: The low-cost Arduino system effectively assessed neurobehavioral shifts. Confinement stress, cumulative fatigue, and noise exceeding 60 dB severely compromise cognitive speed, underscoring the critical need for strict acoustic engineering controls, psychological support, and optimized workload schedules in future space habitats.

KGK2026 Abstract 0043

Influence of Planetary Mineralogy and Biological Conditioning on the Functional Properties of Self-Organised Mineral–Organic Materials

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Future planetary exploration requires functional materials that can be manufactured from locally available mineral resources with minimal processing. Here, we investigated how planetary mineralogy and previous biological conditioning of mineral substrates influence the optical properties of mineral–organic materials assembled by a self-organising microbial consortium. Lunar mare regolith simulant, anorthosite and ilmenite were evaluated using two cultivation strategies: primary cultivation with an active microbial consortium and secondary cultivation on previously conditioned mineral substrates supplied with fresh nutrient medium. The optical properties of the resulting materials were evaluated using UV–Vis transmittance measurements. All investigated mineral substrates supported material formation but produced distinct UV transmittance characteristics. Secondary cultivation produced materials with lower UV transmittance than those obtained during the initial cultivation, indicating enhanced UV-shielding performance. These findings demonstrate that both planetary mineralogy and previous biological conditioning influence the emergent functional properties of self-organised mineral–organic materials and should be considered in the development of autonomous biological manufacturing strategies for future in situ resource utilisation (ISRU).

KGK2026 Abstract 0044

Tailoring Lunar Regolith Simulants for Mobile Selective Laser Melting and Site-Specific ISRU Construction - MOONRISE

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The aim of the MOONRISE project is to develop Mobile Selective Laser Melting (M-SLM) as a laser-based additive manufacturing approach for the in-situ fabrication of lunar infrastructure from local regolith. Within this framework, regolith simulant fidelity is a central factor for process optimization, as the feedstock directly affects melt pool formation, outgassing, porosity and the mechanical quality of the resulting structures. Terrestrial simulants can contain adsorbed H_2O, hydroxyl-bearing phases, oxidized iron phases and non-lunar impurities that may distort the behavior expected from lunar material. This contribution focuses on the preparation and characterization of high-fidelity lunar regolith simulants for M-SLM development. The simulants are volatile-reduced and iron-reduced to better approximate lunar environmental and chemical conditions. Their mineralogical, chemical and physical properties can be tailored to landing-site requirements, including mare or highland composition, glass content, particle-size distribution and site-specific phases. Linking tailored simulant production with laser melting experiments enables process parameter windows to be evaluated using feedstock that reflects realistic lunar variability rather than generic analogue material. This supports robust validation of laser-based ISRU manufacturing and contributes to autonomous, site-specific construction of landing pads, roads and surface infrastructure.

Microplastics as triggers of calcium phosphate precipitation in physiological fluids: implications for biomineralisation in future space habitats

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Long-duration spaceflight disrupts calcium–phosphate homeostasis through bone demineralisation, dehydration and altered fluid dynamics, increasing the risk of pathological biomineralisation. Whether particulate contaminants modify calcium phosphate precipitation under these conditions remains unknown. We tested if polystyrene microplastics modify calcium phosphate precipitation in a saliva-like fluid under undersaturated, saturated and supersaturated conditions. After 7 d, solution chemistry and precipitates were analysed by ICP and SEM-EDS. Microplastics most affected undersaturated and saturated systems, enhancing Ca and P depletion and shifting Ca/P ratios towards Ca–P compositions distinct from controls, whereas differences were minor in supersaturated solutions. SEM-EDS confirmed phosphate precipitation on microplastic particles, consistent with heterogeneous nucleation. These findings indicate that microplastics primarily modify precipitation pathways near the nucleation threshold rather than under thermodynamically favoured conditions. Such effects may affect biomineralisation in closed habitats and should be considered when assessing crew health during long-duration habitation. The results suggest that materials for future life-support systems should be evaluated for mechanical performance, toxicity and potential to influence physiological biomineralisation, introducing biomineralisation compatibility as a criterion for developing materials for future space habitats.

KGK2026 Abstract 0046

Autonomous Assembly of Mineral–Organic Material from Lunar Mare Regolith Simulant by a Self-Organising Microbial Consortium

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Future planetary exploration requires manufacturing strategies that minimise processing while maximising the use of local mineral resources. Here, we demonstrate that a self-organising microbial consortium directly assembles a flexible mineral–organic material from lunar mare regolith simulant during growth, without chemical purification, functionalisation or post-growth modification. The resulting material was characterised in its biologically assembled state. Mineral incorporation increased with regolith concentration while preserving flexibility and enhancing UV-shielding performance, demonstrating that biological self-assembly produced a material with emergent functional properties. Regolith previously exposed to the consortium promoted subsequent cellulose formation under simplified nutrient conditions, indicating persistent conditioning of the mineral growth environment. Following thermal treatment, the hybrid material yielded mineral residues distinct from those obtained from pristine regolith simulant or cellulose alone. These findings demonstrate a previously unexplored route for autonomous biological manufacturing from planetary mineral resources and provide a framework for investigating self-organising mineral–organic materials across diverse planetary environments.

Toward a Gamified Methodology for Studying Short, Lunar-Relevant Communication Delays

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Short lunar-relevant communication delays remain insufficiently studied in realistic mission contexts, and there is a need for standardized tasks that can support both risk characterization and future training studies. This proof-of-concept study evaluated whether a gamified, communication-intensive task can serve as an experimental testbed for research on delayed crew–Mission Control communication. Fourteen analog mission participants began the study and 13 completed it. Participants performed repeated Keep Talking and Nobody Explodes tasks while cooperating remotely with one of three Mission Control experts under 0, 5, 12, and 16 s one-way audio delays. Outcomes included task success, strikes, completion time, and perceived workload measured with NASA-TLX. Preliminary descriptive results indicate that the paradigm was sensitive both to delay and repeated exposure. Mean NASA-TLX increased from 4.4 at 0 s to 5.6 at 16 s, with the strongest increases in temporal and mental demand. At the same time, success rate improved across measurement days from 45.9% to 78.7% and 83.3%, while mean NASA-TLX decreased from 5.8 to 4.9 and 4.8, suggesting substantial learning and adaptation. These findings support the feasibility of using gamified collaborative tasks as repeatable platforms for studying short communication delays and for future evaluation of communication protocols, training, and other mitigation strategies in analog missions.

KGK2026 Abstract 0048

A Critical Appraisal of AI-Enabled Autonomous Space Systems under International Space Law

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KGK2026 Abstract 0049

Zero-copy Inter-Process Communication in Real-Time Audio Systems for Ground-Based Mission Control Centers

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Ground-based Mission Control Centers require ultra-low-latency audio distribution to sustain full-duplex Voice Loop communication during stratospheric and orbital missions. Conventional web-based architectures rely on repeated serialization and kernel-mediated data copying, introducing latency and jitter incompatible with NASA-STD-3001 responsiveness thresholds (100 ms). This work presents the Inter-Process Communication (IPC) layer of the Mission Control Panel (MCP), a system developed within the AGH Skylink project, designed around a zero-copy architecture using shared memory segments (multiprocessing.shared_memory).

Four independent memory segments are mapped directly into the address space of the Audio Engine and Server Hub processes, each implemented as a high-throughput ring buffer accessed via a numpy.ndarray view, eliminating the need for data serialization across the network stack. A triple-buffering scheme with atomic write/read pointers (mp.Value) and mutex-based synchronization barriers (mp.Lock) prevents race conditions between the writing and reading processes, ensuring signal integrity without blocking the audio thread.

The proposed solution achieves microsecond-scale inter-process transfer times, independent of CPU load from other system tasks, enabling stable full-duplex processing of four audio channels within a 1024-sample block size. End-to-end audio latency within the local Mission Control network is maintained below 30 ms. Results demonstrate that general-purpose (non-RTOS) operating systems can meet firm real-time constraints required for spaceflight ground segment operations through careful IPC-layer engineering rather than dedicated real-time infrastructure.

Ground-Testing a Satellite: Hardware-in-the-Loop Continuous Integration Architecture for Fault-Tolerant Embedded Systems Using Cubesat Space Protocol

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Extensive pre-launch testing is critical for satellite missions, as addressing anomalies on-orbit is often impossible. While thorough validation prior to launch is standard practice, implementing a robust Continuous Integration (CI) system allows for continuous codebase testing and incremental review of merged updates, significantly mitigating risk compared to monolithic, late-stage testing. This presentation outlines a CI pipeline developed at SatLab, utilizing a hybrid infrastructure of GitLab-hosted and custom hardware-connected runners.

The pipeline begins by performing linting and formatting of the codebase. Subsequently, a parallel execution phase runs a build matrix, unit testing, and code coverage analysis. The pipeline then transitions to a custom CI server for Hardware-in-the-Loop testing. Initial hardware tests validate the testing framework itself by verifying the transmission and reception of Cubesat Space Protocol (CSP) messages. Following this, end-to-end satellite tests are executed. These include fault-injection scenarios, such as utilizing PyOCD to directly corrupt the memory of an STM32 microcontroller to evaluate system recovery.

As a result, this architecture verifies the fault tolerance and evaluates operational correctness of the system while providing real-time code coverage and unit test statistics throughout the development lifecycle.

KGK2026 Abstract 0052

TEVEL: Student-Built Nanosatellites as Scientific Missions and Educational Ecosystems

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TEVEL is a national Israeli program that integrates space engineering with scientific research and advanced STEM education. High-school students participate in the design, construction, testing, and data-exploration of CubeSats, combining a real scientific satellite mission with authentic project-based STEM education.

In the TEVEL-2 phase, Jewish, Arab and Druze students from nine municipalities across Israel built nine 1U CubeSats as a coordinated nanosatellite constellation. Each local team developed its satellite in a dedicated school-based clean room, while all satellites contributed to a shared scientific mission. The satellites carry payloads for measuring energetic particles and cosmic radiation in the space environment, as well as amateur-radio communication systems.

A case study of the student-satellite program indicated that educational goals can be embedded within a satellite mission. The program therefore offers a dual-purpose model: a scientific nanosatellite constellation that also serves as a sustained educational ecosystem for developing the next generation of space engineers, scientists and technologically literate citizens.

Towards Precise Spectral Masking of Crop Diseases using Satellite Imagery and in situ Measurements

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Crop diseases pose a persistent threat to agricultural productivity and food security, with highest losses, whenever infections spread undetected across fields. Therefore, early and reliable detection is pressing, not only to contain outbreaks, but also to reduce the application of fertilisers and agrochemicals. This work explores how Earth Observation can serve as a tool to address this challenge. We demonstrating a case study in which space resources, namely the satellite imagery, are used to protect terrestrial ones.

The study is conducted as part of the ESA CropWatch project by RadSCAN and Faculty of Space Technologies AGH. The approach connects publicly available Sentinel-2 multispectral data with in-situ field measurements. By pairing satellite reflectance with spectroscopic ground data, we examine which spectral responses are most relevant for identifying disease-related stress in vegetation.

We evaluate a range of methods for reliable disease prediction, including machine learning models built on vegetation indices and other estimators of crop health. The comparative assessment aims to establish which techniques generalise across crops and conditions and remian reliable.

We present our methodology, preliminary findings, and the outlook for integrating satellite-driven disease prediction into sustainable agricultural practice.

Advances in Regolith Simulants for European Lunar and Martian Research

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Growing lunar exploration activities are increasing the demand for high-quality, well-characterized regolith simulants. These materials are essential for developing and testing in-situ resource utilization (ISRU) technologies and for conducting experiments under representative lunar conditions. Standardized simulants improve comparability between studies, reduce the need for in-house material development, and accelerate research and qualification processes.

A European portfolio of lunar regolith simulants has been established to represent the major compositional differences between lunar highlands and maria. It includes LX-T100 (plagioclase-rich highlands), LX-M100 (basaltic maria), and the intermediate type LX-I. All materials feature controlled mineralogy, particle-size distributions, and morphology, providing reproducible conditions for scientific and engineering applications.

The portfolio has recently been expanded with modular components for mission- and experiment-specific tailoring. Additional glass fractions, agglomerates, and minerals such as ilmenite and olivine allow targeted adjustment of key properties, including melting behavior, abrasiveness, and optical characteristics, enabling a more realistic representation of local surface conditions.

To address reduced lunar gravity, a novel low-density simulant has been developed for realistic testing of feeding, transport, and handling systems. Beyond lunar applications, the portfolio now includes LX-MARS, a simulant representing Martian drifting sand. Initial characterization results and future application opportunities will be presented.

KGK2026 Abstract 0055

Influence of Edge-Crack Damage on the Dynamic Behavior of CubeSat Payload Plates Under Launch Vibration

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CubeSat payloads are exposed to severe launch-induced vibrations that can compromise structural integrity, particularly in the presence of localized defects. This study, conducted within the REXUS/BEXUS student program, investigates the influence of edge-crack damage on the dynamic behavior of FR-4 payload plates mounted in an aluminum CubeSat structure. Finite element modal (SOL 103) and frequency response (SOL 111) analyses were performed on a complete CubeSat using MSC Patran/Nastran, under the REXUS qualification random vibration spectrum (12.7 Grms, 20–2000 Hz). Three CubeSat configurations were considered: a baseline with two pristine payload plates and two configurations with the top payload plate replaced by a 3.5 mm or 6.49 mm edge-cracked plate. Modal analysis showed reductions in the first natural frequency of 3.58% and 4.21% for the two damaged configurations, respectively, indicating progressive stiffness degradation. Frequency response analysis showed that both damaged plates exhibited peak displacements at approximately 218 Hz, compared with 257.6 Hz for the pristine configuration, with displacement increases of 9.9% and 11.6% for the 3.5 mm and 6.49 mm damaged plates, respectively. Experimental shaker-table testing showed results comparable to the numerical predictions. These results confirm that vibration-based dynamic analysis can reliably detect and characterize localized edge-crack damage in CubeSat payload plates under realistic launch conditions.

Overview and characteristics of Lunex Simulants for lunar and Martian Research

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Growing lunar exploration activities are increasing the demand for high-quality, well-characterized regolith simulants. These materials are essential for developing and testing ISRU technologies and for conducting experiments under representative lunar conditions. Standardized simulants improve comparability between studies, reduce the need for in-house material development, and accelerate research and qualification processes.

To support a wide range of scientific and engineering applications, a modular portfolio of lunar regolith simulants has been developed by Lunex Technologies. The foundation of this portfolio consists of two base simulants representing the major lunar terrain types: LX-T100 for plagioclase-rich highlands, and LX-M100 for basaltic maria. These materials are characterized by defined mineralogy, particle-size distributions, morphology, and bulk properties, providing reproducible test conditions.

Beyond the base materials, tailored mixtures allow intermediate compositions and application-specific property adjustments. The portfolio is further complemented by agglutinates and glass fractions that reproduce important features of lunar regolith formed through impact processes and space weathering.

For more advanced customization, additives can be incorporated to modify the chemical and mineralogical composition of the simulants. These include individual minerals that enable targeted adaptation to mission scenarios, or experimental requirements.

This contribution provides an overview of the modular simulant portfolio, its components, and their key characteristics, highlighting the flexibility of the approach for both lunar research and technology development.

Effect of Ionizing Radiation on Bacterial Cellulose Produced by a Kombucha Consortium

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Bacterial cellulose (BC) produced by kombucha microbial consortia is a promising biomaterial due to its ease of production, biocompatibility, mechanical stability, and ability to form lightweight protective structures. Understanding its resistance to ionizing radiation and its potential as a shielding material is important for future space applications.

This study investigated the interaction between ionizing radiation and bacterial cellulose in three experiments. First, the influence of ionizing radiation applied during fermentation on BC synthesis was evaluated. Second, structural changes in BC exposed to ionizing radiation were examined. Third, the radiation-shielding properties of BC and the effect of tungsten incorporation were assessed.

The chemical structure of the samples was analyzed using attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR). No significant differences were observed between irradiated and non-irradiated BC produced during fermentation, indicating that the applied radiation dose did not alter the molecular structure of the material. Likewise, direct irradiation of BC did not result in detectable structural modifications.

Gamma-radiation attenuation tests demonstrated that incorporation of tungsten into the cellulose matrix improved the shielding performance compared with pristine BC. These results indicate that bacterial cellulose exhibits high stability under ionizing radiation exposure and may be a suitable matrix for lightweight radiation-protective composites intended for future space-related applications.

