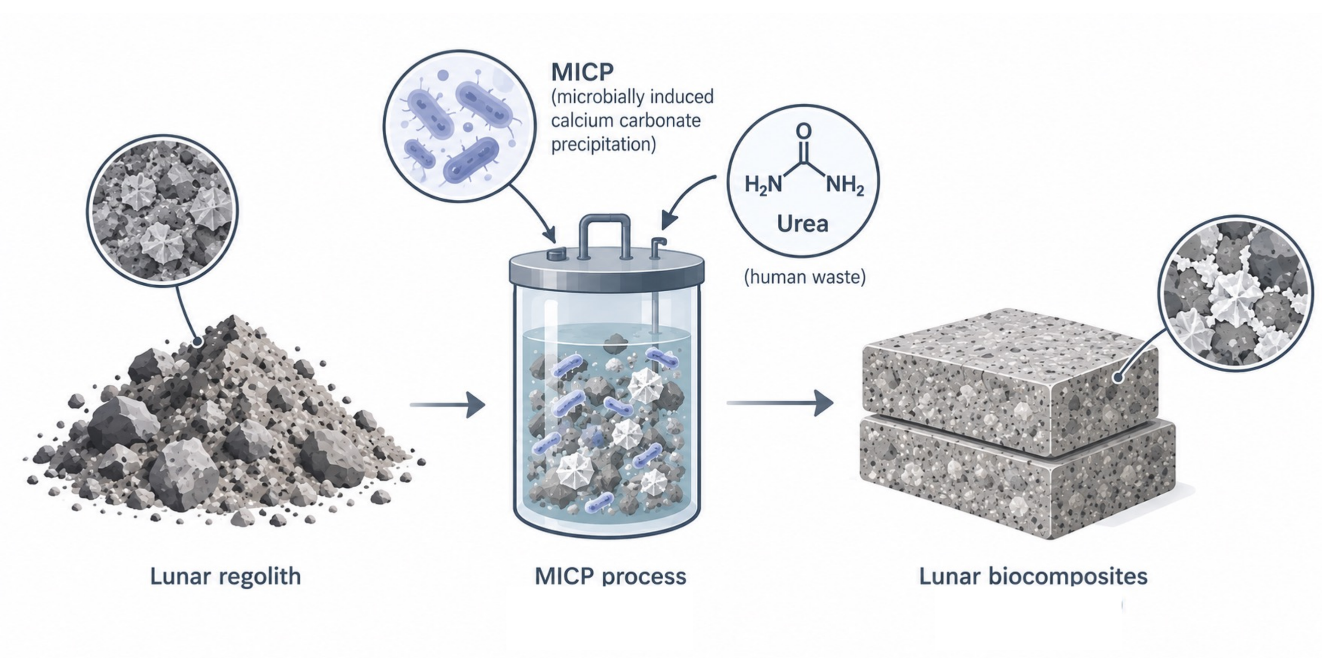
Regolith-Based Biocomposites for Space ISRU: From Raman Spectroscopy to Microbial Consolidation

Claudia Fagliarone[1,2], Rocco Carcione[2], Ilaria Di Sarcina[2], Beatrice D'Orsi[2], Teresa Rinaldi[3], Alessia Cemmi[2].

[1]ENEA, Department of Sustainability (SSPT), C.R. Casaccia, Via Anguillarese 301, 00123, Roma, Italy
[2]ENEA, Nuclear Dept., C.R. Casaccia, Via Anguillarese 301, 00123, Roma, Italy
[3]Sapienza University of Roma, Dept. of Biology and Biotechnologies, Piazzale Aldo Moro 5, 00185, Roma, Italy

