

# Space It Up!

SPOKE 8: Robotic and Human  
Exploration of Extraterrestrial  
Habitats, Architectures and  
Infrastructures

*Firenze, SIU! Days, 26-28 gennaio, 2026*



AGENZIA SPAZIALE ITALIANA



Ministero  
dell'Università  
e della Ricerca



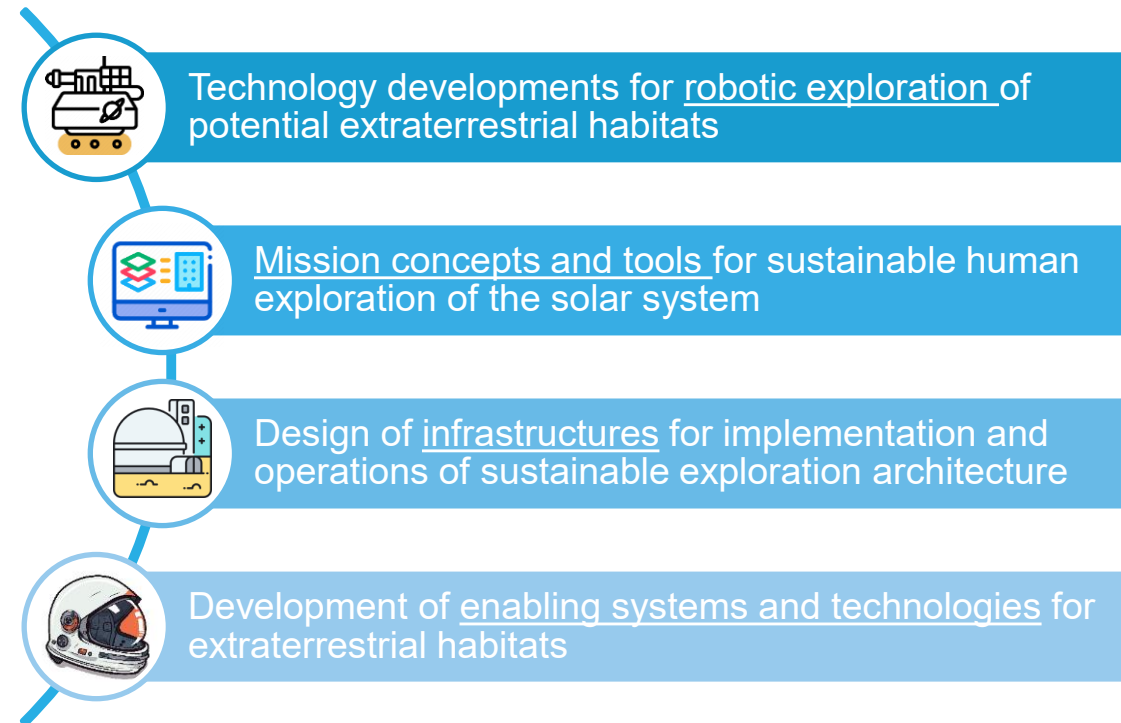
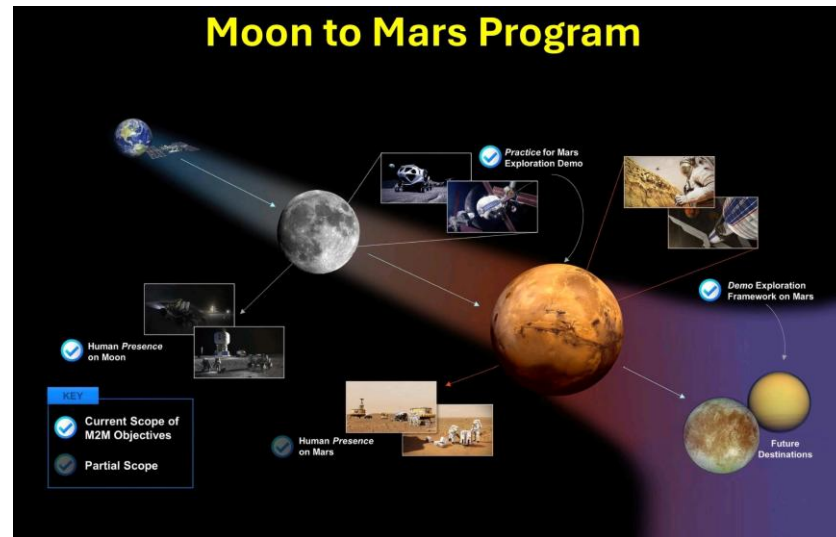
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# Spoke 8