Deep Space Compute Index: A Policy-Driven Asynchronous Automation Trigger and Supervisory Control Framework under Extreme Lunar Environments

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Autonomous planetary operations faced resource failures from latencies and uncoordinated workloads under extreme environmental variations. Known data showed physical constraints limited processing, causing a severe synodic energy supply and demand imbalance, leaving a knowledge gap in standardizing computational expenditure across assets. This study evaluated if a hardware-agnostic metric could regulate cross-platform allocation. A comparative architectural design methodology was used within a simulated lunar data center network. Thirty historical rover anomaly scenarios featuring telemetry loss or thermal runaway were studied, excluding orbital failures. The Deep Space Compute Index framework formulated within a Constrained Markov Decision Process was applied to evaluate protocol coverage, deadlock elimination, and downsampling. Structural evaluation demonstrated a comprehensive architecture mapping all scenarios without deadlocks during threshold breaches. The framework compressed bandwidth through localized transformation into intent packets for ground-station supervisory control. This study demonstrated that software-defined benchmarks can logically regulate stochastic overloads and manage severe diurnal solar thermal phase mismatches without hardware modifications. The study recommended that future deep space deployments adopt this standardized computational metric within international space data protocols to enhance survivability.

Mind the gap: how to detect mid-frequency gravitational weaves

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Mind the gap: how to detect mid-frequency gravitational weaves

Olga Sergijenko for the TVLBAI Proto-Collaboration

Long-baseline atom interferometry is a promising technique for probing various aspects of fundamental physics, astrophysics and cosmology, including searches for gravitational waves (GWs) in the frequency range around ~1 Hz that is not covered by present and planned detectors using laser interferometry. The PX46 access shaft to the LHC has been identified as a very suitable site for the Atom Interferometer CERN Experiment (AICE), a proposed O(100 m) vertical atom interferometer facility at CERN, whose primary scientific goal is the exploration of the dark universe through searches for ultralight dark matter. The facility will also provide a pathfinder towards future gravitational-wave detection in the mid-frequency band. The Terrestrial Very-Long-Baseline Atom Interferometry (TVLBAI) Proto-Collaboration proposes a coordinated programme of interferometers of increasing baselines.

Massive black hole mergers in the era of LISA

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Massive black hole mergers in the era of LISA

Olga Sergijenko for the LISA Astrophysics Working Group

One of the main goals of the Laser Interferometer Space Antenna (LISA) is to constrain the origin and growth of massive black holes (MBHs) through their merger rates and mass distribution. Predicting MBH merger rates requires not only tracing their statistical population from large to small physical scales (kpc to sub-pc) but also modelling their formation, accretion, dynamics, mergers and their galactic physical processes across cosmic time. Within the LISA Astrophysics Working Group, we compare various theoretical predictions of MBH merger rates. Our work is based on about 20 semi-analytical models and cosmological simulations from the literature, all employing distinct approaches to modelling MBH and galaxy physics. We present the expected LISA merger rates given current galaxy formation models and discuss how the merger rate depends on model assumptions.

BIOSIGNATIME: A Multimodal Approach to Investigating Subjective Time Perception During SOLIS100 Analog Lunar Mission

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Long-duration confinement and isolation affect circadian rhythms, cognitive function, and psychological well-being, yet the relationship between these changes and subjective time perception (STP) remain insufficiently explored. BIOSIGNATIME project investigates how prolonged isolation alters STP and its physiological correlates in strict-isolation environments.

The study combines two complementary tests with non-invasive physiological monitoring: STP1 and STP2. STP1, performed using the STPA mobile application, evaluates temporal estimation. STP2, implemented in the ChronaFlow mobile application, assesses active and passive STP. Both tests are conducted twice daily throughout the mission following baseline measurements before habitat ingress. Once per week, testing is accompanied by continuous ECG acquisition using the BITalino sensor and OpenSignals software. Heart rate and electrocardiographic activity are recorded with three surface electrodes before and during task performance under standardized conditions. Additional mission data, including sleep, activity, and environmental parameters, will support the interpretation of behavioral and physiological changes.

Data collection was completed during the SOLIS100 analog lunar mission. The project is currently in the initial stage of data processing and analysis. This presentation focuses on the study design, experimental protocol, and integrated methodology developed to investigate the relationships between subjective time perception, physiological responses, and adaptation to long-term isolation. Preliminary findings will be presented in future publications following completion of the full data analysis.

Lunar Regolith Abrasion: A Review of Wear Models and Material Sensitivity under Extreme Conditions

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As the human's interest is increasing in exploring the moon resources, the most common problem is that the lunar equipment are being abraded out way too fast which makes exploring moon is a huge challenge for operating equipment.

The lunar conditions can't be compared to terrestrial conditions as it has extreme temperature swings from -120 to 150 °C and the temperature drop could happen very fast especially on the sides of the terminator which is the dividing line between day and night, a lack of atmosphere and constant radiation, however the biggest challenge is lunar regolith.

On Earth, wind and water smooth out sand over time, however on the moon, dust stays sharp and jagged due to absence of weathering.

When dust is kicked up by landing rockets or solar winds levitation, it hits surfaces causing deep scratches and material loss.

this paper reviews how these harsh environmental conditions and factors lead to abrasive wear on common materials used in lunar equipment.

the paper will focus on reviewing all the work done to study the severity of abrasion that lunar regolith particles could cause into surfaces, the research aims to create abrasion wear model of regolith in lunar condition to predict how long will the materials survive by understanding the phenomena that happen due to the abrasion impact of regolith on materials taking into consideration the mechanical damage at both micro and macro scales.

Testing materials in the lab under similar lunar environmental condition of vacuum and temperature will help to understand the abrasion model of regolith and will make it possible to build durable, autonomous tools and equipment that could survive for longer missions.

Beyond Open-Loop Metrics: Closed-Loop Evaluation of Predictive Autonomy for Safe Lunar Rovers

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Sustained lunar surface operations—including prospecting, regolith transport, infrastructure inspection, and cargo logistics—require onboard predictive autonomy because communication latency, intermittent connectivity, and limited human supervision preclude continuous teleoperation. We demonstrate that conventional open-loop machine-learning metrics alone cannot validate whether predictive autonomy improves operational safety. To test this hypothesis, we evaluate a compact terrain-conditioned latent world model on a fully reproducible closed-loop benchmark combining real NASA LRO/LOLA lunar topography with physicssimulated telemetry and physics-derived hazard labels. A three-member ensemble achieves an AUROC of 0.802 for next-step hazard prediction, while closed-loop evaluation with a gated intervention policy reduces realized rover hazards by 13.8% across 130 matched-seed simulations. Crucially, two reproducible pipeline defects leave open-loop performance nearly unchanged while completely eliminating closed-loop benefit, demonstrating that conventional evaluation can overlook failures that only emerge during closed-loop operation. These findings demonstrate that predictive performance alone is insufficient for validating safety-critical autonomous planetary systems and support closed-loop evaluation as a necessary methodology for predictive autonomy. The benchmark, code, and evaluation pipeline will be released to enable reproducible comparison and future research.

KGK2026 Abstract 0066

Optical and Algorithmic Detection of Helium-3 in Gases Released from Lunar Regolith

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The primary objective of this project is to develop a conceptual optical system and algorithm for evaluating Helium-3 isotope abundance in gases evolved from lunar regolith. Rather than developing extraction technologies, this study focuses on designing a conceptual instrument for rapid in-situ sample screening and ISRU (In-Situ Resource Utilization) viability assessment. The operational baseline assumes that a regolith sample undergoes thermal extraction, releasing trapped gases, including helium. The evolved gas mixture is subsequently routed into a measurement cell, where an RF or DC glow discharge excites the helium atoms to a metastable state, enabling spectroscopic analysis of the transition near 1083 nm. In this spectral regime, He 3 can be reliably discriminated from He 4 due to the fixed isotopic shift between their respective emission lines.A dedicated algorithm will process the detector signal, identify the reference He 4 line, locate the He 3 peak, and determine the intensity ratio to estimate the relative He 3 abundance within the analyzed sample. Due to the absence of empirical spectra from lunar evolved gases, a numerical model will be developed to generate synthetic spectra. This will facilitate rigorous algorithm verification and define the baseline performance requirements for the optical architecture. Finally, the optical system will be designed and optimized in Zemax OpticStudio, utilizing a Fabry-Pérot etalon as a tunable filter operating in the 1083 nm band.

KGK2026 Abstract 0067

Assessing bottom reflectance contamination in Sentinel-2 imagery of shallow water bodies using laboratory spectroradiometry

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Satellite-derived water quality monitoring, particularly for estimating total suspended matter (TSM) and turbidity, became widely used over the last years as a water quality assessment tool. However, in shallow water bodies, the signal recorded by satellite sensors is frequently distorted by bottom reflectance (the "optically shallow water" effect). This might lead to incorrect estimations in water quality parameters. This study evaluates the magnitude and spectral characteristics of the signal coming from the bottom of the lake in Sentinel-2 (MSI) Level-2A imagery by pairing satellite data with high-resolution laboratory spectroradiometry.

Water samples were collected from multiple shallow and deep reference points within local water bodies, such as Zesławice reservoir, lakes in Przylasek Rusiecki, or Kryspinów lake, synchronized with cloud-free Sentinel-2 overpasses. To isolate the pure water column signal, the samples were analyzed in a controlled, non-reflective laboratory chamber using a spectroradiometer covering the VIS and SWIR ranges. The high-resolution laboratory spectra were resampled to match the Sentinel-2 spectral response functions.

The study will define the discrepancy between satellite BOA reflectance and laboratory-measured pure water reflectance in shallow zones in a quantifiable way. The findings will assess the depth-dependent limits of Sentinel-2 visible bands for local water monitoring and highlight the main artifacts in this kind of observation.

How sensation shapes public view of science: 3I/ATLAS Communication Case Study

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Sometimes our Solar System has unexpected visitors from afar. Such events are a great opportunity to broaden our knowledge about the Deep Space. In summer of 2025 an interstellar object later named 3I/ATLAS reached our proximity. This event was not only a great scientific opportunity, but also a subject of many disputes and conspiracy theories.

How do media outlets frame scientific news? What is their role in shaping the public's perception of science and scientists? Where lies the line between reporting genuine scientific breakthroughs and sensation seeking? Sensation stirs excitement with fear, and it is a fact well known that fear is one of the strongest factors that can influence human behavior.

This case study aims to showcase how most of the well-performing science journaling reports focus on information delivery, by analyzing news publications and their intentions. This might correlate with the ongoing tabloidisation process, as well as the primate human tendencies to rely on cognitive biases and emotions. This phenomenon, however, might be useful to foster society's interest in science, making it more accessible and fun. Therein lies the question: how can we make a good use of those mechanisms, without making the science sound irrational?

The case of 3I/ATLAS presents a unique opportunity to examine the interactions between science, media, public reception, and user-generated feedback. The findings may inform more effective and transparent approaches to science communication in the media.

Prokaryotic communities in bottom sediments across different levels of contamination: community level response and relevance to astrobiology

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Microorganisms form communities that are shaped by the existing conditions. Anthropogenic activity creates novel, naturally-not-occurring niches that impose strong selective pressure on microbial taxa and community functions. Similarly extraterrestrial environments are expected to be polyextreme with conditions far from those found in nature on Earth. Therefore, examination of community level response and adaptation to such conditions can provide important data relevant to astrobiology. Here we have compared the bacteriobiome structure in bottom sediments from water bodies with different levels of pollution. The water bodies included recreational lakes, natural spring, ponds formed on coal waste dump and pond heavily contaminated with hydrocarbons that used to be a dump for chemical industry waste. Bacteriobiome structure was analyzed by sequencing the V3-V4 region of the 16S rRNA gene from DNA extracted from sediment samples. Sequencing data were processed using the QIIME 2 pipeline and the functional potential of microbial communities was predicted using PICRUSt2. The results have shown variable microbial communities enriched in specific taxa depending on the conditions. Such community-level responses are relevant to understanding how microbial ecosystems may adapt to physico-chemically challenging environments, which in the long run can be informative for assessment of habitability and the interpretation of potential biosignatures in extraterrestrial environments.

Space Biology Across Timescales: From Mitochondrial Responses to Evolutionary Adaptation

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Space biology investigates how spaceflight conditions affect living organisms across multiple levels of biological organization. By addressing the limits, resilience, and long-term adaptability of life beyond Earth, the field also intersects with space health and astrobiology. At the Space Biology and Astrobiology Laboratory of AGH University, we investigate how organisms respond and adapt to space-relevant environmental stressors, with a particular focus on mitochondrial function, bioenergetics, and evolutionary processes. Mitochondria are central regulators of energy metabolism and cellular stress responses and are recognized as key mediators of biological responses to spaceflight.
This presentation will provide an overview of our current research, including pilot studies examining the effects of NAD^+ and naturally derived compounds on mitochondrial respiration in simple model organisms. I will also introduce a research project combining experimental evolution with quantitative bioenergetic and genomic analyses to investigate long-term adaptation to simulated spaceflight conditions. By connecting acute physiological responses with multigenerational evolutionary changes, this line of research aims to deepen our understanding of biological resilience and the capacity of life to adapt beyond Earth.

KGK2026 Abstract 0071

Optical and Algorithmic Detection of Helium-3 in Gases Released from Lunar Regolith

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The primary objective of this project is to develop a conceptual optical system and algorithm for evaluating Helium-3 isotope abundance in gases evolved from lunar regolith. Rather than developing extraction technologies, this study focuses on designing a conceptual instrument for rapid in-situ sample screening and ISRU (In-Situ Resource Utilization) viability assessment. The operational baseline assumes that a regolith sample undergoes thermal extraction, releasing trapped gases, including helium. The evolved gas mixture is subsequently routed into a measurement cell, where an RF or DC glow discharge excites the helium atoms to a metastable state, enabling spectroscopic analysis of the transition near 1083 nm. In this spectral regime, He3 can be reliably discriminated from He4 due to the fixed isotopic shift between their respective emission lines. A dedicated algorithm will process the detector signal, identify the reference He4 line, locate the He3 peak, and determine the intensity ratio to estimate the relative He3 abundance within the analyzed sample. Due to the absence of empirical spectra from lunar evolved gases, a numerical model will be developed to generate synthetic spectra. This will facilitate rigorous algorithm verification and define the baseline performance requirements for the optical architecture. Finally, the optical system will be designed and optimized in Zemax OpticStudio, utilizing a Fabry-Pérot etalon as a tunable filter operating in the 1083 nm band.

Mössbauer spectroscopy in space materials investigation

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Space materials, understood both as materials coming from space, such as meteorites and asteroid samples from sample return mission, and as materials for usage in space, like specialized alloys, as well as other advanced materials (MXenes, nanoparticles, etc.), require detailed investigation to study their origin in the former case, and ensure they exhibit the desired properties in the latter.

Mössbauer spectroscopy offers means to determine mineral composition, site occupation in the crystal lattice, and chemical state in the material.[1]It is a technique suitable for in situ measurements[2], therefore a miniaturized spectrometer, MIMOS II, constitutes a part of the equipment of Mars Exploration Rovers Spirit and Opportunity; its purpose is to study the mineralogy of iron-bearing rocks. We have performed Mössbauer study of NWA 869 meteorite, as well as of MXene materials, an iron doped carbon membrane for radiation protection, and of iron oxide nanoparticles for space theranostics. MXenes are already known as materials with properties suitable for space applications since the Ignis mission, while iron oxide nanoparticles are efficient contrast agents for Magnetic Resonance Imaging, a technique which will be applied for research on the effects of space flight on the human body.[3]

The results of our studies will be presented, along with a relation to literature data and a brief history of how space research is intertwined with Mössbauer spectroscopy.

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Prion-Like Proteins as Ancient Architects of Protein Modularity and Epigenetic Inheritance

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Prions are self-propagating protein conformations that transmit structural information independently of nucleic acids. Although first linked to neurodegeneration, prions and prion-like domains (PrLDs) are widespread and can regulate adaptation, stress responses, and heritable phenotypes. We tested the hypothesis that PrLDs are ancient modular elements contributing to early protein evolution and epigenetic control.

Using PLAAC, we identified cyanobacterial PrLDs and selected 20 candidates for analysis. Their amyloid-forming potential was tested in *E. coli* with the curli-dependent amyloid generator (C-DAG) system. Five candidates bound Congo red, indicating amyloid formation. These PrLDs were then introduced into the yeast Sup35 system in place of its native prion domain. Four induced a heritable [PSI+] phenotype, demonstrating their ability to form self-propagating aggregates.

The positive domains originated from proteins annotated as a serine/threonine kinase, a DNA-binding transcriptional regulator, a restriction endonuclease, and an integrase/recombinase. Their association with signaling, gene regulation, genome defense, and DNA rearrangement supports a role for prion-like mechanisms in adaptive diversification.

