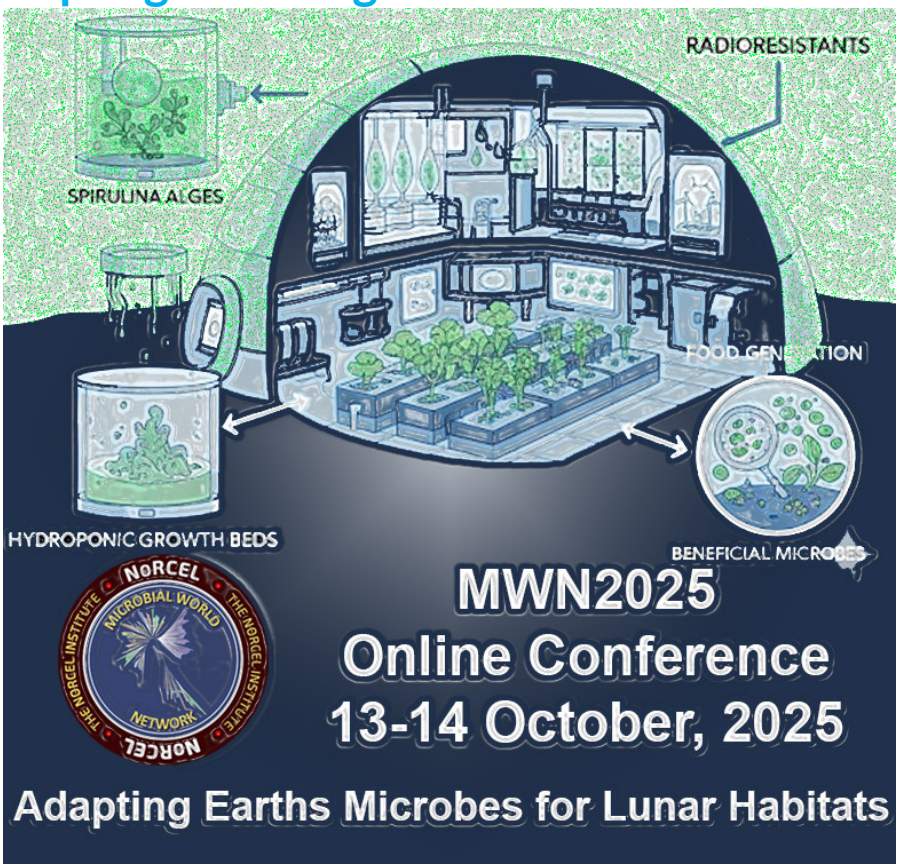
NoRCEL Institute's Microbial World Network: Adapting Microorganisms for Lunar Habitats



Exploring Life's Resilience Beyond Earth

Introduction

The Moon's environment—defined by drastic temperature extremes, high radiation, and the absence of a breathable atmosphere—represents one of the most formidable settings known to science. Yet, it is within these very challenges that the **NoRCEL Institute's Microbial World Network (MWN)** finds its purpose: to explore how Earth's microorganisms might adapt, persist, and even thrive under extraterrestrial conditions.

Bringing together scientists from across the globe, MWN provides a **collaborative framework for investigating microbial adaptability under simulated lunar environments**. Through computational modelling, laboratory experimentation, and open-access data exchange, members study the physiological and genetic mechanisms that enable extremophiles and other resilient microbes to withstand radiation, desiccation, and nutrient scarcity.

A principal aim of this initiative is to identify microbial candidates that could underpin **closed-loop, bioregenerative life-support systems**—self-sustaining biospheres capable of recycling waste, generating oxygen, and producing food to support long-term lunar habitation. In doing so, MWN contributes both to the advancement of **bio-sustainable technologies for space exploration** and to a deeper understanding of life's adaptability within the cosmos.