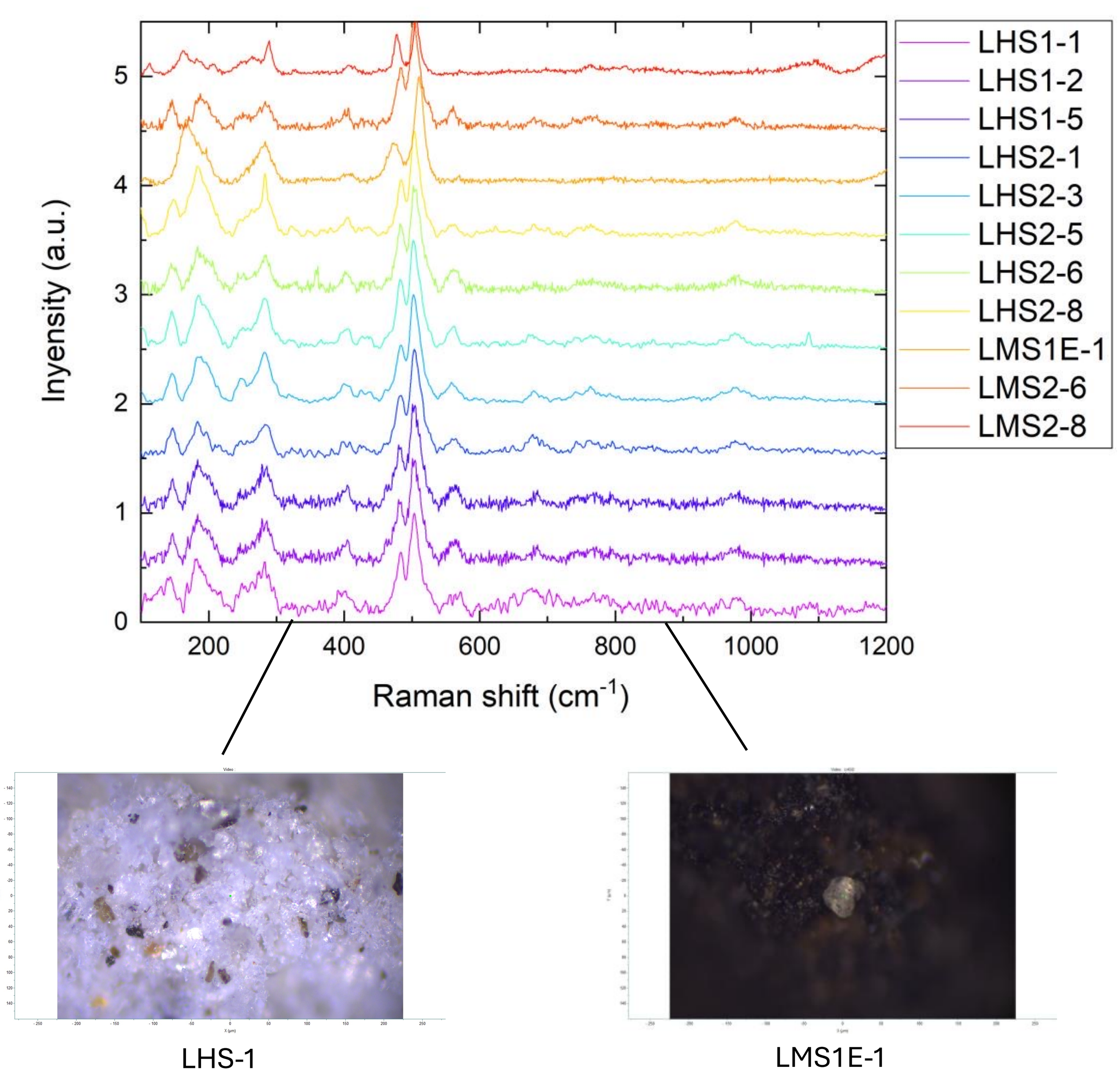
INTRODUCTION & AIM

In-Situ Resource Utilization (ISRU) and Bioregenerative Life Support Systems (BLSS) are key to establishing a sustainable human presence on the Moon. Loose lunar regolith can be consolidated into structural biocomposites via Microbially Induced Calcium Carbonate Precipitation (MICP)[1], while integrating human metabolic waste like urea offers a circular pathway for resource recovery[2].