Together with previous evidence from Archaea, these findings suggest that prion-like inheritance is ancient, modular, and conserved across life. PrLDs may be relics of primordial biology through which simple proteins acquired regulatory and heritable functions.

Outcomes from Moon Harvesting project realization

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The research project “Regolith harvesting on Moon surface: Excavation and beneficiation in low gravity environments” aimed to advance technologies for the extraction and processing of lunar regolith—the layer of dust and fragmented rock covering the Moon’s surface. In the future, regolith may become one of the most important local resources supporting both robotic and crewed lunar bases. Scientists from CBK PAN, AGH and UWM investigated how regolith can be excavated in low-gravity environments, how it can be processed, and how it may be used to support the construction of lunar infrastructure.

One of the project’s major achievements was the development of a conceptual design for an open-pit lunar mine. The analyses showed that producing rocket propellant from local resources would require the excavation of tens of thousands of tonnes of regolith per year, illustrating the scale of future industrial activities beyond Earth. An important part of the project focused on understanding the mechanical behavior of lunar regolith. Through laboratory experiments and DEM computer simulations, researchers investigated particle flow, friction between grains, resistance encountered by excavation tools, and the behavior of regolith during transportation. A particularly exciting aspect of the project involved experiments conducted during parabolic flights organized by the ESA. Under short periods of simulated lunar gravity, the team tested the operation of the RCE excavator and investigated the behavior of regolith during excavation processes.

The results may contribute to future lunar exploration programs conducted by the European Space Agency such as Argonaut mission.

From Population Models to Personalized Physiological Intelligence in Human Space Exploration

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KGK2026 Abstract 0076

Human Remains as an Edge Case for Circular Resource Design in Space

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Future long-duration space exploration will require closed-loop resource management, where every transported from the Earth 'material' becomes a potential resource. This may be applied also to the human body. Following death, skeletal tissue becomes a reservoir of calcium, phosphorus, fluorine and biocompatible mineral material with potential applications in nutrient recovery, medicine and manufacturing. However, utilizing human remains cannot be considered yet another engineering challenge. If anyone will try to utilize human body as a resource one must deal with not only technical constraints, but also take into consideration cultural norms, social practices, human emotions, political positions, religious beliefs.

From the perspective of design methodology this is an edge case. But it still demonstrates that future space materials problems cannot be solved through engineering alone. Technologies involving post-mortem resource recovery will require social legitimacy alongside technical feasibility, particularly where Earth resupply is impossible. So how to approach such problems?

We propose an anticipatory co-design framework combining Futures Studies Thinking and Design Thinking allowing engagement with stakeholders before technological pathways become fixed. Using human skeletal tissue as a technically plausible case study, we illustrate how participatory design can identify acceptable boundaries, map societal expectations, and explore alternative solutions at the earliest stages of materials innovation. The presentation not only introduces the framework but also demonstrates its utility with example of a pilot workshop.

INVESTIGATION OF A 1 J CLASS µPPT USING A PYTHON-BASED NUMERICAL SIMULATION

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The global nanosatellite boom and recent missions like PETRUS (2024) and DUPLEX (2025) have driven growing interest in micro-Pulsed Plasma Thrusters (µPPTs), owing to their structural simplicity, low power requirements (<10 W), and safe solid propellants that eliminate the need for valves and pressurized tanks. These thrusters use pulsed electric discharges (with energies of up to 26 J) to vaporize a thin layer of the propellant (such as Teflon) into a cloud of charged propellant particles. These particles are accelerated via electromagnetic forces, thereby generating thrust. Due to the precise micronewton-second impulse bits and a very high specific impulse (up to 3800 s), µPPTs are suitable for attitude control and station-keeping maneuvers. However, PPT efficiency remains low (5–15%), and improving it requires a better understanding of the physical phenomena that drive PPTs. This study addresses this challenge, presenting a Python-based numerical simulation framework derived from the literature. It models the processes of Teflon ablation, discharge dynamics, and plasma plume expansion to predict propulsion performance. The framework will evaluate a µPPT prototype built from COTS components, with a main discharge circuit using a 1 µF capacitor charged to 1500 V via a DC/DC converter. By bridging the gap between COTS prototyping and a simulation platform, this work provides a tool for µPPT performance evaluation and a baseline for future designs.

COLLOID THRUSTER DEMONSTRATOR DESIGN AND PREPARATIVE WORK

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A Colloid Thruster (CT) is an electric propulsion system that operates by electrostatically accelerating highly charged droplets emitted from conductive fluids like ionic liquids or solvents. Although this technology has been studied for over sixty years, the recent boom in micro-satellite constellations has triggered a massive resurgence of interest due to its high-power efficiency (60% to 80%, compared to 40% to 65% for Field Emission Electric Propulsion) and micro-Newton thrust precision.

While my overall thesis focuses on exploring metal additive manufacturing for the engineering of CT, this specific preparatory work serves as the critical first step: mastering CT operational physics to subsequently enable deep structural and fluidic design optimization for 3D printing. To understand these principles, a colloid propulsion demonstrator was designed, and numerical models were developed using MATLAB and ANSYS to match the demonstrator's geometry. To do so, a specialized hardware testbed was engineered to study fluid meniscus deformation, electrohydrodynamic droplet extraction, and electrostatic beam acceleration. Concurrently, analytical scaling laws and numerical simulations were executed to evaluate the prototype's propulsive performance and benchmark its efficiency metrics, establishing the mandatory physical foundation required before initiating the metal additive manufacturing design phase.

Phage Diversity and Distribution Across the International Space Station and Cleanroom Environments

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The Earthrise Effect: Psychological Dimensions of the Overview Effect in Art, Photography, and Astronaut Experience

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The Overview Effect, first described by Frank White in 1987, refers to the profound cognitive and emotional shift experienced by astronauts upon viewing Earth from space – a heightened sense of planetary unity, interconnectedness, and diminished ego-boundaries. While extensively documented through astronaut testimony, the phenomenon remains underexplored as a subject of interdisciplinary inquiry bridging cognitive psychology, visual art, and cultural studies. This work examines the Overview Effect through the lens of its most iconic artifact – the 1968 "Earthrise" photograph taken during Apollo 8 – tracing its influence on subsequent artistic, photographic, and literary representations of Earth-from-space imagery.

We analyze the psychological mechanisms underlying the effect, including shifts in self-construal, awe-induced cognitive restructuring, and the role of perceptual distance in altering existential perspective, drawing on empirical studies on astronaut cohorts and cognitive science literature on awe. In parallel, we examine how these psychological shifts have been translated into cultural production, from environmental movements inspired by Earthrise to contemporary space art and speculative literature engaging with planetary consciousness.

We conclude by proposing the Overview Effect not merely as an anecdotal phenomenon, but as a measurable psychological pattern with tangible cultural consequences – one that offers a valuable case study for interdisciplinary research bridging space science and the humanities.

Writing Through the Void: Astronaut Journals and Diaries as a Narrative Coping Strategy for Isolation

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Prolonged isolation and confinement remain among the most significant psychological stressors faced by astronauts during long-duration spaceflight, particularly as missions extend beyond the support structures available in low Earth orbit. Journaling has long served astronauts and cosmonauts as both a personal coping mechanism and a formal behavioral research tool, most notably in NASA's studies on astronaut journals. This work examines astronaut diaries and memoirs as a literary and psychological corpus, analyzing how narrative practice functions as a mechanism for emotional regulation, identity maintenance, and meaning-making under extreme confinement.

Drawing on published astronaut memoirs, including Clayton Anderson's *The Ordinary Spaceman*, alongside behavioral research literature, we examine recurring narrative strategies -- humor, ritual, nostalgia, and reconstruction of terrestrial routines -- through which astronauts negotiate the psychological demands of isolation. Particular attention is given to *psychological closing*, described by Vadim Gushin, in which diminishing communication with mission control is reflected in shifting patterns of self-disclosure within personal writing.

We conclude that astronaut journals constitute a valuable interdisciplinary source, situated at the intersection of psychology, life-writing studies, and behavioral sciences of human spaceflight, offering insight into both individual coping strategies and the broader narrative structures through which humans make sense of isolation.

Satellite-Based Assessment of Agricultural Pesticide Use: Detecting Necessity, Quantity, and Regulatory Compliance from Earth Observation Data

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Pesticide application in agriculture remains largely self-reported and difficult to verify at scale, creating challenges for both regulatory enforcement and environmentally sustainable farming. This work explores the feasibility of a satellite-based Earth Observation system designed to assess three interconnected aspects of pesticide use: whether a crop actually requires chemical treatment based on detectable pest presence, how much pesticide has plausibly been applied to a field, and whether that application is consistent with regulatory limits.

Pest infestations can be detected through multispectral and thermal satellite imagery by analyzing shifts in vegetation indices such as NDVI, changes in canopy reflectance, and elevated leaf temperature associated with pest-induced stress. Pesticide application levels can be estimated by correlating classified crop types from satellite time-series data (e.g., Landsat, Sentinel-2) with known regional application patterns. Building on these techniques, we propose a system architecture combining a satellite data ingestion pipeline, vegetation-index feature extraction, and a classification layer flagging fields where chemical application appears disproportionate to actual pest pressure or inconsistent with declared usage.

Such a system could support regulators in verifying compliance and help farmers reduce unnecessary chemical input through targeted rather than blanket treatment, while contributing to broader environmental monitoring goals.

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Towards Uncertainty-Aware Selective Information Acquisition in Heterogeneous Autonomous Systems

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Governing Autonomous Space Systems: A Governance Framework for Future Space Resource Operations

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Future space resource operations will increasingly depend on autonomous systems coordinating prospecting, extraction, logistics, and infrastructure across environments where continuous human oversight is impractical. While current discussions primarily focus on technological capabilities, legal ownership, and resource utilization, considerably less attention has been given to the governance of autonomous operational decision-making.

This paper argues that growing autonomy fundamentally changes how future space resource systems should be governed. As intelligent systems assume greater responsibility for operational decisions, governance must evolve beyond regulating physical assets toward ensuring transparency, accountability, resilience, and meaningful human oversight within autonomous decision environments.

Rather than proposing new legal regulations, the paper develops a governance perspective that integrates principles from AI governance, risk management, and space policy into the emerging field of space resource utilization. The proposed framework is intended to support policymakers, commercial operators, and international stakeholders as autonomous systems become increasingly embedded in future lunar, Martian, and asteroid resource operations.

By shifting the discussion from technological capability to governance readiness, the paper contributes an interdisciplinary perspective on one of the most significant institutional challenges facing the future space economy.

Bridging Post-Quantum Cryptography and Deep-Space Communications: Reusing HQC Error-Correcting Codes for Ultra-Reliable Links

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As deep-space exploration pushes the boundaries of communication distance and data volume, the demand for high-rate, ultra-reliable, and secure communication links becomes critical. Concurrently, the growing need for quantum-resistant cryptographic protocols introduces significant resource overhead from the adoption of the post-quantum cryptography (PQC). This work explores a novel, resource-efficient approach by leveraging the error-correcting codes inherently used in the Hamming Quasi-Cyclic (HQC) post-quantum key encapsulation mechanism (KEM) and reusing them for payload Forward Error Correction (FEC) in fragile or ultra-reliable space communication links. Interestingly, Reed-Muller (RM) codes, which played a foundational role in early deep-space missions before being largely sidelined for decades, are now experiencing a renaissance through their integration into HQC (along with more popular Reed-Solomon codes). We investigate and propose various strategies for building FEC schemes based on these codes, evaluating options such as multi-layer architectures alongside tailored optimizations of the decoding process. By leveraging the high-rate characteristics of HQC-native schemes, this approach aims to deliver highly resilient communication architecture for extreme deep-space environments. We present a framework for these integrated KEM-FEC systems, laying the groundwork for hardware deployment and comprehensive simulation baselines.

Daily Report Writing as a Coping Mechanism in Isolated Analog Habitats

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This study presents a linguistic and behavioral analysis of daily reports produced during Polish analog space missions conducted in isolated habitats. Each crew member completed a structured three-question daily log covering emotional state, operational activities and nutrition. The work integrates findings from research on long-duration isolation and confined environments, highlighting that daily reporting may function as a cognitive and emotional regulation tool supporting adaptation and maintaining psychological stability during extended confinement.

The analysis evaluates lexical richness, syntactic complexity, emotional markers, informal language, orthographic errors, anonymity patterns and crew-referencing styles. These metrics reveal individual stress responses, engagement levels, communication tendencies and group cohesion indicators, as well as subtle behavioral deviations that emerge over time. The results contribute a quantitative framework for assessing human performance and psychological resilience in analog missions, offering insights relevant for designing monitoring tools, communication protocols and support systems for future long-duration spaceflight.

Spaceflight-Associated Neuro-Ocular Syndrome: Multifactorial Pathophysiology and the Role of Glymphatic Dysfunction

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Spaceflight Associated Neuro-ocular Syndrome (SANS) is considered by National Aeronautics and Space Administration (NASA) as a major risk for human spaceflight. Symptoms of SANS include optic disc edema, chorioretinal folds, globe flattening, and hyperopic shift. The glymphatic system (GS) consists of perivascular spaces (PVS) and endfeet of astrocytes. GS regulates circulation and clearance of cerebrospinal fluid (CSF). This review synthesises 44 articles on SANS and the role of the GS in its development. The publications focused on the effect of microgravity or spaceflight analog on changes in the eye, optic nerve (ON) and brain. Diagnostic tools included Magnetic Resonance Imaging, Optical Coherence Tomography, fundoscopy, and tonometry. Comparison of SANS and idiopathic intracranial hypertension showed divergent fold patterns and paradoxical ON sheath and Bruch membrane opening displacement relative to papilledema. This supports a multifactorial model of SANS pathophysiology that include venous congestion, cephalad fluid shift, reduced CSF flow and sleep disorders. Novice astronauts showed enlarged PVS after spaceflight, unlike experienced ones. Post-flight changes also included enlarged lateral ventricles and reduced subarachnoid space, suggesting impaired GS function. However, no consistent association between SANS and PVS was found. SANS relationship with the GS remains complex, requiring further research to understand its pathophysiology.

Variability of the Antarctic lichen microbiome in a trophic and spatio-temporal gradient (Maritime Antarctica)

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Lichens are a complex, multi-organismal symbiosis inhabiting almost all latitudes of the Earth. They are especially successful in Antarctica, with over 400 species thriving in this region, despite the severe, polar environment. This success is predominantly due to the components that make up a lichen: the heterotrophic fungus, the photoautotrophic partner, as well as the microbiome inhabiting the lichen. While the physiology and role of the fungal and photoautotrophic counterparts are known, the diversity of the bacteriome and its contribution to the lichen symbiosis remains uncertain. Here, we demonstrate the relation between the Antarctic lichen-hosted bacterial communities and nutrient amounts in close lichen proximity, the lichen thalli age, as well as the lichen itself, with seven lichen species growing within naturally formed gradients in the Antarctic landscape. Additionally, the differences between the diversity of the whole lichen-inhabiting community and the fraction that actively transcribed ribosomal genes were compared. The obtained results suggest that the lichen bacteriome is a well-established community that partakes in the lichen symbiosis, and can be divided into two distinct fractions: the external fraction, less abundant, more phylogenetically diverse, and the internal fraction, larger, but far more specific-taxa oriented. Moreover, microbial abundance, structure and its metabolic functions change with the lichen thalli age. As the lichen ages, the more the internal and external bacterial communities differentiate from each other, with the external microbiome becoming much less diverse, and the internal microbiome becoming additionally influenced by other factors.

Mechanical Design and Preliminary Tests of the CAPYBARA Parabolic Flight Experiment

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CAPYBARA (Capillary Absorption and Permeation in Biomimetic Additive Research for Aerospace) is an experiment by the AGH Lunar Technologies student team, developed with the support of the ESA Education Office as part of the ESA Academy Experiments Programme and flying on a parabolic flight campaign. It studies capillary-driven liquid transport in 3D-printed Triply Periodic Minimal Surface (TPMS) lattices under microgravity, targeting passive, pump-less fluid management for spacecraft and ISRU systems.

In TPMS media the wicking rate is set by pore geometry, specific surface area and wettability, but on the ground this signature is masked by gravity. During the ~22 s of 0 g per parabola capillarity acts alone, exposing the geometry-transport relation. We compare lattice families — Gyroid, Schwarz Primitive and Diamond — over a controlled range of unit-cell size and wall thickness. Samples are made with an in-house parametric generator with resin-print compensation. A double-containment payload injects dyed liquid into ten samples at once; injection is autonomously triggered by real-time IMU detection of 0 g, and backlit dual-camera imaging records the advancing front, yielding wicking kinetics (meniscus height vs. time) per sample. Quick-swap frames give up to 300 samples per flight. This presentation details the concept of operations, the mechanical architecture, the parametric TPMS generation, and preliminary ground-test results.