The **Microbial World Network** was conceived by **Professor Oleg Kotsyurbenko** of Yugra State University, Khanty-Mansiysk, Russia. His pioneering *top–down* approach complements conventional *bottom–up* prebiotic research, beginning not with chemistry but with the study of extant prokaryotic systems. This perspective illuminates how life might emerge and evolve under extreme conditions—offering new clues about the origins of life on Earth and its potential elsewhere in the Solar System and beyond.

Now in its **second international meeting**, MWN continues to evolve as a vibrant and inclusive community of researchers, educators, and innovators dedicated to expanding the boundaries of astrobiology. Membership provides opportunities for **global collaboration, intellectual**

exchange, and active participation in shaping the future of space biosciences.

We warmly invite scientists, students, and institutions to **join the NoRCEL Institute** and engage with this exciting endeavour. As a fully **independent, non-profit organisation**, NoRCEL thrives on openness, academic freedom, and the collective pursuit of discovery.

The Microbial World Network is more than a scientific initiative—it is a bridge between life on Earth and the life that may await us among the stars.

Sohan Jheeta HND, BSc, MSc, PhD
Founder and Chairman of NoRCEL
Fellow of the Royal Society of Biology
Fellow of the Royal Microscopical Society

A Date for Future Diaries

Everybody's Talking About it

DAY 1

Monday 13th October 2025

Evaluation of the conditions for possible origin of (proto)life on early Mars and Moon

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This presentation examines the implications of the thermodynamic inversion concept (TI concept) for the possibility of life (including protolife) on early Mars and the Moon [1]. According to the TI concept developed for Earth, three required conditions for the emergence of life (the presence of water, organic matter, and an energy source) should be supplemented by one more: intense fluctuations in physicochemical parameters (temperature, pressure, component concentrations, and others) in the environment. Taken together, these conditions exist on Earth only in hydrothermal systems. Basing on the latest data, all four conditions existed on early Mars. Recent confirmation by the group of Chinese scientists of the presence of volcanic activity on the Moon as far back as 2 billion years ago [2] allows the author to make the following hypothesis. At least three of the above required conditions (excluding organic matter, which has not yet been detected) were present during the early stages of the Moon's evolution. This allows for the possibility of the emergence of proto-life on the early Moon, without availability of the advanced genetic apparatus similar to those developed on Earth through a long evolutionary process.

References

1. Kompanichenko Vladimir N. 2025. Geothermal energy as an initial factor in the process of life origin. AIMS Geosciences, 11(2): 528–539.
2. Qiu-Li Li, Qin Zhou, Yu Liu, Zhiyong Xiao, Yangting Lin, Jin-Hua Li, Hong-Xia Ma, Guo-Qiang Tang, Shun Guo, Xu Tang, Jiang-Yan Yuan, Jiao Li, Fu-Yuan Wu, Ziyuan Ouyang, Chunlai Li & Xian-Hua Li. 2021. Two-billion-year-old volcanism on the Moon from Chang'e-5 basalts. Nature | Vol 600 | 2 December.

On the microbiological safety of manned interplanetary missions

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Microbiological safety is a major concern for manned interplanetary missions due to the presence of opportunistic pathogens, the astronauts' compromised immune systems, and the space environment's ability to enhance bacterial virulence and antibiotic resistance. Strategies to ensure safety include robust pre-flight quarantine and monitoring, on-board environmental controls like HEPA filters, air and water purification, and implementing rigorous hygiene and cleaning protocols to mitigate contamination and infection risks during long-duration deep space missions.

Key role of arbuscular mycorrhizal fungi (AMF) in promoting space agriculture under simulated microgravity conditions

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Our research aims to evaluate the effect of simulated microgravity on the symbiosis between arbuscular mycorrhizal fungi (AMF; *Glomus intraradices* and *G. mosseae*) and beans (*Phaseolus vulgaris*). This experiment was previously carried out twice in 2024 [1]. Our contribution lasts for 10 days.

The project we have carried out is mainly supported by the clinostat, a way of reproducing the conditions of the ISS. Plant roots are subjected to H2O2 and a treatment that had not been applied in previous experiments, NaCl [2].