## Robotic and Human Exploration of Extraterrestrial Habitats, Architectures and Infrastructures

Mission statement Fostering research and development activities to **support future human missions** with a strong interdisciplinary connotation. Main activities will involve **enhancement of current capabilities on space robotics, sensors, instrumentations, extra-terrestrial habitats, infrastructures and architectures.**

F. Esposito (INAF), Moon to Mars:  
From Robotic to Human Exploration.  
→ **Session M3**





# Partners and Resources

180+ researchers involved

Spoke Leader  
Co-Leader

|                 |   |                    |  |
|-----------------|---|--------------------|--|
| <b>POLITO</b>   | Management, algorithms for AMRs, models for space habitats and robots, NAVCOM, pressurized modules, Lunar CNS                     | <b>21 Partners</b> |  |
| <b>UNIBO</b>    | Risk and data management, lab-on-chip devices, NAVCOM, CF components, wearable diosimeters  |                    |  |
| <b>INAF</b>     | Quality management, miniaturized sensors/instruments, micro-rovers for Moon/Mars, sterilization system                            | <b>CNR</b>         | Reusable fibre reinforced ultrarefractory ceramics, testing materials in Mars-like conditions, functionalized porous materials     |
| <b>UNINA</b>    | Robotic systems & tech, meta-materials, 3D printing, pressurized modules, superhydrophobic materials , coatings                   | <b>GSSI+</b>       | Optical fiber sensing, advanced human-robot interfaces, mission autonomous mobile robots   |
| <b>UNIROMA1</b> | Surface/subsurface mapping, monitoring crew conditions, GNSS-for Moon/Mars, sterilization system                                  | <b>LINKS</b>       | Analyzing positioning/navigation requirements, contributing to AI-based rover navigation algorithms for space exploration.         |
| <b>UNIROMA2</b> | Designing biomarker sensors, developing regenerative technologies, and contributing to shielding materials for human exploration. | <b>ENEA</b>        | Designing high-tech greenhouses, researching nuclear small modular reactors, and testing radiation shielding materials             |
| <b>UNIPD</b>    | Miniaturized sensors for environment, radiati effects on microelectronics, and developing "smart" technologies for habitats       | <b>ALTEC</b>       | Contributing to habitat operational design, leveraging expertise in space exploration communication and navigation                 |
| <b>POLIBA</b>   | Numerical modeling for space structures, testing protection systems, and prototyping deployable structures for space exploration  | <b>TAS-I</b>       | Designing subsystems for a Lunar Pressurized Rover, integrating rover prototypes, and analyzing results for terrain adaptability   |
| <b>UNIFI</b>    | Modeling spaceports with extraterrestrial resources, human space protection and qualifying monitoring instruments for habitats    | <b>Telespazio</b>  | Leading space exploration communication and navigation initiatives for sustainable Human & Robotic missions.                       |
| <b>UNICAL</b>   | Mission concepts, spacecraft constellation configurations, synthetic data, concurrent Engineering, uncertain environments         | <b>CIRA</b>        | Design of an innovative lightweight, high-performance bulk material (not a coating), S/W simulation, and air sterilization systems |
|                 |   | <b>Leonardo</b>    | Propulsion systems, powertrain, lightweight materials, and advanced navigation technologies  |
|                 |   | <b>ARGOTEC</b>     | Supporting communication and navigation with miniaturized technologies for Moon and Mars robotic exploration                       |
|                 |   | <b>IIT</b>         | Validating robotic technologies for mining applications in the context of space exploration  |