Factors Affecting Lunar Regolith Simulant Behavior: Wall Material and Charging

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Different laboratories report very different results for the same lunar regolith simulant, which makes the numbers hard to trust when designing ISRU hardware. Part of the reason is electrostatic charging, which is usually named as the cause but rarely measured. Charging depends on what the powder, and just as much on whether the charge has a way to escape. This paper follows that one idea through two measurements.

First, charging is measured directly with a nanocoulombmeter and a Faraday cup for different simulants in air and in vacuum. The simulants differ strongly, with charge per gram varying by more than ten times. What matters more is what happens when the charge is given a way out: grounding the sample lowers it and can even reverse its sign, and moisture in air does the same thing naturally.

Second, the same idea is tested on flow. In an automated rotating drum, the angle of repose is read from video for different wall materials and chamber pressures. Conducting metal walls and insulating PTFE or PETG behave differently, and those differences grow as the pressure falls and moisture is removed.

Both measurements point the same way: what matters is not only how much charge builds up, but whether it can drain away. This also explains part of the spread between laboratories, because humidity, grounding and wall material are rarely reported, yet each of them changes the result.

Computationally Efficient Nonlinear Model Predictive Control for a Free-Floating Motor-Driven Space Soft Robot: A Comparative Study of Analytical and Neural Network Prediction Models

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Nonlinear model predictive control (NMPC) is a promising control strategy for free-floating soft space robots because it effectively handles nonlinear dynamics and system constraints. However, its application to space soft robots remains limited by highly nonlinear dynamics, strong spacecraft–manipulator coupling, and the computational burden of online optimization.This paper presents a computationally efficient NMPC framework for a free-floating motor-driven space soft robot through a comparative study of three prediction models: an analytical dynamic model, a neural-network surrogate model, and a computationally optimized Rust implementation of the analytical model. To ensure a fair comparison, all prediction models are integrated into the same NMPC framework under identical controller settings. Their performance is evaluated in terms of computational efficiency, prediction accuracy, trajectory tracking, and real-time feasibility. Simulation results show that the Rust implementation preserves the prediction accuracy and tracking performance of the analytical model while substantially reducing computational cost. For the reference trajectory, it reduces the total NMPC computation time by 73.6% and 30.0% compared with the MATLAB analytical and neural-network models, respectively, while maintaining the same tracking accuracy as the analytical model.

KGK2026 Abstract 0092

Supervision System for a Payload Computer on the 2U PUCHACZ satellite.

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One of the core parts of the PUCHACZ mission is the Imaging Payload powered by a single-board computer running Linux operating system. Unlike the satellite's core subsystems, which run FreeRTOS on STM32H5 microcontrollers over CAN and are considered flight-safe, this payload is a peripheral exposed to Linux-specific failures - kernel hangs, filesystem corruption, boot failure - that could interrupt payload operation. Recovering an unresponsive Linux instance in space is a fundamental challenge – there is no physical access, and every failure must be resolved remotely. This challenge is compounded by a limited uplink budget, which makes transmitting a full disk image to repair a broken installation impractical, so recovery must rely only on what is already on board. These constraints make a dedicated recovery mechanism a necessity, one that combines autonomous fault handling with the ability to diagnose and trigger repairs from the ground, giving the mission a reliable path to restoring the payload.
This paper presents the hardware architecture, communication design, and software stack used to interface with and control Linux on the payload computer. It also describes the fault-detection logic and layered recovery strategy, along with the threat modeling analysis conducted to ensure mission success.

Mechanical Characterization of PHB and Lunar Regolith Simulant Composites for ISRU in Lunar Construction

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As humanity advances toward the establishment of extraterrestrial habitats, development of a self-sufficient environment to reduce the dependency on Earth's resources becomes crucial. Microalgae, the pioneers of life, could play a vital role in life support systems (LSS) by sequestering CO2, and hence also in lunar construction, thanks to biomass produced in the process. Under nutrient stress, particularly nitrogen scarcity, some algae species accumulate polyhydroxybutyrate (PHB), a thermoplastic polymer with promising physiochemical properties and availability for enzymatic biodegradation. Following in situ resource utilization (ISRU) principles, for the purpose of lunar construction composites composed of PHB and lunar regolith simulant were investigated. To prepare the materials, isolated PHB was mixed with selected mass fractions of a standard lunar regolith simulant, followed by molding and controlled curing. Basic mechanical testing was conducted under ambient laboratory conditions. To determine flexural strength and elastic modulus, three-point bending test was employed and supported with uniaxial compression where applicable. Scanning electron microscopy (SEM) was used to assess the microstructure. Together with other physical properties (density, porosity), matrix-filler interactions and dominant failure mechanisms were determined. This early-stage exploratory effort contributes to the broader framework of polymer-regolith composites for additive manufacturing (3D printing) in extraterrestrial habitats. Results will guide subsequent optimization, including vacuum/thermal cycling compatibility, printability assessments, and scalability.

Orbital Laser Communication: Hardware and Optical Architecture of a Custom Downlink Module for the PUCHACZ 2U CubeSat

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This paper outlines the hardware and optical architecture of a custom laser downlink module developed for the PUCHACZ 2U CubeSat satellite. Designed exclusively for satellite-to-ground data transmission, the system employs On-Off Keying (OOK) modulation driven by an FPGA, a pulse generator, and a high-speed transistor.

To ensure that sufficient optical power reaches the receiving ground telescope, a high-power 1550 nm pulsed laser diode is utilized. However, the physical characteristics of the diode– specifically its highly asymmetrical, non-point emitter (350 x 1 um), present significant beam-shaping challenges. It was addressed through the design of a custom optical collimator and a precision mount, which ensures optical element alignment with micrometer scale accuracy. Because this extended light source cannot be perfectly collimated, the resulting beam footprint on Earth will be an ellipse spanning several hundred meters. Furthermore, as the module is rigidly secured to the satellite frame, targeting relies entirely on the satellite body-pointing. This introduces a critical system-level trade-off: minimizing beam divergence significantly enhances signal quality at the receiver, but concurrently imposes high-precision pointing requirements on the Attitude Determination and Control System (ADCS). This study explores the hardware implementations, optical alignment strategies and the essential compromises required to achieve a reliable space-to-ground optical link.

FROM REGOLITH TO INFRASTRUCTURE: INTEGRATED UTILIZATION OF MARTIAN RESOURCES FOR FUTURE HUMAN EXPLORATION

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Martian regolith is one of the most valuable local resources for future human exploration, with the potential to reduce dependence on supplies transported from Earth through In Situ Resource Utilization (ISRU). Although commonly regarded as a construction material, its technological value extends far beyond structural applications, encompassing advanced manufacturing and the extraction of critical resources. This presentation discusses two complementary pathways for Martian regolith utilization. The first focuses on its application as a filler in composite feedstocks for additive manufacturing and prefabricated components using mineral, polymeric, or sulfur-based binders. The influence of regolith properties on processing, printability, and the fabrication of structural elements, radiation shielding, and habitat infrastructure will be addressed. The second pathway explores regolith as a source of oxygen, hydrogen, sulfur, and technologically important metals. Particular attention will be given to sulfate minerals and other sulfur-bearing compounds, which can be processed using thermal, chemical, and electrochemical methods. Concepts of integrated ISRU reactors capable of simultaneously producing construction materials, water, oxygen, and chemical feedstocks from local resources will also be presented. By combining materials engineering, additive manufacturing, and resource extraction, Martian regolith can become the foundation of a circular ISRU strategy, enabling sustainable infrastructure development and increasing the autonomy of future human missions to Mars.

Maintaining functional integrity under simulated Mars-like conditions: fungi-dominated biocrusts

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Biological soil crusts (biocrusts) are self-sustaining microbial communities that act as integrated functional units, exhibiting remarkable tolerance to environmental extremes and making them promising models for astrobiological research. To investigate the response of fungi-dominated biocrusts to simulated Martian conditions, samples were exposed in the Mars simulation facility at the Space Research Centre of the Polish Academy of Sciences to a CO_2-dominated atmosphere (ca 6 mbar), temperatures decreasing from 20 °C to −30 °C, and simulated solar radiation using a UV-enhanced xenon lamp with a sun-like emission spectrum. The exposure significantly increased total exopolysaccharide (EPS) concentrations in biocrust, suggesting enhanced extracellular protection. Total antioxidant capacity was lower than in the control, which may reflect active scavenging of reactive oxygen species. Despite an initial reduction in photosynthetic efficiency following rehydration, experimental biocrusts recovered to control levels within 8 h, suggesting that fungal dominance may confer indirect protection to co-occurring photoautotrophs. Collectively, these findings indicate coordinated protective and recovery mechanisms that maintain the functional integrity of fungi-dominated biocrusts under simulated Martian conditions, highlighting their relevance for astrobiological research.

The research was funded by the National Science Centre, Poland, under project 2022/45/B/NZ8/01961.

KGK2026 Abstract 0097

PACE-Era multisensor forecasting of mineral-dust optical depth: an event-grouped benchmark with implications for space biology, health, and astrobiology.

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Mineral dust is an important atmospheric hazard affecting air quality, visibility, transport safety, and environmental exposure. This study presents a reproducible multisensor framework for short-horizon forecasting of mineral-dust optical depth using PACE OCI hyperspectral observations, PACE aerosol retrievals, ERA5, Sentinel-5P, CAMS EAC4, NASA FIRMS, and AERONET. The dataset comprised 35 operationally defined dust-event cases, 420 checksum-verified event-linked files, and 22 additional CAMS files used for event definition and target generation. After quality filtering, 2691 analytical units from 34 events were evaluated using event-disjoint nested cross-validation and 2000 event-level bootstrap replicates. At +24 h, the full multisensor model achieved MAE = 0.0810, RMSE = 0.1153, and R^2 = 0.1810 against CAMS EAC4. A persistence baseline obtained a lower point-estimate MAE of 0.0738, although the paired bootstrap interval included zero. For q90 high-load classification, the multisensor model achieved balanced accuracy = 0.5872 and ROC-AUC = 0.7468. Regional and temporal holdout tests showed reduced generalization. The results provide a rigorous PACE-era benchmark and support conservative use of multisensor models for terrestrial and future space-habitat particle monitoring, without implying toxicological equivalence between terrestrial, lunar, and Martian dust.

Student-built cubesat for multispectral imaging with optical communication module – PUCHACZ mission overview

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The PUCHACZ satellite is the next step of the SATLAB student research group activity. It will be a 2U cubesat satellite that will be demonstrator of multispectral imaging and an optical communication module. This mission will enrich students experience in building larger satellites, designing optical systems and remote sensing. The use of 2U cubesat platform will allow for a significant reduction in the costs of satellite construction and launch. The main payload of the satellite will be a 4-band multispectral camera. Thanks to the use of sun-synchronous orbit, data will be aquired reguraly at short intervals. The next task will be the Earth observation in higher resolution in RGB bands, which will allow testing AI algorithms that increase the resolution of multispectral images. The acquisition of multiple images during the mission led to the development of a miniature laser communication module. The purpose of this module will be provide a broadband downlink. The satellite will also carry BEAR research payload.

The PUCHACZ is a low-cost Earth observation satellite. Multispectral and RGB cameras will be used to develop student skills in building and using more advanced payloads. In turn, the laser communication module will develop competences in the construction of optical systems. In future versions, this module will be very helpful in building smaller cubesat satellites (1-3 U), which will have to transmit a lot of data.

Two months, two selfies - a retrospective on "HYPE" 1P PocketQube satellite mission

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The "HYPE" 1P PocketQube developed by SatLab AGH research group was the first Polish 1P PocketQube. Launched in January 2025 aboard the Transporter-12 mission, the satellite was designed as a technology demonstrator for a custom nanosatellite platform. Its payload included a miniature VIS-NIR spectrometer for experimental Earth observation alongside a unique outreach module - an LCD screen and deployable "selfie-stick" camera.

While the mission did not survive long enough to downlink the spectroscopy data, the satellite successfully validated its core 1P architecture in Low Earth Orbit. Over its 54-day operational lifespan, the ground station collected vital system telemetry, performed a file transfer and successfully downloaded two in-orbit images of the satellite.

The HYPE mission provided critical data for evaluating small-satellite hardware and firmware. This retrospective analyzes the recovered flight telemetry to characterize the mission's anomalies, ranging from early thermal fluctuations in the radio subsystem to the final loss of signal. Through this post-flight analysis, key engineering insights are outlined, and specific hardware and software mitigations - currently being implemented in the subsequent 2U CubeSat architecture - are detailed to enhance overall system reliability and environmental fault tolerance.

Thermodynamic Modeling and Processing of Transparent $MgO–Y_2O_3$ Ceramics for Space Optical Applications

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Transparent $MgO–Y_2O_3$ ceramics are among the most promising materials for optical windows and protective components operating in the visible and infrared spectral ranges. They are of particular interest for space applications, where high optical transmittance must be combined with resistance to extreme service conditions, including cosmic radiation, severe thermal fluctuations, and vacuum environments. Their excellent mechanical performance, characterized by high hardness and strength, together with the cubic crystal structure and wide solid-solution range of the $MgO–Y_2O_3$ system, make these ceramics attractive candidates for advanced transparent optical materials.

In this study, the phase equilibria of the $MgO–Y_2O_3$ system were investigated using FactSage thermodynamic software to model phase evolution in multicomponent oxide systems. The predicted crystalline phases and the fraction of liquid phase as a function of temperature were compared with experimental X-ray diffraction (XRD) results and literature data.

The obtained results provide insight into the relationships between chemical composition, phase evolution, and the resulting functional properties of transparent $MgO–Y_2O_3$ ceramics, identifying processing conditions that are favorable for the development of high-performance optical components for space technologies.

Funding

This study was funded by the SONATA BIS grant (2025/58/E/ST11/00434) awarded to the author A. K. by the National Science Centre, Poland.

The studies were partially financed by the "Excellence Initiative – Research University" program (IDUB) at AGH University of Kraków and from the subsidy of the Minister of Science and Higher Education for the AGH University of Kraków.

Season and Platform dependent Sentinel-1 InSAR coherence over a freeze-thaw dominated terrain in Longyearbyen, Svalbard

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InSAR underpins operational deformation monitoring, but its reliability in high latitude freeze-thaw terrain is season dependent and its continuity depends on constellation configuration. This study quantifies season and platform dependent Sentinel-1 coherence over Longyearbyen, Svalbard, from 2590 Interferometric Wide Swath SLC products spanning Sentinel 1A, 1B, 1C and 1D, starting from Sentinal-1A data from 2014 up until Sentinel-1D data released in April 2026. The record is stratified into four periods: the A/B dual-satellite period; the A-only period following the December 2021 Sentinel-1B anomaly and August 2022 end of mission; the restored A/C period; and the present A/C/D period preceding Sentinel-1D's replacement of Sentinel-1A. Coherence is compared for single-satellite and cross-satellite pairs at matched temporal baselines, orbit geometry, polarisation and seasonal window. Processing uses the ESA SNAP TOPS chain (precise orbits, ESD back-geocoding, Copernicus 30m DEM phase removal, multilooking, and terrain correction). A three-tier scheme (reliable >0.5; usable with caution 0.3-0.5; not reliable <0.3) turns the distributions into decision support. Our preliminary research across 1A, 1B, and 1C indicates summer coherence over snow, melt and moisture affected surfaces falls to 0.31, while winter values over bedrock and infrastructure reach 0.56.

Keywords: Sentinel, InSAR, coherence, arctic monitoring, freeze-thaw, SNAP

Development of the LPMT – Laser Polarisation Modulation Transceiver at AGH Skylink

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This work presents the design and development of a high-precision experimental setup for measuring magneto-optical Faraday rotation. The system determines the rotation angle of linearly polarized light as a function of the applied magnetic field and forms the core of the Laser Polarisation Modulation Transceiver.

The setup uses a 405 nm laser, a magnetic field generation system based on an RLC circuit operating at 1 kHz, and a sensitive polarimeter. A Glan–Thompson polarizer defines the input polarization, while a two-lens telescope produces an approximately 2 mm collimated beam. A dichroic beam splitter directs a small fraction of the optical power to a reference photodiode, enabling compensation for laser intensity fluctuations and measurement of sample transmittance.