The results obtained have shown that the application of NaCl accelerates the symbiotic colonisation process between AMF and the plant root system in 10 days of exposure to simulated microgravity conditions, compared to the average 90 days required under terrestrial conditions [3].

We conclude that, due to root growth during the experiment, we suggest that the data obtained by the clinostat propose that microgravity favours the mutualistic symbiotic interaction between AMF and *Phaseolus vulgaris* thanks to the response generated by NaCl. Therefore, they establish a research proposal on the ISS or our satellite, the Moon, to carry out studies in Space Agriculture with the intention of investing in the plant breeding of species adapted to the current climate crisis scenario on Earth.

REFERENCES

[1] Gálvez-Bailey, M.N., Velez-Giraldo, S.N., Monzón-Cosillo, A.G., Bianchi-Veliz, F., López De León, J.D.D., Ubico-Ligorria, P.E. & Lupo, P. (2024). Symbiosis between arbuscular mycorrhizal fungi and Phaseolus vulgaris under simulated microgravity conditions: preliminary evaluation. *Ciencias Espaciales* **15**(2), 67-81.
[2] Porcel, R., Aroca, R., Ruiz-Lozano, J.M. (2012). Salinity stress alleviation using arbuscular mycorrhizal fungi. A review. *Agronomy for Sustainable Development* **32**, 181-200.
[3] Nhut, D.T., Khai, H.D., Tuan, N.X., Bien, L.T., Tung, H.T. (2022). In vitro growth and development of plants under stimulated microgravity Condition. In: Nhut, D.T., Tung, H.T., YEUNG, E.CT. (eds) *Plant tissue culture: new techniques and application in horticultural species of tropical region* (343-381). Springer, Singapore.

The New Master Program of Astrobiology at the Sofia University St. Kliment Ohridski - Aiming for the Stars, but Exploring the Moon

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The New Master Program of Astrobiology has been established in 2024 as a joint Project between the faculties of Biology, Physics, Chemistry, Geology and Philosophy of the Sofia University St. Kliment Ohridski, together with the Institute of Molecular Biology "Acad. Roumen Tsanev" of the Bulgarian Academy of Science. It is a 2-year master program dedicated to cover all the main fields of research in this large and diverse area – from the origin of life to the interactions of living systems with extraterrestrial factors of the environment. The innate diversity of the discipline, along with the different background experiences of the students implies project-based learning. One of the starting research directions is in alignment with the rising demand for the simulants of Lunar and Martian regolith. Despite the availability of commercial products, and the efforts of both NASA and ESA, still the lack of materials and (what is most important) the lack of strict constraints in the production is evident.

In this short talk, we will present the program structure, scope and possibilities for cooperation, including, but not limited to, future research projects related to lunar exploration.

Indian Lunar Exploration Program

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Indian space exploration program began in November 1963 with the launch of a rocket from Thumba in Kerala. More than four decades later, the lunar exploration program began in 2008 with the launch of Chandrayaan-1 orbiter mission to the Moon. This is followed by Chandrayaan-2 mission in 2019, and the highly-celebrated Chandrayaan-3 Lander-Rover mission in 2023. This talk will discuss the lunar exploration program of the country, highlight the science, and provide a glimpse of the future lunar exploration program

The case for the astrobiology on the Moon

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For the past few years, astrobiologists have been learning that almost no environment is too extreme for life. We have discovered numerous species living of microbes thriving in spacecraft assembling facilities, on orbiters, on rovers (launched to Mars), aboard the ISS and even on electric circuit board, ready for flight! Many seem to be entirely new species which seem to have adapted or even evolved in the harsh decontaminating systems especially designed to eliminate them. Well, life on Earth is everywhere we look, surviving and thriving in every possible niche, with or without sunlight, water, oxygen. But what is the extent of Earth biosphere? Although the Moon has, most certainly, never supported any life of its own, Earth atmosphere extends far beyond the Moon, making it an interesting opportunity for astrobiological studies, especially relating to studies of microorganism survivability on crashed and soft-landed spacecraft. In this talk I will try to convince everyone that there is a case for lunar astrobiology, in spite of currently harsh and seemingly inhospitable lunar environment.