This study aims to establish a mineralogical baseline for lunar highland (LHS-1/2) and mare (LMS-1E/2) simulants using non-destructive Raman spectroscopy. Furthermore, it evaluates the matrix compatibility and viability of the carbonatogenic bacterium *Lysinibacillus fusiformis* in combination with artificial urine formulations as a sustainable approach for bio-consolidation.

RAMAN SPECTROSCOPY

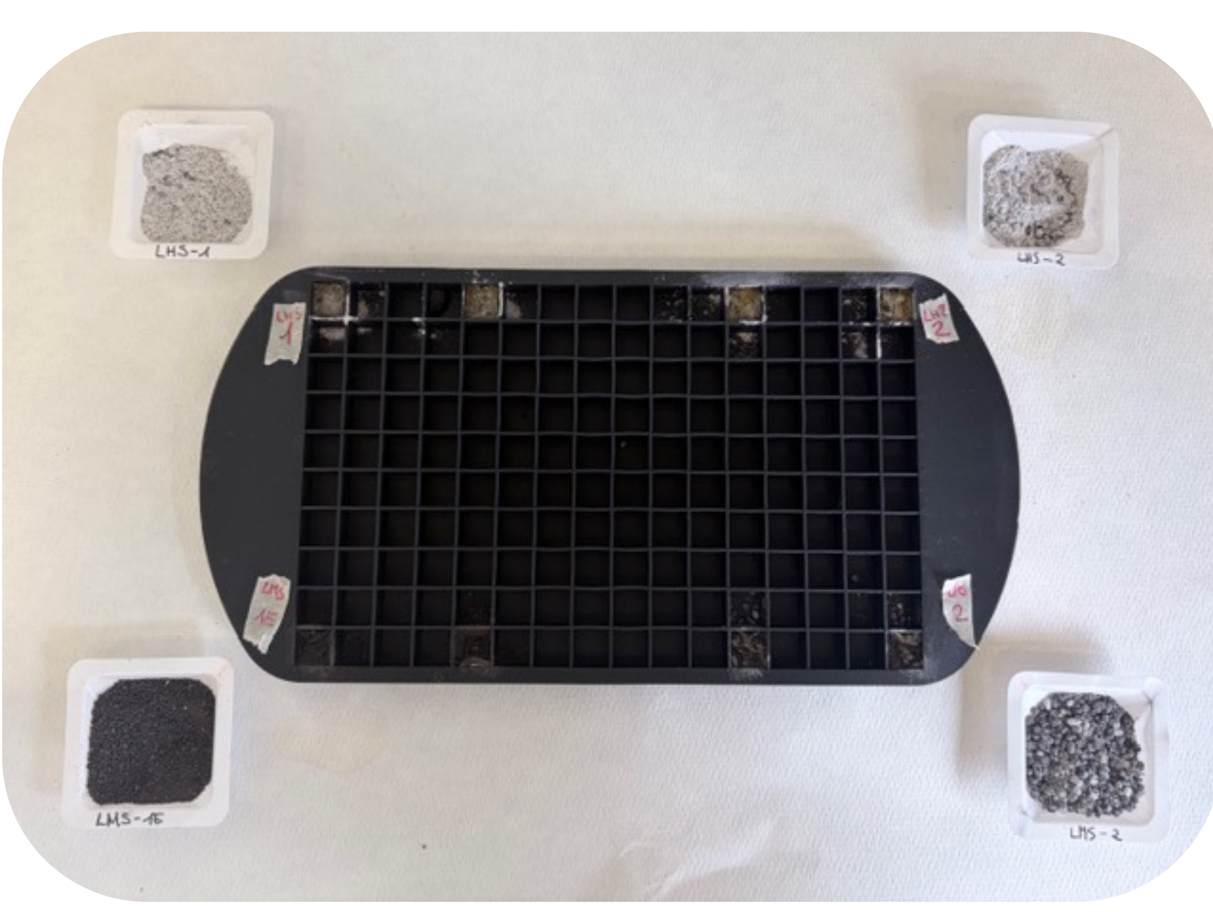


Laser power and integration times were systematically calibrated at 785 nm to prevent sample thermal degradation. The acquired spectra successfully resolved the primary mineral phases, distinguishing plagioclase-rich highlands from pyroxene/olivine-rich mare simulants, establishing the required baseline.