The main beam passes through the investigated sample placed inside the magnetic field generated by an open-core iron inductor. Air-core inductors were insufficient because fields of approximately 100 mT are required to obtain polarization rotations in the range of 1°–10°. After the sample, a Wollaston prism separates the beam into two orthogonally polarized components detected by a balanced photodetector. The differential signal is demodulated using a lock-in amplifier, enabling sensitive detection of small polarization rotations.

Acknowledgements

This work was supported by the AGH University of Kraków rector's grant project "LPMT – Laser Polarisation Modulation Transceiver." The authors thank the AGH Skylink team for their contributions to the design, construction, and testing of the setup.

KGK2026 Abstract 0103

The PIRX rocket - systems engineering perspective

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PIRX is the first rocket developed at the Faculty of Space Technologies at AGH University of Krakow. It was launched during the Czech Rocket Challenge in 2027, receiving the maximum number of points in the Innovation, Payload, and Design Presentation categories. This work presents the mechanical and systems-engineering aspects of its development.

The main topics include mass and aerodynamic optimisation, computational fluid dynamics simulations for a theoretical analysis of active guidance, integration of different subsystems, and solutions to problems encountered.

A carbon-fibre airframe was selected to reduce mass while maintaining mechanical strength. Internal subsystems were mounted on a universal cage inspired by Thorlabs optical rail systems. This enabled integration and testing outside the rocket body and significantly shortened final assembly time. The modular design also allowed new subsystem mounts and components to be added in less than 24 hours.

Both the rocket and its biological payload survived the flight. The recovered vehicle will be exhibited during the presentation.

Nie można wyświetlić obrazu.

KGK2026 Abstract 0104

Concept of a Flexible-Path Bucket Conveyor for Icy Regolith Transport from Lunar Craters

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Lunar regolith is an extremely abrasive bulk material that requires specialized handling systems capable of operating in the harsh lunar environment. This presentation introduces a three-dimensional bucket conveyor concept developed for In-Situ Resource Utilization (ISRU) applications, enabling efficient regolith transport from permanently shadowed regions and ice-bearing craters near the Lunar South Pole.
The key innovation is a flexible conveyor route that allows continuous transport in horizontal, vertical, inclined, and arbitrary three-dimensional directions. This solution has no direct counterpart in conventional terrestrial bulk material handling systems. The design was preceded by laboratory investigations at AGH University of Krakow focused on improving reliability while reducing energy consumption and system mass.
The prototype LUREBUCON3D employs a roller chain as the traction element and dedicated track components enabling precise three-dimensional guidance. Self-orienting buckets ensure stable transport and reliable discharge of regolith. To mitigate dust-related challenges, an innovative pulse feeder derived from the TOLRECON project provides efficient bucket loading while minimizing dust dispersion.

Initial experimental results demonstrate the feasibility of the concept and its potential as a key enabling technology for future lunar ISRU infrastructure and sustained human presence on the Moon.

KGK2026 Abstract 0105

MXene material and its new modification

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KGK2026 Abstract 0106

On the development of algorithms for Event-Based Anomaly Detection for Telemetry Data using ESA-AD Benchmark

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This paper delves into anomaly detection in spacecraft telemetry. We investigated the benefits of using the ESA Anomaly Detection Benchmark gathered during three European Space Agency missions. We focused on the first mission. The dataset contains years of time series data from 224 telemetry channels and 821 telecommands, as well as 1430 annotated events, including 157 anomalies, rare nominal events, and communication gaps. We processed a subset of channels 41 to 46 over a 42-month period, with 3,677,761 samples per channel. We evaluated a lightweight unsupervised detector, its morphological filtering variant, other unsupervised methods, Anomaly Transformer, and AnomalyBERT. Performance was assessed using event-based metrics, whereby an event deemed to have been detected if at least one predicted timestamp fell within its annotated window. The F0.5e score combined event precision and recall, giving greater weight to precision to reduce false alarms. Morphological filtering reduced the average number of false positive events of LOO KDE from 3657 to 2, and Mo LOO KDE achieved the best F0.5e score among unsupervised methods. Filtering increased event precision for AnomalyBERT from 0.785 to 0.985, reducing false-positive events from 18 to 1. In the filter comparison, the EWMA filter achieved the highest F0.5e score of 0.672, followed by the morphological opening with 0.662. Overall, filtering enhanced the quality of event detection and reduced the number of alarms.

KGK2026 Abstract 0107

Physics as an Audit Channel: Hardware-Level Verification of Delegated Work in Agentic Space Systems

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Agentic systems are arriving in space — software that plans, tasks peers, and reallocates work with no human in the loop. Every delegation rests on an unverified premise: that the receiving machine can do the job, and did. Attestation establishes who is speaking, not whether a claimed capacity or reported result is physically possible. A degraded node signs a well-formed statement about a false state, and the workload placed on it is lost silently.

We present an architecture reconciling three ledgers: claimed state (attestation), observed state (emission and behaviour), and possible state (thermodynamic bounds); trust is the residual. Identity is anchored in a minimal secure compute base, using TCG DICE for hardware-derived identity and IETF RATS for attester/verifier roles; payload and inference compute sit outside the trusted root, as subjects of attestation. A physical capability certificate then carries attested remaining work capacity — thermal headroom, compute, delta-v — and a sealed-key admission mechanism decrypts a workload only for a node whose certificate covers its demand. Degraded hardware is excluded before it receives work, not diagnosed after it fails.

Waste heat is conserved: a node claiming idle while radiating at load is detectable without internal access, so work performed is measurable, not merely promised. We argue side-channels are better treated as regulatory instruments than attack vectors, and identify ground-based radiometric observability as the limiting open question

KGK2026 Abstract 0108

Neural Debris Removal: Continuous Unlearning of Backdoors in Orbital Streak Detectors

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KGK2026 Abstract 0109

Can MXene-Based Sensors Enable Force-Aware Robotic Excavation on the Moon? Reduced-Gravity Regolith Cutting Tests Study

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Force-sensing capability at the tool-regolith interface is a key enabler for adaptive robotic excavation on the Moon, where soil properties vary unpredictably and open-loop cutting strategies risk inefficiency or mechanical overload. MXene-based nanomaterial sensors have recently emerged as a lightweight, flexible alternative to conventional force sensors, but their viability for space robotics applications, particularly under the mechanical and environmental demands of regolith interaction, remains largely unproven. This work evaluates the performance of an MXene-based force sensor mounted on the leading edge of a blade end-effector during parabolic flight campaigns simulating lunar gravity, alongside a reference sensor for direct comparison. The blade was driven through three regolith simulants at multiple cutting speeds, following calibration of both sensors against known loads using a universal testing machine. Preliminary results indicate that the MXene sensor can be used to track force trends across varying regolith types and cutting speeds, though some discrepancies in readings relative to the reference sensor point to areas requiring further refinement. These findings suggest that MXene sensors are a promising, though not yet fully mature, candidate for integration into future lunar excavation robots, offering a pathway toward lightweight, distributed force feedback for autonomous ISRU tool control pending further qualification

KGK2026 Abstract 0110

A Gentle Introduction to Defending Deep Space Debris Detectors from Data Poisoning with Feature Attribution Techniques

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The security of algorithms used in mission-critical environments is a serious concern, and awareness of potential exploits and attack vectors is on the rise.
As such, the explainability of AI models is gaining more traction. This study's main objective is to analyze a deep learning model that has been poisoned with a Trojan horse backdoor through the lens of XAI techniques.
The model in question comes from the “Neural Debris Removal in Streak Detection” competition organized by the European Space Agency, as well as the data employed for the experiments [1]. The neural network used to detect deep-space debris was affected during training with the backdoor trigger present in the images in the dataset. The goal of the competition is to de-poison the existing model. Using XAI methods such as GradCAM, SHAP, and LIME, we pinpoint the model’s infected behavior. We assess how intense the model’s reaction to triggers is and how effectively it unlearns an unwanted behavior [2]. After compiling the results from the three effective methods, a clear picture emerges of how deeply the trigger lies within the model and how effective the unlearning really is. The findings suggest that, with available XAI techniques, models employed in mission-critical environments can be examined in great detail to ensure that any malicious interference is detected and dealt with.

KGK2026 Abstract 0111

Benchmarking Deep Learning Models for Radio Frequency Interference Detection in Sentinel-1 Quicklook Imagery

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When working routinely with SAR satellite data, unexpected difficulties are often encountered due to artifacts in these images. This work covers the experience gained during the ClearSAR challenge [1], which focused on detecting radio frequency interference in Sentinel-1 SAR quicklook RGB images using bounding-box object detection. The progress of the proposed algorithms has been tracked using mean average precision to summarize detector accuracy and confidence. Additionally, for the verified artifacts, the intersection over union has been evaluated to assess the quality of the predicted bounding box overlaps relative to the provided ground truth. Our experiments compared several deep learning architectures, including the best-performing YOLO11 [2] and YOLO26 [3] detectors. The newer model slightly outperformed the older version. In zero-shot evaluation, YOLO11L achieved a MAP score of 0.4377, while YOLO26L achieved 0.4019. For RFI detection, the newer architectures do not automatically deliver better performance, especially when the target objects are thin, irregular, and visually distinct from those in common object-detection datasets. A key part of the investigation involved improving techniques such as data augmentation, varying training data splits, tuning the confidence threshold, changing image sizes, and performing inference parameter sweeps. The greatest improvements were not achieved by switching to a newer detector, but by combining several YOLO11L partial solutions.

KGK2026 Abstract 0112

SULIAP: A COTS-Based RGB-NIR Camera Payload for Land Imagery Applications on the Maya-7 2U CubeSat

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The Maya-7 2U CubeSat, developed under the Philippine Space Agency's ENCRADLE project, trains Filipino space engineers through complete, hands-on nanosatellite development by University of the Philippines Diliman master's students with four university payload teams from the 2022 Nanosatellite Mission Idea Contest. Its principal mission is the Sensing Unit for Land Imagery Applications Payload (SULIAP), a camera system that extends the COTS imaging lineage begun by Maya-1 under BIRDS-2. SULIAP integrates a COTS 1/4-inch CMOS image sensor (3 um pixels, 326 mW) and a 50 mm, f/3.1 VIS-NIR lens with a purpose-built FPGA controller board implementing sensor configuration, data capture, telemetry, and data distribution; a sensor board; and custom optomechanics within a 270 g allocation. Operating in pushframe mode triggered by the attitude control system, the design achieves 48 m ground sensing distance at 400 km against an 80 m requirement, bounds image files to 345.6 kB for a 4800-bps UHF downlink, and is verified through an MTF budget at the 166.7 lp/mm Nyquist frequency and image-chain simulations. Captured RGB-NIR images feed three onboard classification missions (COEUS shoreline classification, GreenSat agricultural land detection, MASID NDVI vegetation health), demonstrating resource-efficient onboard image classification for downlink prioritization. The project is in proto-engineering model development: board fabrication, testing, bracket FEA, and bus integration.

KGK2026 Abstract 0113

Synthesis and Characterization of Surface Plasmon Resonance Silver Nanoparticles for Antimicrobial and Photocatalytic Biofilm Control in Extraterrestrial Environments

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Extended space missions promote microbial persistence and biofilm formation because of confined environments, limited sanitation options, altered microbial behavior, and prolonged crew occupancy. Developing multifunctional antimicrobial materials for food & biomedical use is therefore essential to astronauts' health and spacecraft hygiene. This study synthesized and tested silver nanoparticles (AgNPs) exhibiting surface plasmon resonance (SPR) incorporated into 3D-printable transparent resins for biofilm control. AgNPs were characterized by dynamic light scattering (DLS) and Zeta-potential measurements to determine size and stability. The shape was studied by scanning and transmission electron microscopy (SEM & TEM). Microbial adherence and biofilm formation were evaluated under static and flow conditions against

Gram+ and Gram- pathogens and yeast. Statistical analysis included two-way ANOVA and post-hoc Student's t-test, at $p < 0.05$. By varying the reagents, nanoparticle dispersions of different colors (Red, Green, Blue, and Yellow) were obtained. The average particle size was 49 nm ± 40 nm (Y> G > R > B). AgNPs demonstrated antibacterial activity, starting at 56 ppm. When incorporated, the resin preserved aesthetics (transparency) and favorable mechanical properties and inhibited biofilm formation. Obtaining the primary colors (RGB+Y) opens the possibility of creating broad-spectrum antimicrobial 3D printable resins in virtually all shades of the visible spectrum. Also, beyond their intrinsic antimicrobial activity, SPR-mediated photocatalytic effects may enhance reactive oxygen species generation under UV light exposure, providing additional self-disinfecting functionality.

KGK2026 Abstract 0114

Effectiveness of Blue-Green Infrastructure in Moderating Urban Heat: Remote Sensing and Field Evidence from the Upper Silesian Metropolis

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This study assesses the effectiveness of blue-green infrastructure (BGI) in moderating land surface temperature (LST) in the Upper Silesian and Zagłębie Metropolis (GZM), Poland, from 1985 to 2024, building on prior GZM evidence on land cover and thermal change [1]. Urbanisation intensifies local surface warming, while vegetation and water can reduce heat exposure [2,3,4,5]. Landsat 5, 8 and 9 imagery processed in Google Earth Engine was combined with ECOSTRESS and Sentinel-2 data to derive LST trends and environmental indices (NDVI, NDWI, NDBI, EVI, SAVI, NDMI and albedo) [6,7]. Urbanised areas showed a warming trend of 0.15 °C per year ($p = 0.001$), while LST correlated negatively with NDVI ($r = -0.41$) and NDWI ($r = -0.18$).

Measurements from 55 Thermochron iButton sensors deployed across contrasting land covers correlated strongly with satellite LST ($r = 0.81$–0.83) [8]. On 28–29 August 2024, forested sites and sites near water were 10–11 °C cooler (19.8–22.1 °C) than industrial and paved sites (30.1–30.8 °C), where temperatures remained above 35 °C for up to 97 hours. OpenMeteo data provided meteorological context.

A survey of 105 residents showed that BGI awareness increased with education, support was stronger in rural areas, and perceived thermal benefits were largely intuitive. Integrating satellite, field and social data, the study provides a replicable framework for evaluating BGI cooling and supporting climate adaptation in formerly industrial metropolitan regions.

References in File

KGK2026 Abstract 0115

A Damage Index Approach for Lamb Wave Based Damage Detection in Thin-walled Structures Under Temperature Variations

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Lamb-wave structural health monitoring (SHM) can inspect metallic plate-like structures, which are widely used in aerospace and space applications, but temperature changes alter wave amplitude and phase and can mask damage. This study presents a damage detection method for metallic plate-like structures, combining cointegration, wavelet multi-resolution analysis, and a stationarity test, for use in space structures design. Cointegration learns a baseline from undamaged Lamb-wave signals recorded at different temperatures. This baseline removes the temperature effect and leaves stationary residuals. New signals are checked against this baseline; if damage is present, the signal no longer fits, and its residual becomes non-stationary. The residual is split by a discrete wavelet transform, and the augmented Dickey-Fuller statistic is calculated at each level. The most sensitive levels are combined into one scalar Damage Index, so each test gives a single number, and thresholds can be set statistically. As a preliminary test, aluminium plates were tested from 35-70 °C, comparing an undamaged plate with a 5 mm through-hole thin-walled plate. Results show the Damage Index separates damaged from undamaged plates across the full temperature range. Work in progress extends this to multiple damage sizes and estimation of the smallest detectable defect.

KGK2026 Abstract 0116

High-Resolution Respirometry of Whole-Daphnia Homogenates: A Pilot Study with Resveratrol and Curcumin

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Mitochondrial dysfunction is a hallmark of ageing and environmental stress, yet methods for assessing mitochondrial respiration in small aquatic invertebrates remain limited. This pilot study aimed to establish a high-resolution respirometry protocol for whole daphnia homogenates using the Oroboros O2k system and to evaluate preliminary effects of resveratrol and curcumin supplementation on mitochondrial function. Adult daphnia magna was exposed for five days to resveratrol or curcumin vs control. Whole-animal homogenates were analyzed using a substrate–inhibitor titration (SUIT) protocol including Routine respiration, OXPHOS through Complex I, cytochrome c test, combined Complex I and II respiration, LEAK,

residual oxygen consumption (ROX) and Complex IV activity. Respiratory parameters were corrected for ROX and Complex IV activity to account for non-mitochondrial oxygen consumption and differences in mitochondrial content. The developed protocol produced reproducible respiratory profiles with high OXPHOS and low ROX. Preliminary results indicated lower Routine and OXPHOS respiration in resveratrol and curcumin treated animals compared with controls after normalization to Complex IV activity, whereas the relative contributions of Complex I and II remained similar among groups. These findings demonstrate the feasibility of high-resolution respirometry for studies investigating mitochondrial responses to pharmacological interventions in context of spaceflight countermeasures.