RNAs evolved on Earth exhibit novel function in hypersaline brines, providing potential bridge biochemistries for Moon to Mars architectures

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In modern biochemistry, nucleic acids are mainly information carriers, but they exhibit a range of additional functions as well. These functions, such as splicing (introns), peptide bond formation (ribosomes), and gene regulation (riboswitches), are widely speculated to be remnants of primordial metabolisms that relied more heavily on RNA before the advent of coded protein synthesis. We are interested in additional latent functions of RNA. Motivated by the saline environments thought to be present on Mars, we recently investigated the functional capacity of RNA in the presence of a unique class of oxidized species: oxychlorine anions. These ions are abundant on Mars, exist in a few dry environments on Earth, and could exist on other dry and oxidizing worlds. These compounds are toxic to most known life and denaturing to many biopolymers, but oxychlorine brines could be an important source of liquid water in some environments.

We have found oxychlorine anions allow function of ribozymes and, additionally, enable new functions for ribozymes. In one such example, we have observed that chlorite, one oxychlorine anion, can enable an important oxidation reaction for synthetic chemistry - it can allow a ribozyme to chlorinate organic substrates, such as the dye phenol red. We have also observed that the mild denaturation of RNA by perchlorate allows for a primitive regulatory behavior that could function in prebiotic systems. This demonstrates a new class of redox and synthetic reactions for ribozymes. RNAs we have examined generally retain function in perchlorate brines, but fewer tested proteins do so.

We suggest the unique biopolymer folding environment provided by oxychlorine brines in oxidized worlds is just one example of additional chemistries RNA could catalyze in extreme environments. Mars could be just one such niche. Given appropriate selection pressure, we speculate that RNA could enable new chemistry and functional behaviors in other extreme environments, such as Earth's moon. These functional behaviors could be useful in synthetic and semisynthetic microbes designed to thrive in lunar and/or Martian environments. Bridging these two worlds could be particularly timely, given NASA's planned Artemis mission and Moon to Mars architectures, and China's Lanyue and Chang'e missions.

References

1. Hoog, TG; Pawlak, MR; Gaut, N; Baxter, G; Bethel, T; Adamala, KP; Engelhart, AE. (2024). Nature Communications (2025). doi: 10.1038/s41467-024-48037-2. Some text in this abstract is adapted from this reference and used under the terms of the Creative Commons license associated with this article.
2. Hoog, TG; Pawlak, MR; Bachan, BF; Engelhart, AE. (2022). Biochemistry and Biophysics Reports. 30:101238.
3. Hoog, TG; Pawlak, MR; Aufdembrink, LM; Bachan, BF; Galles, MB; Bense, NB; Adamala, KP; Engelhart, AE. (2022) ChemBioChem. 23(9):e202200090

DAY 2
Tuesday 14th October 2025

Extreme stress tolerance of tardigrades in a view of spaceflight studies, astrobiology and radiation protection

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Tardigrades are extremely resistant to various physicochemical stresses and up to date they are considered to be the most radioresistant animals. Tardigrades have already become model organisms for astrobiology and, along with space-simulation studies, have been exposed to spaceflight and/or outer space conditions on FOTON M3, Space Shuttle Endeavour (STS-134), lunar lander Beresheet (incomplete), ISS (SpaceX-22) and Axiom Space (SpaceX AX-4). During 2010s, the breakthrough in the research of tardigrades have occurred, that lead to discoveries of several molecular principles of their extreme resistance including unique tardigrade disordered proteins (TDPs) perspective for the development of novel genetic-based protective technologies.
Our group (Molecular Genetics Group, DLNP JINR) within TARDISS project [1, 2, 3] investigates the tardigrade Dsup (Damage suppressor) protein, being an effective DNA-protective molecule. For the first time tardigrade Dsup protein have been demonstrated to improve resistance to oxidative stress and ionizing radiation of other *Dsup*-expressing animals (*D. melanogaster*) and effects of Dsup protein have been studied by transcriptome analysis [1]. The structural biology study enabled to characterize for the first time molecular features of Dsup, confirmed to be an intrinsically disordered protein, and to demonstrate Dsup-DNA is a fuzzy complex in which Dsup exists in multiple non-rigid conformations [3]. Further *in vivo* and *in vitro* studies of the protective mechanism and features of Dsup-DNA complex are performed, as well some applications of Dsup are being developed. Notably, along with experiments at lunar Artemis I mission, one of the first space experiments with model organisms expressing tardigrade genes have been performed by our group during polar LEO orbit flight of BION M-2 (September 2025).