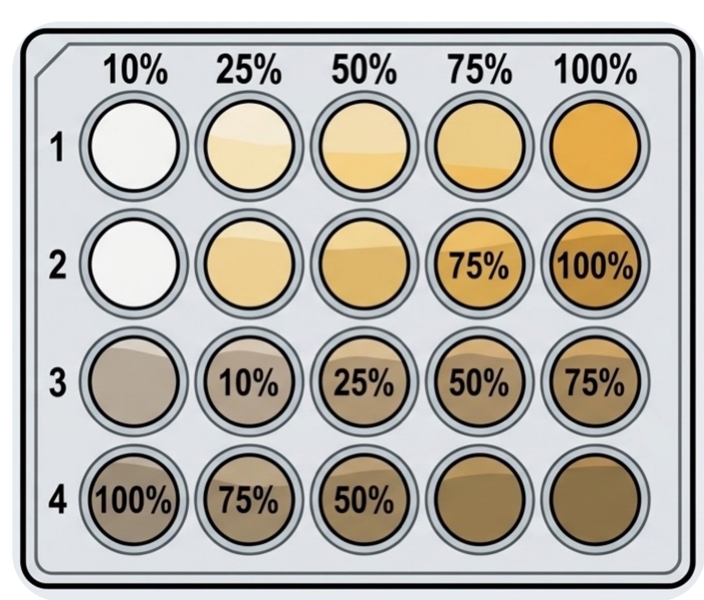
BIOLOGICAL INTEGRATION & CONSOLIDATION

Bacterial Viability & Matrix Compatibility

Pilot experiments evaluated the interaction between *Lysinibacillus fusiformis* and lunar simulants (LHS-1/2, LMS-1E/2) across different grain sizes. Microorganisms demonstrated high viability when embedded in the mineral matrices, confirming their suitability for Microbially Induced Calcium Carbonate Precipitation (MICP).



L. fusiformis viability tests on lunar simulants



MP-AU screening on regolith matrices

Synthetic Urine Screening & Circular ISRU

To integrate human waste streams into Bioregenerative Life Support Systems (BLSS), chemical-matrix screening was conducted using Multi-Purpose Artificial Urine (MP-AU, 10-100% v/v; 25 g/L urea). Tests confirmed optimal absorption and homogeneity across all simulants, establishing non-toxic urea thresholds to drive subsequent $CaCO_3$ precipitation.

CONCLUSIONS AND FUTURE DIRECTIONS

This work successfully validated the preliminary biological and chemical baselines required for space-bound bio-consolidation. Integrating non-destructive mineralogical screening with circular waste management proves the feasibility of regolith-based biocomposites for sustainable ISRU and BLSS applications. Ongoing efforts will focus on triggering active $CaCO_3$ mineralization within the optimized matrices, followed by radiation resilience characterization at the ENEA Calliope facility to assess biocomposite performance under harsh space environments.

References:
[1] Dikshit R, Gupta N, Dey A, Viswanathan K, Kumar A. Microbial induced calcite precipitation can consolidate martian and lunar regolith simulants. PLoS One. 2022 Apr 14;17(4):e0266415. doi: 10.1371/journal.pone.0266415. PMID: 35421143; PMCID: PMC9009621.
[2] Verbeelen T, Leys N, Ganigué R and Mastroleo F (2021) Development of Nitrogen Recycling Strategies for Bioregenerative Life Support Systems in Space. Front. Microbiol. 12:700810. doi: 10.3389/fmicb.2021.700810.