KGK2026 Abstract 0117

SOMBA.Systematic Oral and Brain Gut Axis

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Published data on the effects of spaceflight-associated stressors on oral health and the interactions between oral and systemic physiology remain scarce. Existing evidence suggests that microgravity, isolation, circadian disruption, and operational workload may contribute to temporomandibular disorders, bruxism, inflammation, muscle fatigue, and oral microbiome dysbiosis, potentially compromising astronaut health and mission performance. However, these findings are based on limited studies, highlighting the need for multidisciplinary research.

The Systemic-Oral-Microbiota-Brain-Axis (SOMBA) project will investigate interactions between the oral microbiome, inflammation, coagulation, autonomic regulation, and cognitive resilience in validated spaceflight analogs, including head-down bed rest, dry immersion, parabolic flights, and isolation. Non-invasive assessments—including heart rate variability, salivary biomarkers, electromyography, oral examinations, and questionnaires—will characterize physiological and psychological responses. Biomarker panels will identify signatures of maladaptation, while exploratory analyses will assess sex-related differences. Results will be compared with astronaut datasets, including the NASA Twins Study, Inspiration4, and NASA GeneLab. As the first study to integrate oral microbiome dynamics with systemic inflammation and autonomic regulation across multiple spaceflight analogs, SOMBA will generate much-needed evidence to support biomarker discovery, countermeasure development, and risk mitigation for future long-duration exploration missions.

KGK2026 Abstract 0118

Technical Competence and Network Stability Analysis in a Lunar Analog Mission

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An exploratory analysis of day-to-day stability of multiplex influence networks and the predictive role of perceived technical competence during a seven-day lunar analog mission with an eight-member crew at Analog Astronaut Training Center 2 (AATC2), Poland (EMMPOL_2026). Formal, technical, and social peer-nomination networks were constructed daily and compared across consecutive days using Jaccard edge overlap and Spearman rank correlations of in-degree centrality. Mixed-effects and lagged models tested

whether technical-network centrality predicted formal and social influence. The three networks did not stabilize in parallel: technical rankings converged and then remained highly stable, social rankings stabilized in the mission's second half, and formal rankings showed renewed fluctuation when operational task demands declined during mission closure. Technical centrality correlated positively with concurrent formal and social centrality, but only predicted next-day social influence, not formal influence, indicating that expert power accumulated gradually rather than displacing legitimate authority over short intervals.

Keywords: analog space mission, sociometry, social network analysis, leadership emergence, influence networks, ICE environments, daily diary methodology, NAWA, EMMPOL_2026, EuroMoonMars, Poland AATC, Moonbase

KGK2026 Abstract 0119

Who Stays in the Center? TIPI, Formal Command, and Morale dynamics in an ICE Crew

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This exploratory study presents an sociometric investigation of influence network emergence and evolution among an eight-member crew during a seven-day analog space mission conducted at Analog Astronaut Training Center 2 (AATC2), a lunar analog habitat facility in Poland as one of missions from EMMPOL_2026 plan. Using daily peer nominations, three multiplex networks were tracked: formal (legitimate power), technical (expert power), and social (referent and informational power) (French and Raven's, 1959). Network centrality was computed daily; unweighted in-degree, a simple count of how many crew members nominated each person and served as the primary metric given the small sample size (N = 8). Pre-mission personality data were collected via the Ten-Item Personality Inventory (TIPI; Gosling et al., 2003) to contextualize leadership emergence patterns with reference to the Big Five trait literature. This investigation examines the persistence of formal command as the principal source of influence, the utility of TIPI-derived personality profiles for leadership emergence, and the relational dynamics of group morale and the perceived power. The findings suggest that effective adaptation in isolated and confined environments depends on complementary leadership roles around a persistent core, and that personality assessment and longitudinal sociometry provide complementary information for crew selection and behavioral monitoring in future exploration missions.

KGK2026 Abstract 0120

An excavating system designed to collect, store and transport lunar regolith

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Title: An excavating system designed to collect, store and transport lunar regolith.

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An excavating system to collect, store, and transport lunar regolith was designed as a part of the DISTOBEE project for the ESA 2nd Space Resources Challenge. The system was separated into two related modules, one for excavating the regolith and the other for beneficiation of the collected material into the desired fractions.

The excavation module was designed to operate on a moving platform, creating a dual-screw excavating rover. The mechanism was designed to perform two critical functions: it serves as the primary excavation module and provides temporary on-board storage for collected material. The operational cycle is driven by rotating screws that convey regolith along the length of the tubes. During the digging phase, the module is tilted at a specific angle relative to the surface, allowing the excavating head to penetrate the lunar soil. Once the storage capacity is reached, the module is raised back to a horizontal position. This adjustment is vital for the mission, as it reduces motion resistance and enhances the rover's overall stability during transport across uneven, cratered terrain.

Field tests of the device were conducted at the ESA's LUNA facility in Cologne, Germany. During testing, the prototype operated stably and fault-free, in accordance with the adopted design assumptions. The results confirmed the high effectiveness of the proposed solution, and the achieved loading and storage performance exceeded the values assumed at the design stage.

KGK2026 Abstract 0121

Understanding Bone Cell Responses to Ionizing Radiation: A Step Toward Radiation Protection in Future Space Missions

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Space missions expose astronauts to ionizing radiation, including high-energy protons, which may negatively affect the musculoskeletal system. In combination with microgravity, radiation may cause alterations in bone metabolism and changes in remodeling dynamics. The biological response of bone cells to different radiation types and doses remains an active research area.
This work presents the response of normal human osteoblasts (NHOst) and osteosarcoma (MG63) cells to proton irradiation, low-dose X- and gamma-radiation. Measurements included cell viability, cytotoxicity, proliferation, and GADD45 expression to assess radiation-induced damage and cellular adaptation capabilities.
Furthermore, the project supports ongoing research on how cells respond to ionizing radiation and lays the foundation for future studies on radiation protection.

KGK2026 Abstract 0122

The multi-stage sieving mechanism for beneficiation of the lunar regolith

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Title: The multi-stage sieving mechanism for beneficiation of the lunar regolith

The multi-stage sifter was developed as part of the DISTOBEE project for ESA 2nd Space Resources Challenge. This system is specifically engineered to separate regolith into three distinct size fractions: below 100 µm, 100–500 µm, and 500–1000 µm.

To accelerate development and maximize process performance, a dedicated laboratory test stand was designed to reproduce the screening module’s geometry and kinematics while enabling rapid reconfiguration and safe testing across a wide operating range. A systematic parametric study was conducted

to identify favorable operating parameters and component geometries. The examined variables included the number of brush arms per level, brush geometry and contact pressure, vibration frequency, brush rotational speed, and the overall axial inclination of the unit. The test stand enabled process evaluation based on metrics such as screening efficiency, separation effectiveness across the target fractions, and resistance to clogging over time.

A key functional feature is the dual-mode operation of the brush system. By reversing the drive shaft direction, the brushes switch between a sifting mode and a discharge mode, actively conveying processed material from the sieve centre toward the outlets. The axial inclination ensures controlled material transport across the sieve surfaces, so brushing and vibrations can sustain effective screening within the sifter without any additional transport mechanisms. The experimental campaign provided clear guidance on operating ranges and design choices that improve the repeatability and reliability of the multi-stage sifting process scenarios.

KGK2026 Abstract 0123

From Framework to Flight: A Reusable Software Stack for the 2U Puchacz CubeSat

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Student satellite missions frequently develop flight software from scratch, limiting reuse and increasing development effort and technical risk. This work presents a reusable software architecture developed for Puchacz, a student-built 2U CubeSat, designed to provide a resilient and scalable foundation for future CubeSat missions.

A hardware-independent framework was implemented in modern C++ with emphasis on modularity, portability, and resource-efficient operation under embedded real-time constraints. The architecture integrates common satellite services, including logging, housekeeping, time synchronization, CubeSat Protocol communication and file transfer. Software resilience is enhanced through a radiation-tolerant dual-bank bootloader, redundant firmware updates, CRC verification, ECC support, watchdog supervision, and fault detection and recovery mechanisms. A dedicated build system enables consistent integration of subsystem applications, while unit and integration testing support software verification.

The framework serves as the common software foundation for all Puchacz subsystems and payloads. Each function is implemented on an STM32-based board running FreeRTOS, including radio and laser communication modules and scientific payloads such as a multispectral camera. The satellite is scheduled for launch, providing an opportunity for near-term in-orbit validation.

The presented architecture demonstrates that a unified flight software stack can support diverse CubeSat subsystems while reducing software duplication and simplifying future mission development. Future work includes flight validation, framework extension to larger satellite platforms, and public release.

KGK2026 Abstract 0124

Flight-tested software for the avionics and ground station of the PIRX rocket

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KGK2026 Abstract 0125

Stratospheric Weathering of Modified Wood: A Low-Cost Approach to Sustainable Aerospace Materials

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Democratizing space requires sustainable, accessible research pathways. New commercial wood-impregnation methods are opening possibilities for space construction. With the recent creation of wood based space projects such as wooden satellite LignoSat and plywood stratospheric gondola of BEXUS EVE CURiE experiment the qualification of stratospheric performance of modified wood becomes an important yet unexplored matter.

To assess these materials a stratospheric balloon is being flown in august. The experimental design evaluates both raw and impregnated variants of European Beech and Scots Pine. European Beech, as a diffuse-porous hardwood, serves as a locally abundant analogue to the Japanese Magnolia used in LignoSat. The sapwood of Scots Pine is a foundational material for commercial modification processes such as Accoya, and Kebony which are achieved by acetylation and furfurylation, respectively. Those processes will be used for both Pine and Beech as they are proven to significantly enhance mechanical properties of wood.

Post-flight diagnostics will quantify the impact of stratospheric vacuum and freezing environments through mass loss, moisture content and geometric deformation. Furthermore, physicochemical shifts will be evaluated using CIELAB colorimetry, while radiation-induced polymer bond cleavage will be mapped via FTIR spectroscopy and EPR. The resulting dataset is intended to support low-cost, wood-based aerospace structures for space programs globally.

KGK2026 Abstract 0126

Power budget assessment of an active heating system for a stratospheric gondola: feasibility of innovative power sources for long-duration missions

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Stratospheric gondolas allow for conducting experiments under near-space conditions. At highest flight altitudes of 20–30 km, the ambient pressure approaches vacuum, temperatures decrease to approximately −60°C, and exposure to ultraviolet and cosmic radiation is significantly higher than at ground level. These conditions make stratospheric gondolas valuable platforms for studying the effects of near-space radiation on living organisms, but survival of the biological payload requires continuous active thermal regulation against the low temperature. The energy this demands remains a key design constraint.

The paper aims to evaluate the power budget of an active heating system integrated into a stratospheric gondola designed for biological experiments. The environmental control system is intended to maintain an internal temperature of 30–37°C, enabling bacterial growth during flight. Heater power consumption will be estimated using a thermal-power simulation, and verified in flight through shunt-based current sensing, to assess achievable mission duration.

Heating demand is expected to be non-uniform, peaking during ascent near the tropopause, easing at float altitude. The study will estimate the battery capacity required for missions of varying duration, and assess whether added insulation or innovative power sources could extend mission duration without increasing battery mass, establishing their feasibility for long-duration stratospheric missions.

KGK2026 Abstract 0127

Design and manufacturing of environmental control system gondola for stratospheric astrobiology research

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Stratospheric balloon flights offer a unique, cost-effective analog for space environments. At altitudes of approximately 30 km, biological samples are exposed to low pressure, extreme cold, and elevated ultraviolet and ionizing radiation. Conducting astrobiology research under these conditions requires specialized platforms capable of maintaining highly controlled micro-environments. A low-cost astrobiology research platform was designed and manufactured to carry and protect biological payloads during stratospheric missions. Developed specifically to support astrobiological exposure experiments, the platform houses cultures of Paenibacillus macerans and Bacillus subtilis within customized cuvettes. While ensuring strict hermetic isolation, the system integrates a radiation-transparent quartz window to allow exposure to the external radiation environment. Furthermore, to counteract extreme stratospheric temperatures, the Habitat utilizes an active heating system designed to maintain a stable internal climate. To validate the platform's operational viability, a comprehensive testing methodology has been established. The structural and thermal integrity of the gondola will be evaluated through simulated flight conditions. This design and methodological framework provides a foundational, low-cost architecture for stratospheric astrobiology research, aiming to ensure reliable specimen exposure and recovery for future analytical studies.

KGK2026 Abstract 0128

Ambipolar Thermoelectric Energy Conversion in Graded MoS_2/MoS_2–MoO_2 Films: A Single-Material Route to Bidirectional Power Harvesting in Space Thermal Environments

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Spacecraft and planetary systems experience large thermal gradients that periodically reverse during eclipses, terminator crossings, and lunar cycles [1]. Conventional thermoelectric generators cannot exploit such conditions efficiently because fixed carrier polarity causes output reversal; bidirectional operation requires separate p- and n-type legs, increasing mass, interconnect complexity, and failure risk. We report a single-material alternative using radially graded MoS_2/MoS_2–MoO_2 films grown by two-zone chemical vapour transport (S at 200 °C, MoO_3 at 760 °C). A decreasing sulfur-to-oxide vapour ratio produces a continuous transition from MoS_2 at the edge to a composite at the centre. Electron probe microanalysis resolves six regions, with oxygen increasing from 0 to 30 at.% and sulfur decreasing from 36 to 22 at.%. Junction reciprocation (switching the hot side) reverses the Seebeck coefficient from −20 to +69.5 µV K^{-1} [2]. Spectroscopy attributes this to reduced Fermi-level pinning at MoO_2 and energy filtering across internal barriers; a 5 K Debye temperature reduction indicates lattice softening and modified electron–phonon

coupling. Voltage saturation is faster at the graded junction (465 s vs 1174 s) and stable over repeated cycles. This demonstrates a thermoelectric material whose polarity is set by the applied gradient, eliminating paired p/n legs. Future work will exploit microgravity growth to enable diffusion-controlled, programmable gradients for efficient space waste-heat recovery and planetary power [3].

KGK2026 Abstract 0129

Miniature Rotor System for Optical and RF Space Communications

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The development of laser and space communication solutions for space applications requires an accurate and stable positioning platform, referred to as a rotor. The system features a lower frame incorporating a bearing with a central cable passthrough, a gear-coupled horizontal (azimuth) rotation servo, a direct-drive vertical (elevation) servo and a weather-proof shell for placing the system in areas exposed to the elements. The rotor assembly is controlled by an ESP32 embedded system featuring a three-axis magnetometer, a barometer and a GPS/GALILEO module. The software includes a geomagnetic model for applying a local heading deviation, a list of preprogrammed target tracks with a possibility of updating target and weather data (important for beam path deviation for optical and microwave systems) through a website hosted on the device. Precise time, system position and altitude data from GPS/GALILEO, coupled with altitude data from the barometer, deviation-corrected azimuth orientation from the magnetometer and external corrections allows for a complete and accurate self-tracking unit. The device can be placed onboard stratospheric missions for automatic target tracking and was intended to be placed on the 12.08.2026 solar eclipse photography mission.

Acknowledgements
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KGK2026 Abstract 0130

Additive Manufacturing of Thermoelectric Legs for Complex-Geometry Space Power Systems

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Thermoelectric generators are a proven, moving-part-free option for space power systems, from radioisotope generators on deep-space probes to waste-heat recovery from onboard electronics. Conventional fabrication of Bi_2Te_3-based legs relies on subtractive shaping of sintered ingots, limiting geometric adaptability to compact, mass-constrained spacecraft enclosures. Laser Powder Bed Fusion (LPBF) offers layer-by-layer, near-net-shape fabrication of complex leg geometries, but its rapid melting and solidification produce microstructures that differ fundamentally from conventionally sintered material, with uncertain consequences for performance. This work compares LPBF-processed $Bi_{0.5}Sb_{1.5}Te_3$ with material consolidated by Pulsed Electric Current Sintering (PECS), spanning a wide range of crystallographic texture (Lotgering factor F ~ 0.02–0.20) to isolate how processing-induced microstructure governs transport. Highly textured PECS samples reached a thermoelectric figure of merit (ZT) of ~1.1, while near-isotropic LPBF material reached ZT ~ 0.4–0.5, and finite-element modeling of device-level performance quantified the resulting difference in conversion efficiency (9.7% vs 5.6% at 600 K). These results identify the microstructural factors limiting LPBF-printed thermoelectric performance and outline a path toward additively manufactured, geometrically adaptable thermoelectric legs for space power systems.