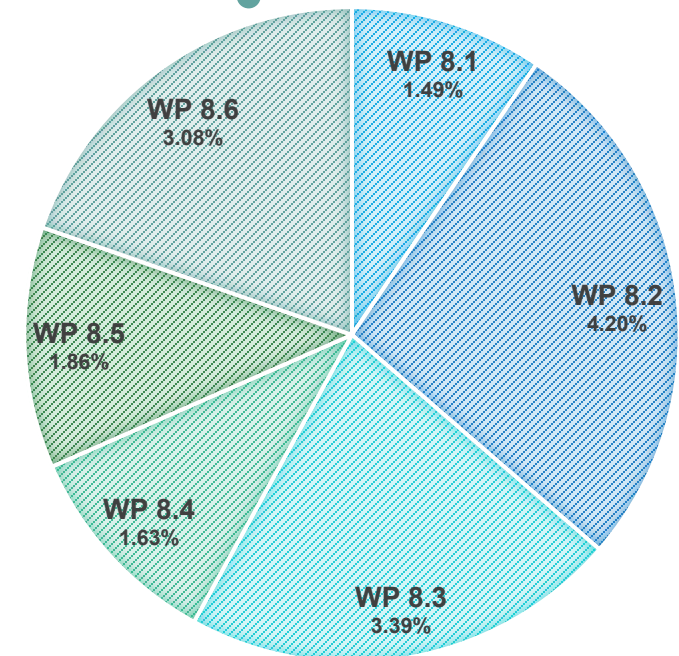
Spoke management, dissemination and exploitation

Experimental research for advanced space exploration

Resources of Spoke 8 / SIU!

~ 16%

\* Excluding co-funding



# Figures @M18

- ❑ **31 deliberables submitted**, of which 26 already approved by ASI.
- ❑ 3 spoke technical reports.
- ❑ **28 peer-reviewed article journals published**, plus 34 congress proceedings.
- ❑ Kick-off event @ POLITO (130+ participants).
- ❑ Joint plenary event with Spoke 9 @ UNIFI.
- ❑ Transfer of knowledge: new collaborations between Universities and Industry.

# Synergies: a holistic approach

## Spoke 1

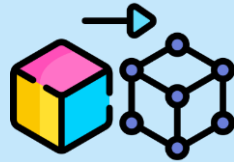
Enabling Technologies for Novel Near-Earth And Exploration Missions



- ❑ Advanced materials for harsh environment
- ❑ Air-breathing propulsion
- ❑ orbit optimal control systems
- ❑ In-orbit assets servicing and protection
- ❑ Autonomous operations of miniaturized platforms
- ❑ Resources extraction

## Spoke 2

Advanced Design and Analysis of Space Missions and Systems and Innovative Digitalization-System Engineering and Digital Twin



- ❑ High-fidelity integrated simulators
- ❑ Digital Twin and hardware-In-the-Loop systems
- ❑ Model-based design for Additive Manufacturing
- ❑ Digital twins and AI tools

## Spoke 3

Future Imaging Systems for Microwave and Optical Remote Sensing



- ❑ Hardware solutions for antennas
- ❑ Distributed SAR
- ❑ DSAR image forming
- ❑ Spectrometer on-chip
- ❑ Technologies for free-form optics-based
- ❑ 3D-printed test-vehicles of RF components

## Spoke 4

Next generation detectors of ionizing radiation and fields for remote sensing



- ❑ Arrays of large area, low-power, high-granularity radiation sensors
- ❑ BEE and DAQ deployment
- ❑ Readout and DAQ electronics
- ❑ GRS prototype for geodesy missions

## Spoke 6

Protection of critical infrastructures and Space Weather



## Spoke 5

Planetary protection and geohazards mitigation

## Spoke 7

Space for the sustainable development of the planet



**Spoke 8: Robotic and Human Exploration of Extraterrestrial Habitats, Architectures and Infrastructures**

**Spoke 9: Habitat Space and Science**

**FUNDAMENTAL KNOWLEDGE**

Lessons learnt

- Technology-Driven Science
- Science-Informed Technology
- Interdisciplinary Collaboration