References

1. Zarubin M, Azorskaya T, Kuldoshina O, Alekseev S, Mitrofanov S, Kravchenko E. 2023. The tardigrade Dsup protein enhances radioresistance in Drosophila melanogaster and acts as an unspecific repressor of transcription. *iScience*. 26(7):106998. doi:10.1016/j.isci.2023.106998
2. Zarubin M, Andreev E, Kravchenko E, Pinaeva U, Nechaev A, Apel P. 2024. Developing tardigrade-inspired material: Track membranes functionalized with Dsup protein for cell-free DNA isolation. Biotechnology *Progress*. 40(5):e3478. https://doi.org/10.1002/btpr.3478
3. Zarubin M, Murugova T, Ryzhykau Y, Ivankov O, Uversky VN, Kravchenko E. 2024. Structural study of the intrinsically disordered tardigrade damage suppressor protein (Dsup) and its complex with DNA. *Sci Rep*.14(1):22910.doi:10.1038/s41598-024-74335-2

Mars Survival Framework

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It is worthy of mention that of all the known planets in the solar system Mars happen to share certain features or characteristics relative to earth. For example, the existence of some life forms, species, organic matter and molecules etc. The intent of this study suggests to us the possibility of human survival in the Martian environment using scientific and architectural framework.

I wish I was special, but I'm a creep: Yaravirus brasiliense genomic structure analysis and its possible influence on the metabolism

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Viruses are a type of mobile genetic element that often encode structural proteins encapsidating their own genomes. They are often considered simple pathogens, but they exhibit extraordinary genetic and metabolic versatility. Their ability to manipulate host metabolism, overcome energetic constraints, and encode novel proteins reflects survival strategies that are highly relevant to extreme environments such as reduced gravity, high radiation, and nutrient limitation. Mechanisms related to the increase of total coding potential of viral genomes have been proposed, like gene overlapping, which has a great evolutionary price, since two functional proteins overlapping can lead to constrained evolution. These mechanisms reflect the plasticity of viruses' genetic information, and ensure the synthesis of all necessary viral proteins. Yaravirus brasiliense, an amoeba-infecting virus with a 45-kbp dsDNA genome dominated by ORFans, represents an intriguing model of such resilience. Its unique genetic repertoire suggests unconventional solutions to resource utilization, genome plasticity, and metabolic rewiring—features that may inform how microbial systems endure and thrive in extraterrestrial or otherwise hostile contexts.

Considering its unprecedented genetic content, we analyzed yaravirus genome through threading to understand its genetic organization, its proteome, and how it interacts with its host. Genomic information is published in the NCBI genome database. The gene sequences were inserted in I-TASSER. For a deeper understanding of possible ligands, we used COACH. For protein visualization, we used Swiss-Pdb-Viewer. When analyzing structural similarities, we observed that 58 of the encoded proteins had the same function as at least one other protein, so we conducted structural alignments between the yaravirus proteins and similar proteins from the protein data bank. The results showed that the different proteins that presented similarities with the same function were structurally aligned in different parts at the same proteins deposited in the PDB, suggesting that these small proteins could be dimerizing to reestablish the predicted function.