KGK2026 Abstract 0132

Landsat assessment of surface urban heat anomalies and land cover controls in Tarnów, 2021–2025

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Previous Landsat studies confirm the value of satellite land surface temperature for analysing urban heat patterns in Polish cities [1–5]. This study examines heat anomalies in Tarnów, a medium sized city in southern Poland, from 2021 to 2025. Landsat 8 and Landsat 9 scenes were used to retrieve land surface temperature, calculate NDVI and derive a standardized SUHI indicator. For each scene, LST was normalized against the city mean and standard deviation, allowing relative anomalies to be compared between dates. Copernicus land cover data were used to relate thermal response to surface classes.

The strongest positive SUHI anomalies occurred in dense urban, industrial, commercial, transport and impervious areas. Lower LST values were linked to forests, parks, vegetation and areas close to water. Strongly urbanized areas were, on average, more than 2 °C warmer than vegetation dominated areas, while water bodies were about 4 °C cooler than central urban surfaces. The LST difference between Tarnów Market

Square and Strzelecki Park reached about 6 °C, showing a clear contrast between compact urban fabric and green infrastructure.

The results indicate that Tarnów's thermal pattern is controlled by land cover and modified by scene specific weather and surface moisture. Integrating Landsat LST, NDVI, standardized SUHI and Copernicus land cover data provides a reproducible basis for monitoring urban surface heat and selecting priority areas for heat adaptation.

Keywords
Landsat; land surface temperature; surface urban heat island; Tarnów; NDVI; Copernicus land cover; urban heat adaptation

KGK2026 Abstract 0133

From Packaging to Resource: Seaweed Biopolymers for Closed-Loop Space Missions

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Closed-loop life support systems are central to long-duration space missions, whether in Earth orbit, on the Moon, or on Mars, where minimal resupply requires every material entering a habitat to have a planned fate. Packaging for food, tools, and consumables is launched in large, recurring quantities and typically becomes unmanaged waste once used. Seaweed-derived biopolymers are increasingly proposed as biodegradable plastic replacements, owing to land- and freshwater-independent cultivation, cohesive non-toxic films, and versatility for reprocessing into secondary forms. Existing research largely treats this as a substitution question, evaluating whether seaweed films can match plastic performance, while packaging remains framed as waste once its protective role ends. This paper argues such framing underestimates the opportunity: packaging should be designed as a resource performing a planned sequence of functions, not a disposable object. The Circular Space Packaging Innovation Framework integrates circular product innovation and circular business model theory with seaweed materials science around four phases: protection, use, transformation, and regeneration. Value capture is reframed accordingly: circularity is measured not through resale, as in terrestrial economies, but through avoided launch mass, reduced resupply, and mission resilience across orbital, lunar, and Mars contexts. Materials-development priorities and transferable implications for closed-loop environments on Earth are identified.

KGK2026 Abstract 0134

Mining NASA GeneLab for Space Oral Health: Oral Microbiome Dysbiosis and Endothelial Inflammatory Signatures

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Long-duration spaceflight may alter microbial ecology, immune regulation and vascular physiology, yet the contribution of the oral microbiome to systemic adaptation remains insufficiently understood. We used publicly available NASA OSDR/GeneLab data, complemented by NCBI GEO datasets, to investigate whether spaceflight-associated oral microbiome changes converge with inflammatory and endothelial pathways relevant to cardiovascular health. Astronaut salivary 16S rRNA data were analysed across pre-flight, in-flight and post-flight phases and integrated with gingival and endothelial transcriptomic datasets, including microgravity-exposed endothelial cells. Preliminary analyses demonstrated mission-phase-associated shifts in oral microbial community structure and activation of inflammatory and adhesion pathways in microgravity-exposed endothelial cells. SELE, CXCL1 and CXCL8 emerged as candidate bridge genes across oral and endothelial layers. These findings support a potential oral-systemic interaction axis during spaceflight and illustrate how openly accessible NASA GeneLab datasets can enable independent research in space oral health.

KGK2026 Abstract 0135

Beyond Frozen GeoFMs: New Perspectives on Drift, Adaptation, and Forgetting

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Foundation Models Geospatial foundation models (GeoFMs) are the default backbone for Earth observation (EO), pretrained on unlabelled imagery, then frozen. Self-supervision is used because labels are scarce and costly to obtain. But the EO environment is non-stationary. Changes (drifts) may arise on many fronts: the imagery shifts with seasons, illumination and atmosphere, while the targets evolve into novel situations such as new vegetation diseases or a disaster's unpredictable spread. Some appear only onboard, in orbit, during the mission. A frozen model quickly becomes outdated, and retraining is unsustainable. Continual self-supervised learning (CSSL) may be the solution. However, work on CSSL has so far limited its scope to unimodal observations, RGB computer-vision tasks, and has not been applied to GeoFMs. Within the CSSL setting, a fundamental question arises. Since drift is traditionally defined for supervised problems, what does it represent in this context? Is it just a shift in the input distribution, or can we define new forms of drift by exploiting the latent space learned up to that point?
A well-known consequence of adapting to drift is forgetting. As a model updates on new data, it may lose previously acquired knowledge. In the CSSL setting, however, forgetting requires a new definition: without a supervised task, what is actually forgotten, and how should it be measured? Can it be quantified directly from the learned representations, or must it rely on downstream task performance?

KGK2026 Abstract 0136

Performance Comparision of D-D, D-T and Neutron Sources for Neutron Activation Aanalysis of Martian Regolith

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Neutron Activation Analysis (NAA) is one of the most promising techniques for determining the local elemental composition of planetary regolith. To date, nearly all proposition for planetary exploration have relied on D-T neutron generators, providing a high flux of 14.1 MeV neutrons. While this approach enables the interrogation of larger volumes of material and the detection of gamma rays from inelastic neutron scattering, it also increases detector background, and radiation damage. The potential of lower energy D-D neutron generators for planetary applications has received considerably less attention. The aim of this work is to compare the performance of D-D, D-T and AmBe neutron sources for neutron activation analysis of Martian regolith. Monte Carlo simulations were performed using the MMS-2 Martian regolith simulant to investigate the sensitivity to selected elements. The obtained results will provide the basis for the experimental verification planned in the next stage of the research.

KGK2026 Abstract 0137

Application of a Fringing-Field Capacitive Sensor for Analyzing Regolith Distribution Inside a Pipe

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Title: Application of a Fringing-Field Capacitive Sensor

for Analyzing Regolith Distribution Inside a Tube

Authors: Valadar Harelikau, Krzysztof Jabłoński, Kuba Kociszewski

One of the challenges in regolith transport systems for planetary exploration missions

is the lack of information regarding material distribution within enclosed structural

components during operation. The absence of such data limits the capability to detect

anomalies associated with non-uniform filling, void formation, or clogging.

This paper presents a concept for utilizing a fringing-field capacitive sensor (Fringe Field

Capacitive Sensor) for non-invasive monitoring of regolith distribution inside a non-

metallic pipe. The measurement principle is based on detecting variations in the

electric field induced by changes in the dielectric properties of the medium during its

movement, as well as variations in the quantity of material within the sensor's sensing

region.

The proposed system is designed for integration with the DISTOBEE platform, which is

equipped with a screw element for regolith transport. The study encompasses the

development of the measurement system and an evaluation of the relationship

between the sensor signal and both the position and quantity of the material located

inside the tube.

The developed method can serve as the foundation for a lightweight and energy-

efficient system to monitor bulk material transport processes in autonomous robotic devices.

KGK2026 Abstract 0138

Gravitropism and phototropism in different gravity conditions

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This research paper presents and describes the results of an experiment studying the develop ment of peas and radishes under simulated gravitational conditions in aeroponic chambers. The project was conducted in an isolated Analog Astronaut Training Center to best replicate the condi tions encountered in space. The analysis focuses on the effects of light and gravity on the seedlings across three separate micro-environments. In addition, it refers to the temperature and humidity levels and compares various methods of placing test subjects in chambers using different substrates

KGK2026 Abstract 0139

Mandibular Adaptation to Microgravity: From Bone Remodeling to Temporomandibular Function

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Introduction: Prolonged exposure to microgravity induces profound skeletal adaptations; however, its effects on the mandible and temporomandibular joint (TMJ) remain poorly understood. As future exploration

missions require preservation of astronauts' musculoskeletal and oral health, understanding craniofacial adaptation has become increasingly important.

Methods: We reviewed available experimental and clinical evidence regarding mandibular bone remodeling under microgravity and integrated these findings with a translational framework for future assessment of stomatognathic function in astronauts.

Results: Animal studies demonstrate inconsistent mandibular responses to spaceflight. STS-131 reported reduced mandibular bone volume fraction (84.2% vs. 80.7% in controls), whereas STS-135 showed no significant changes, suggesting mission-dependent variability. Human evidence remains scarce, and no standardized protocols exist for evaluating TMJ function or masticatory muscles before and after spaceflight. To address this gap, we propose a multimodal assessment combining surface electromyography, three-dimensional jaw tracking, postural analysis, and imaging of mandibular bone quality.

Discussion: The mandible may represent a unique model of craniofacial adaptation to microgravity. Integrating structural, functional, and biomechanical assessment could improve understanding of TMJ health during long-duration missions and support the development of targeted physiotherapeutic countermeasures to reduce the risk of orofacial dysfunction in astronauts.

KGK2026 Abstract 0140

Lunar regolith composite as a shield against X-rays

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Keywords: radiation shielding, lunar regolith, composites, X-rays

Identifying inexpensive, lightweight materials that provide effective radiation shielding is a crucial issue for space exploration. In outer space, lacking the natural protection of Earth's atmosphere and magnetosphere, astronauts are particularly exposed to radiation. It concerns especially the secondary X-ray radiation excited in the surroundings by high energy particles. Thus, it is vital that shields are constructed from radiation-blocking materials.

This presentation reveals results of a study of radiation transmission through composites of lunar regolith simulant with sulphur. Also the regolith-sulphur samples doped with barium sulphate were investigated. The measurements were conducted on plates of composites at the X-ray source of XRF apparatus using a Geiger-Müller counter. By measuring the intesities of impinging beam and transmitted beam the shielding performance was determined. The results are discussed with respect to the composites content and the X-ray energy and conclusions on their applicability are drawn.

KGK2026 Abstract 0141

Concept for using extreme environments (the Arctic and Antarctica) to test the construction of planetary base infrastructure

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Testing large-scale and autonomous space technologies on Earth is essential to achieving the goal of exploring and colonizing other celestial bodies. To ensure the required level of reliability for systems that enable the survival of humans and equipment on the Moon or Mars, it is crucial to verify their operation under simulated space conditions. For individual spacecraft, the laboratory infrastructure of space agencies- such as vacuum chambers or Faraday cages- proves sufficient. In contrast, for topologically extensive and autonomous systems, appropriate conditions can only be provided by bases located in polar regions: the Arctic and Antarctica. This article presents a concept for using these extreme environments to test technologies related to the construction of space habitats. The authors drew inspiration from NASA's updated lunar base architecture (Moon Base) in the South Pole region as well as ESA's multi-area strategy (*Terrae Novae*). In addition, the technological implementation for the use of in situ resources (ISRU) were evaluated, with particular emphasis on autonomous 3D printing using various types of lunar regolith. Arguments were also presented in favor of using the A. Dobrowolski Polish Antarctic Station (Bunger Oasis, East Antarctica) as an extraterrestrial analog. This environment could facilitate the testing of Polish space technologies and create suitable conditions for conducting scientific research. The suitability of the Bunger Oasis for conducting geophysical observations using autonomous and automated measuring devices was

demonstrated during the most recent Polish expedition to the A. Dobrowolski Station at the turn of 2021 and 2022.

KGK2026 Abstract 0142

Mechanical design of a model rocket - lessons learned from building the first FST AGH rocket for CRC 26

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The Czech Rocket Challenge (CRC) provides an opportunity to design, integrate, and validate experimental rockets in flight using a solid rocket motor supplied by the organisers. For the 2026 competition, ThrustLab AGH was responsible for the rocket's mechanical design and manufacturing, with particular focus on a spring-loaded parachute recovery system and a full-circumference fin carrier with removable stabilisers.

The recovery system deployed the parachute using energy stored in a compressed spring, released after a burn-wire mechanism cut a nylon retaining string. The project included the design, manufacturing, and assembly of this mechanism. The fin carrier was developed to simplify precise fin alignment and improve joint strength through integrated centering features and adhesive channels that reduced air pockets.

During the competition flight, parachute deployment failed because the parachute became stuck inside the body tube and the recovery sequence was initiated at the wrong time. Although the recovery system was not fully validated in flight, testing identified packaging and geometry as the main areas for improvement. The fin carrier performed as intended and also enabled rapid fin replacement before launch. The project highlighted the importance of comprehensive end-to-end system testing, with future work focusing on improving deployment reliability and expanding pre-flight verification procedures.

KGK2026 Abstract 0143

Manufacturing and Preliminary Characterization of an LP/SP Electrically Controlled Solid Propellant

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Electrically controlled solid propellants (ECSPs) offer a potential alternative to conventional solid propellants by enabling electrically initiated combustion, multiple restarts, and controllable thrust generation. This work focuses on the manufacturing and preliminary characterization of a specific ECSP formulation containing lithium perchlorate and sodium perchlorate (LP/SP).

The propellant manufacturing process is presented, with particular attention given to material preparation, component mixing, sample formation, and the repeatability of the resulting propellant structure. The combustion mechanism of the LP/SP-based formulation is analysed to identify the key physical and chemical processes responsible for electrically controlled ignition and sustained combustion.

The quality of the manufactured propellant is evaluated by examining its homogeneity, structural integrity, surface condition, and consistency between individual samples. Preliminary experimental tests are also

presented, providing an initial assessment of the propellant's electrical response, ignition behaviour, combustion stability, and burning characteristics.

The obtained results are used to identify the principal factors affecting the manufacturing quality and performance of the LP/SP-based propellant. The study provides a basis for further optimization of the formulation and manufacturing process, as well as for future testing in an electrically controlled solid-propellant thruster.

KGK2026 Abstract 0144

Electrohydrodynamic (EHD) Propulsion for Manouvering and Altitude Control on an Unmanned Balloon Platform

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Electrohydrodynamic (EHD) Propulsion for Manouvering and Altitude Control on an Unmanned Balloon Platform

Electrohydrodynamic (EHD) propulsion offers an alternative to conventional thrusters by ionizing ambient air to generate directional ionic wind. EHD thrusters operate without any moving parts and are able to utilize atmospheric air as propellant. This offers a cheap and silent propulsion method with minimal mechanical complexity, making it well suited auxiliary propulsion system for small UAVs as well as space vehicles (small satellites/probes).
This project demonstrates the integration and control of custom EHD thrusters onto a helium balloon unmanned aerial vehicle (UAV) to achieve both active maneuvering and station-keeping. To meet the strict mass constraints of high-voltage payload systems, we engineered lightweight custom electronics. Off-the-shelf high-voltage modules were modified by replacing manual inputs with remote operated power transistors, enabling precise digital control.

Flight control is governed by custom-developed software, designed to translate low-level voltage signals into stable propulsion vectors. Experimental results validate the system's ability to maintain position and navigate controlled trajectories in indoor environments. By pairing passive buoyant lift with ionic wind propulsion, this platform demonstrates the potential applications of the EHD propulsion systems.

KGK2026 Abstract 0145

Performance Enhancement of an Electrohydrodynamic Thruster via Emitter Electrode Heating in a DC Configuration

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Electrohydrodynamic (EHD) thrusters are propulsion devices that generate thrust through the application of high voltage, which induces the ionization of nearby gas molecules to create an ionic wind. Despite their simple mechanical construction, modern EHD thrusters face significant limitations regarding their low efficiency, which remains orders of magnitude lower than that of conventional propulsion systems.

An alternative and highly promising method that could potentially enhance the efficiency of EHD thrusters involves using thermal energy by elevating the surface temperature of the emitter electrode. While previous studies demonstrate that increasing the temperature leads to a significant decrease in the ignition voltage, a comprehensive investigation focused directly on the coupling between emitter temperature, aerodynamic thrust generation, and the resulting thrust-to-power ratio has not yet been thoroughly established in the literature.

To address this gap, this study provides a comprehensive investigation of the effects of thermal emitter modulation on EHD propulsion performance. Systematic experimental validation is presented, evaluating the generated thrust and electrical characteristics across various inter-electrode gaps and conductor materials, including tungsten and nickel-chromium wires. Experimental results comparing the baseline performance of an unheated wire to an actively heated electrode configuration reveal that elevating the emitter temperature significantly increases both the discharge current and the generated thrust force at a given applied high voltage.