# Technology developments for **robotic exploration** of potential extraterrestrial habitats

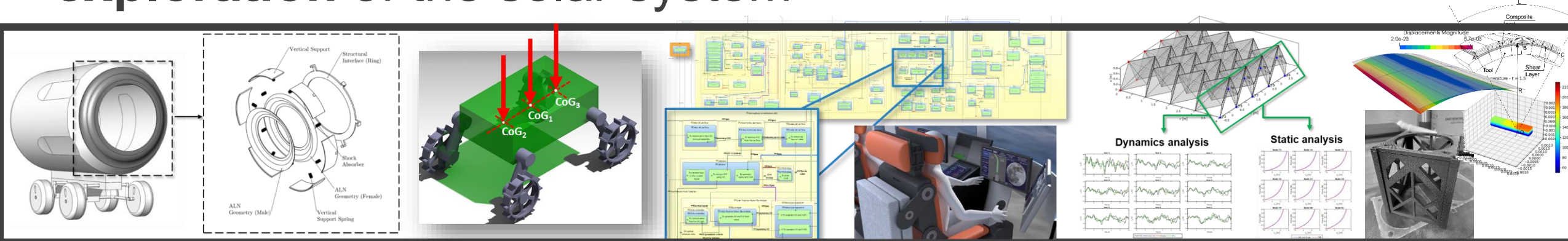


## WP 8.2 - Latest results

- ❑ **Lunar Ants swarm of micro-rovers (INAF, UNINA, UNIPD, POLIMI, UNIBO, CIRA, IIT)** - Autonomous navigation, AI and simulation; Scientific payloads; Onboard data handling and edge intelligence; Mobility and interfaces; Mission and system analysis; TRL advancement. → **Session M3**
- ❑ **Technologies for on-orbit and surface observations (INAF, UNIBO, GSSI+)** - Advanced sensing technologies; Fiber-optic sensing; Astrobiological and astrochemical sensing; Spectroscopic analysis for remote detection; Smart Shape-Memory Composite Materials for Deployable Space Structures. → **Sessions M3 & P2**
- ❑ **Robotic manipulation (POLITO, IIT)** - Design of modular robotic arms and cooperative transport systems, including inflatable solutions; Lightweight robotic manipulators; Miniaturized robotic arm using lightweight materials. → **Session M3**
- ❑ **Control systems, SW for autonomous and swarm robots, autonomous navigation, localization (UNINA, POLITO, UNIBO, UNICAL, ARGOTEC)** - Swarm learning and nav strategies, cooperative transport systems and robotic arm control architectures, optimal/distributed control algorithms and toolboxes, novel decentralized coordination protocols. → **Session M3**
- ❑ **Pressurized Rover (POLITO, POLIBA, CIRA, UNIBO, TASI, LEONARDO, Telespazio, IIT, ALTEC)** → **WP 8.3**



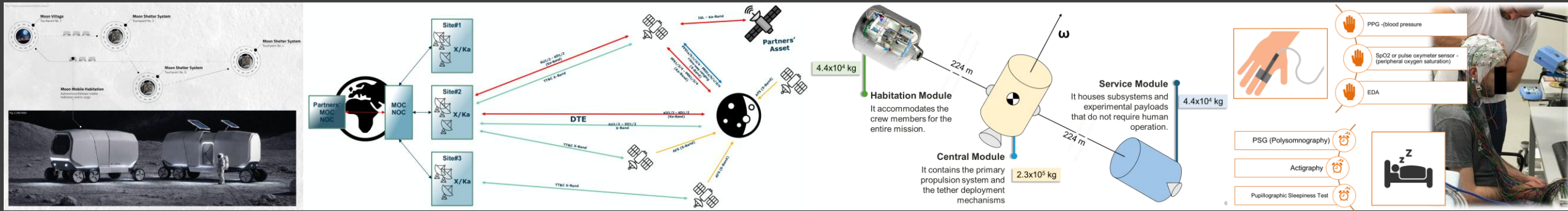
# Mission concepts and tools for sustainable human exploration of the solar system