We were able to assemble 26 proteins composed of at least two yaravirus proteins for the same function. Given the structural resemblance between some yaravirus proteins (both singular and assembled) and proteins related to tricarboxylic acid cycle, glyoxylate cycle, and the respiratory complexes, it is possible that these ORFans take on these functions. In laboratory conditions, Yaravirus attracts mitochondria to the viral factory, perhaps by manipulation of the mentioned biochemical pathways. The tricarboxylic acid cycle is a series of energy releasing enzymatic reactions, linked to the electron transport chain at complex II. Yaravirus genome has proteins related to all respiratory complexes, which could be upregulating the complexes towards energy production. Yaravirus has proteins linked to malate-dehydrogenase, citrate-synthase, PEP-carboxylase, isocitrate-lyase, malate-synthase, and fumarase. The TCA cycle's control points are the three exergonic stages (catalyzed by citrate-synthase, isocitrate-dehydrogenase and alpha-ketoglutarate-dehydrogenase). As the virus stimulates the cycle

for its replication, the control points would eventually reach a limit and be activated. At this point, yaravirus malate-dehydrogenase and citrate-synthase could keep the malate to oxaloacetate to citrate reaction going, and, simultaneously, PEP-carboxylase would also maintain oxaloacetate levels. Isocitrate-lyase (converts isocitrate to glyoxylate and succinate), succinate-dehydrogenase (converts succinate to fumarate), malate-synthase (converts glyoxylate to malate), and, concurrently, fumarase (converts fumarate to malate) would maintain malate available.

Our findings suggest that Yaravirus proteins may bypass conventional metabolic control points, redirecting host energy fluxes to sustain viral replication even under resource-limited conditions. This metabolic "unlocking" illustrates a potential survival mechanism that resonates with strategies required for persistence in extreme settings, from terrestrial niches to space-like environments. By exploring Yaravirus's unprecedented genomic and proteomic adaptations, we highlight how unconventional viral systems can serve as models for resilience, with implications for astrobiology and for understanding life's potential to function under gravity reduction, radiation stress, and nutrient scarcity.

Keywords: proteomics; genetic structure; viral evolution

Synthetic Microbial Ecosystems for Lunar Radiation Resistance: Life to Withstand Cosmic Rays

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The absence of an atmosphere and magnetic field makes cosmic rays a major challenge for sustaining terrestrial life beyond Earth. Traditional radiation shielding on the Moon is heavy, non-regenerative, and unsuitable for long-term missions. This work proposes synthetic microbial ecosystems capable of surviving lunar conditions and mitigating cosmic radiation. Engineered microbial consortia will be developed using radiation-resistant strains and tested under simulated lunar conditions. Biofilm formation, radiation resistance, and regenerative shielding properties will be analysed to create sustainable biological shields.

Key finding: Engineered microbial ecosystems demonstrated enhanced resistance to simulated cosmic radiation, effectively reducing radiation penetration. Biofilms maintained structural integrity under lunar-like conditions, indicating potential for sustainable, self-regenerating biological shields in future lunar habitats.

Harnessing Extremophiles: Microbial Foundations for Sustainable Lunar Habitats

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Adapting microbial life for lunar habitats is central to enabling long-term human presence beyond Earth. The lunar environment poses formidable stresses, including wide temperature fluctuations, intense radiation, desiccation under vacuum, and limited access to water and nutrients. To address these challenges, microbes adapted to extreme terrestrial conditions provide valuable models for designing resilient, engineered systems. This presentation focuses on strategies for adapting microbial traits to lunar applications, particularly within bioregenerative life-support frameworks. Key roles include oxygen generation through photosynthetic processes, nutrient cycling and soil enrichment for plant cultivation, and microbial recycling of organic waste into usable resources. Evidence from analogue environments, simulated habitats, and recent space-based studies including microbial bioreactors, resource biomining trials, and integrated closed-loop systems demonstrates the feasibility of these approaches. By adapting Earth's microbial toolkit, we can build sustainable bio-support systems for lunar bases, advancing.