KGK2026 Abstract 0146

Project THOR (Tremor Observation and Response): Post-Flight Analysis of a Custom Biological Payload on the PERUN Suborbital Rocket

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The inaugural launch of the Polish suborbital rocket PERUN to an altitude of 50 km took place in 2025. During this mission, the AstroBio AGH Student Scientific Club conducted an experiment assessing the resilience of biological samples to extreme flight conditions.

The study involved algae (*Chlorella vulgaris, Arthrospira platensis, Porphyridium cruentum*), yeast (*Saccharomyces cerevisiae*), and *Drosophila melanogaster* larvae, embedded in agarose and capsular media. The entire payload was developed in-house, featuring custom 3D-printed biological plates, a PCB for active environmental control and data logging, and a robust sheet metal casing attached directly to the rocket's platform. The flight experiment was evaluated against an identical ground control.

By focusing on short-term mechanical stressors (hypergravity and vibrations) rather than long-term microgravity, this study filled a crucial gap in space biology. Following an unexpected hard landing, findings indicated that capsular media provided superior mechanical protection for the samples compared to standard agarose. These results offer valuable insights into biological stress responses, supporting the development of resilient protective media for future space biotechnology.

KGK2026 Abstract 0147

Plasma-Produced Carbon Monoxide as the Keystone of Martian Industry: An Interactive Simulator Coupling Propellant, Metals, Life Support and Agriculture

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The Martian atmosphere — 95% CO_2 at ~600 Pa — is an excellent feedstock for plasma dissociation of CO_2 into CO and O_2; its ~2% argon additionally permits on-line plasma temperature measurement by near-IR emission spectroscopy of excited Ar, enabling real-time process control. CO plus H_2 from polar ice gives syngas; conversion of syngas into organic compounds has been proven at industrial scale by Sasol, whose coal-to-liquids plants supply about 30% of South Africa's liquid fuels plus alcohols, monomers and polymers. CO also reduces the Fe_2O_3 abundant in regolith to iron. Plasma CO production is therefore the critical enabling technology for Martian industrialisation, not merely for propellant supply.

Most Mars ISRU studies treat propellant in isolation, obscuring its competition with life support, metals and agriculture for the same hydrogen, oxygen and power. We present Mars Chemical Works, an interactive simulator of a polar ice-cap plant: fission reactor, plasma torch and ice electrolysis feeding methanol synthesis, Fischer-Tropsch, CO methanation or Sabatier, carbothermal iron reduction and Haber-Bosch. A fixed-point solver closes three recycle loops and balance-of-plant load at sol-averaged steady state. It runs

forward (allocate power, see output) or inverse, turning a colony order book — refuellings, headcount, tonnes of steel, plastic, fuel — into required reactor size and process split.

The binding constraint proves stoichiometric, not thermal: hydrogen, not reactor power, sets the plant's shape.

KGK2026 Abstract 0148

Dynamic Traffic Management and Adaptive Routing for Hybrid LEO-Terrestrial Quantum Key Distribution Networks

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Low Earth Orbit (LEO) satellites play a pivotal role in scaling terrestrial Quantum Key Distribution Networks (QKDNs) to global distances. However, establishing spaceborne Quantum Key Distribution (QKD) links introduces severe operational constraints: short optical visibility windows during satellite overpasses, elevation-dependent atmospheric attenuation, and time-varying, bottlenecked key generation rates. Conventional static routing algorithms in telecommunications struggle to cope with dynamic topologies and transient link availability of this scale. We present an adaptive traffic management framework designed to optimize key utilization and route secret key material across space-ground interfaces. Leveraging QuAriadNet, our specialized research simulator for quantum networks, we model topology dynamics of LEO orbital pass schedules, tracking constraints, and key pool dynamics. The work shows how to integrate our system with a Graph Neural Network (GNN) to capture the time-varying spatial topology of the satellite-terrestrial graph, paired with a Deep Q-Network (DQN) agent to dynamically allocate keys and select optimal key relay paths. We outline our evaluation strategy for assessing how the ML controller handles dynamic topology changes and autonomously manage terrestrial key buffers to ensure network resilience.

KGK2026 Abstract 0149

Quasicrystals as promising hydrogen energy storage materials for space missions

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Quasicrystals as promising hydrogen energy storage materials for space missions

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In 1984, Shechtman et al. reported the existence of an extraordinary form of matter, later called quasicrystals. Since Shechtman's discovery, quasicrystalline alloys have been investigated for different technological applications due to their unique physicochemical properties.

Here we report on the optimization of the hydrogenation reaction procedure as well as the structural and microstructural characterization of the $Ti_{45}Zr_{38}Ni_{17}$ quasicrystalline ribbons prepared by the melt spinning technique at the spinning speed of 30 m/s. Compared with the aforementioned references, the $Ti_{45}Zr_{38}Ni_{17}$ quasicrystal studied here reaches a higher capacity (up to 2.60 wt.%) from a simpler ternary, single-phase composition, without multi-element optimization.

Hydrogen stored in quasicrystals is significant for powering autonomous devices in space or as energy stores that can be a source of energy for future missions to the Moon or other celestial bodies.

The optimized procedure enabling the production of high-quality i-phase hydrogenated ribbons with a very high hydrogen capacity of 2.60 wt.% was developed, with no need to grind or modify the pristine ribbons. Our results confirm the possibility of applying bulk quasicrystalline materials in hydrogen storage, which can be used for energy storage in space missions.

KGK2026 Abstract 0150

Behavioral Performance and Task-Related EEG Activity during Complex Visuospatial Problem Solving across a Multi-Day Analog Isolation Mission

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Problem-solving abilities are crucial when facing challenges during space missions. Although these abilities can be evaluated under controlled circumstances, less is known about how astronauts' performance varies during multi-day isolation while facing complex visuospatial problems.

This study investigated behavioral performance and task-related EEG activity during a seven-day analog mission with a group of N = 5 analog astronauts. Participants solved five Ubongo Extreme puzzles across six daily sessions, while solution time, task outcome, and subjective sleepiness were recorded. Additionally, EEG activity was recorded from a subsample of n = 2

Results showed a high overall puzzle completion rate, with 142 of 150 trials successfully completed, representing a completion rate of 94.6 %. Solution time varied across participants and puzzles and did not show a monotonic change across the isolation period. The observed pattern was compatible with increasing task familiarity. EEG recordings differed between the two EEG participants, with no consistent shared trend across participants.

These exploratory findings provide no evidence of systematic change in visuospatial problem-solving performance during the observed isolation period. Instead, they show the importance of puzzle difficulty, practice effects, and inter-individual variability when interpreting repeated cognitive measurements in analog environments.

KGK2026 Abstract 0151

Radish Seedling Resilience to Electric Fields and Ascorbic Acid in Space Habitats

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Biological Life Support Systems (BLSS) are essential for long-duration space missions, serving as a reliable method for fresh food production and supporting crew psychological well-being. However, crops in closed artificial habitats are constantly exposed to background environmental stressors, including anthropogenic electric fields and microclimate fluctuations. This study evaluated the growth response and resilience of radish (*Raphanus sativus*) seeds and seedlings exposed to low-frequency electric fields and exogenous ascorbic acid irrigation during a 7-day analog space mission. The experiment was conducted across four independent trials with 30 seeds for each. To accurately simulate habitat integration, plants were grown alongside the crew without environmental isolation, maintaining identical ambient conditions (temperature, humidity, air composition). The setup compared unshielded electric field exposure against Faraday cage isolation, irrigated with distilled water or ascorbic acid solutions. The application of high-concentration, unbuffered ascorbic acid severely acidified the growth substrate. This extreme acid stress led to root damage and total seedling mortality in all ascorbic acid-treated groups. Conversely, water-irrigated seedlings exhibited successful growth and survival, regardless of Faraday cage shielding. While Faraday cages effectively isolate crops from low-frequency electric fields, unbuffered chemical supplements introduce a critical risk. When growing crops directly in human habitats without isolated climate chambers, maintaining substrate pH stability and controlling chemical inputs is far more vital for crop survival than electric field shielding.

KGK2026 Abstract 0152

SKRRT: SKilltest on Rhythm and Reaction Time of Astronauts in the Analog Astronaut Training Center (NAWA Mission 112)

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This study examined whether playing *Taiko no Tatsujin* with button or Joy-Con motion controls produced different immediate effects on reaction time (RT) during a seven-day analog mission. Five participants completed four sessions each, producing 20 sessions: 10 per mode. Each session included a three-minute Psychomotor Vigilance Test (PVT) before and after two songs. Subjective ratings and Taiko performance were recorded.

The primary outcome was the change in median correct PVT RT from pre- to post-session. A linear mixed-effects model included participant as a random effect and mode, mission day, and pre-session sleepiness as fixed effects. Mean RT change was +4.80±17.86 ms in button mode and +1.30±10.52 ms in motion mode. The adjusted motion-minus-button difference was -3.75 ms (95% CI=-16.06 to 8.57 ms, $p=0.551$). No clear differences occurred in PVT accuracy, false starts, or lapses.

Motion mode had higher physical-effort and frustration ratings, although not significantly, while enjoyment was high in both modes. Button mode had a higher timing-judgment index, and game performance improved across mission days, indicating a strong practice effect.

Neither mode showed a clear advantage for immediate psychomotor vigilance. Both were feasible and engaging, but motion control was more physically demanding and affected by movement and Joy-Con

recognition. The small sample and lack of a passive control limit the conclusions; larger studies are recommended.

KGK2026 Abstract 0153

Autonomous Bioluminescent Lighting System for Space Habitats

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Long-duration space missions require the development of energy-efficient, autonomous, and sustainable lighting systems. As part of this project, a concept for a bioluminescent lighting system utilizing living organisms capable of emitting visible light was developed. The proposed solution combined a biological culture with an electronically controlled microfluidic reactor. The system was designed as a transparent chamber manufactured using 3D-printing technology and containing a controlled culture of selected bioluminescent organisms. Environmental parameters and the process of triggering light emission through controlled mechanical stimulation of the fluid were automatically regulated by a microprocessor. The possibility of activating bioluminescence in response to motion in the vicinity of the device and during power failures was also investigated. The effectiveness of the solution was evaluated based on the intensity of emitted light, response time, energy consumption, culture stability, and environmental conditions within the reactor. The objective of the study was to determine whether biological light sources could complement conventional LED lighting systems used in closed habitats. The results made it possible to assess the potential of this technology as a low-energy emergency lighting source, a solution supporting crew well-being, and a component of bio-integrated systems intended for future lunar bases, Martian habitats, and space stations.

KGK2026 Abstract 0154

Continuous Environmental Monitoring of a Crewed Analog Habitat with a Low-Cost Sensor Node: Diurnal CO_2 Dynamics and Field Reliability

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Continuous environmental monitoring is a core life-support concern for crewed habitats, yet analog missions often rely on manual spot-sampling that cannot resolve short-timescale dynamics. During the seven-day mission AAT-112 (AATC Habitat 2.0, Poland, 24–31 July 2026, six crew), a custom Raspberry Pi sensor node ("BioNode") was placed centrally in the common area and autonomously logged CO_2 (NDIR), volatile organic compounds (TVOC), temperature, humidity, and illuminance at 0.5 Hz, recording over 300,000 time-stamped readings.

CO_2 ranged 645–1719 ppm (mean 828), stayed below occupational limits throughout, and exceeded the 1000 ppm comfort guideline during only 3.7% of the mission, consistent with continuous ventilation. CO_2 showed

a highly repeatable diurnal cycle of ~236 ppm amplitude—lowest when the common area was unoccupied, highest during evening crew congregation—a direct atmospheric signature of collective occupancy, corroborated by concurrent TVOC and illuminance variation. Temperature and humidity held near 20–32 °C and 40–59%. One sensor became intermittent from day two; redundant measurement and fail-soft logging contained the fault to a single non-critical variable.

The deployment shows that continuous, high-resolution environmental characterization—and instrument field-reliability assessment—is achievable in an analog habitat with a compact, low-cost, autonomous node, resolving crew activity rhythms directly from the habitat atmosphere.

KGK2026 Abstract 0155

Connectivity- and Resource-Aware Deep Reinforcement Learning for Cooperative Multi-Robot Planetary Exploration

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Autonomous robot colonies offer a promising means of exploring planetary surfaces, moons, asteroids, and other remote environments where fixed communication infrastructure is unavailable and energy, computation, and bandwidth are severely constrained. In such missions, explorer robots must enlarge the surveyed area while preserving continuous multi-hop communication with a central node, potentially through mobile relay robots. This work presents a simulation framework in which deep reinforcement learning (DRL) is used as the control strategy for cooperative robot deployment and motion. By explicitly defining system states, actions, and rewards, the framework facilitates the systematic transfer of control design choices from simulation to real-world deployments. The DRL controller selects robot activation and movement actions from information on exploration progress, inter-robot connectivity, and resource conditions. Its reward promotes newly explored regions while penalizing communication disruptions, excessive robot deployment, energy expenditure, and unnecessary decision steps. Building on communication-aware link-maintenance approaches, the proposed method integrates exploration coverage, persistent connectivity, and resource efficiency into a unified DRL-based control strategy for infrastructure-free environments.

KGK2026 Abstract 0156

Space-Tested Nitinol Artificial Muscle: Thermal Characterization of a Biomimetic Compliant Mechanism on MISSE-19 (ISS)

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An artificial muscle compliant mechanism made of Nitinol alloy was flown to the ISS on a SpaceX mission and tested in the vacuum of space to see the feasibility of the material for future space exoskeletons, inspired by the biomimetics of the human sarcomere. MCB-1 was cut from a single piece of Nitinol, driven by two hafnium actuators, and mounted on the exterior truss for four months. Muscle contracts with no gears, bearings or lubricant, the three things that fail hardest in vacuum and regolith. But a shape-memory element works only across a narrow transformation window, and orbit sweeps a comparable range every 93 minutes, so an actuator built for the wrong envelope is driven by its orbit, not its controller. MCB-1 sat on the ram face of MISSE, taking maximum atomic oxygen fluence. Four thermometers, two on the mount and two on the moving element, returned 153,937 one-minute records from 22 November 2024 to 31 March 2025, covering about 1,655 thermal cycles. It ran between -19.4 and +35.7 °C, inside the design envelope with 10.6 K cold and 9.3 K hot margin. The moving element swings 31.2 K in one orbit while the mount moves only 10.7 K, and an internal gradient averaging -5.4 K, spanning -19.7 to +12.4 K, separates them and reverses sign between eclipse and sunlight. A compact space mechanism cannot be specified against one body temperature. We flew the actuator topology, not a coupon: a first qualification step for gearless artificial muscles for planetary exoskeletons.

Space Resources as an Enabler of Space Transportation Technology Development

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With the growth of interest in ISRU (In Situ Resources Utilization), very important part of it is the use of space resources, including energy, to propel and for production of propellants for space vehicles, which determines what propulsion technology will be used in specified location of exploited space resources.

Important factor influencing it is the operational environment, where aforementioned vehicles will be operating. One is the Moon and cislunar space, another is the Mars and its orbit, asteroid belt and another is the interplanetary space connecting aforementioned destinations including Earth.

In opinion of author, space resources availability, its location and available space transportation technologies developed will shape the future shape of space transportation connecting near-term destinations in Solar System.

KGK2026 Abstract 0158

They're Here! – A Case Study of Non-Native Species in the Vicinity of the Henryk Arctowski Polish Antarctic Station

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Antarctica, one of the most remote and harsh regions of the Earth, is successfully separated from the rest of the Earth by the Antarctic Circumpolar Current, which, due to its strong oceanic and atmospheric circulation, prevents the air and water masses from lower latitudes to mix with those further South. Moreover, it poses an impenetrable barrier for most of the world's living organisms, with the exception of migratory seabirds and marine mammals, thus, protecting the delicate Antarctic ecosystem entailing many unique and often endemic biota, such as: lichens, mosses, liverworts and invertebrates. Nevertheless, an influx of non-native species is being observed in the region, driven by various factors, among which anthropogenic pressure and climate-change play a significant role. While only a limited number of these species have established populations on the Antarctic continent itself, with no confirmed reports of their spread to other locations within Antarctica beyond areas influenced by human activity, this pattern differs in other regions, particularly the sub-Antarctic islands and Maritime Antarctica. King George Island, home to 11 Antarctic stations, including the Henryk Arctowski Polish Antarctic Station, is no exception. Here, we present results of registered non-native species Poa annua and Trichocera maculipennis and efforts to eradicate them in the vicinity of the Polish Antarctic Station and ASPA 128 in the spatio-temporal gradient between the years 2019-2026.