## WP 8.3 - Latest results

- ❑ **Lunar Pressurized Rover (POLITO, POLIBA, CIRA, UNIBO, UNINA, TASI, LEONARDO, Telespazio, IIT, ALTEC)** - Methods and models for conceptual design: *Habitat, powertrain, docking, structures, VR*; Mobility System Analysis and Wheel Design; Wheel/Soil interaction and lunar soil-trafficability-based derivation for the evaluation of mobility performances and wheels requirements. → **Sessions M1 & M3**
- ❑ **Numerical models (POLITO, POLIBA, CIRA)** - Nonlinear FEM and multi-body simulation; Material and process modelling (AM and ISRU); Advanced Joining Technologies; Active and passive magnetic fields; Real Time Operating Systems; Reduced models for Origami deployable structures; Thermo-structural analysis. → **Sessions M1 & M3**
- ❑ **Mission analysis: Modeling & Simulation fragments development (POLITO, CIRA, ALTEC, UNICAL, ARGOTEC)** - Architectural modeling; Implemented ECLSS sizing & reliability analysis module; Implemented ECLSS dynamic simulation & performance analysis; ConOps analysis; Operative Modes analysis; Integration of operational evaluations into the system design; Technology fragments development (communication technology, etc.), Fragments metamodeling.
- ❑ **Technology Roadmap (CIRA, POLITO, UNIBO, ARGOTEC, UNIROMA2, ASI)** – Questionnaire definition; Data analysis & Prioritisation, Results evaluation and synthesis.

# Design of infrastructures for implementation and operations of sustainable exploration architecture

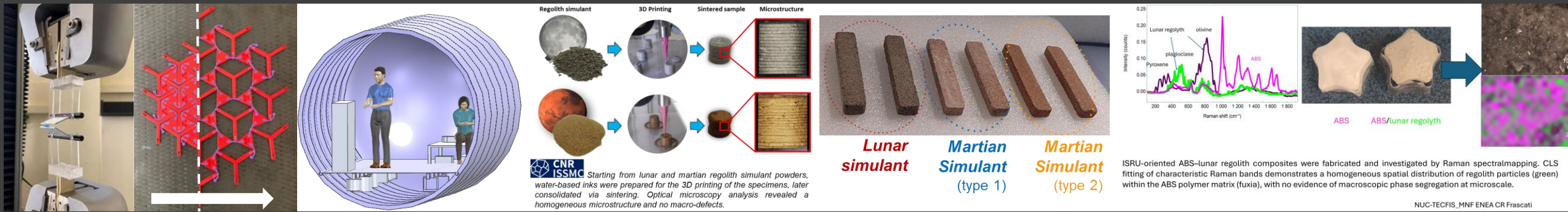


## WP 8.4 - Latest results

- ❑ **Space access, mobility and EDL systems (UNIPD, CNR-ISSMC)** - Artificial gravity via tethered spinning masses, to be validated through SPARTANS; evaluation of radiation shielding and advanced thermal protection ceramics. EDL studies converged on a glider solution, favoring retractable wings over alternative concepts. → **Session M3**
- ❑ **Human Factors | Tech (UNIROMA1, POLITO, ENNAK, CNR-ISSMC, UNIBO, UNIROMA2)** - Identification of key physiological and behavioral signals and sensing methods; comparison of analogue and extreme environments. Research addresses both individual and crew dynamics, noting increased emotional criticality after mid-mission (third-quarter phenomenon). → **Session P2**
- ❑ **Design of habitable space infrastructures for the human exploration (UNIFI, POLITO)** - Focus on extended human operations enabled by mobile modules and shelter networks, with integrated design criteria covering user needs, livability, human factors, materials, and technologies. → **Session M3**
- ❑ **Space exploration communication and navigation (POLITO, UNIROMA1, Telespazio, LINKS, ARGOTEC)** - Emphasis on lunar navigation and communications, using real mission data (LuGRE) and ESA Moonlight; includes radionavigation, visual navigation, and mission analysis to assess infrastructure performance. → **Sessions M1 & M3**



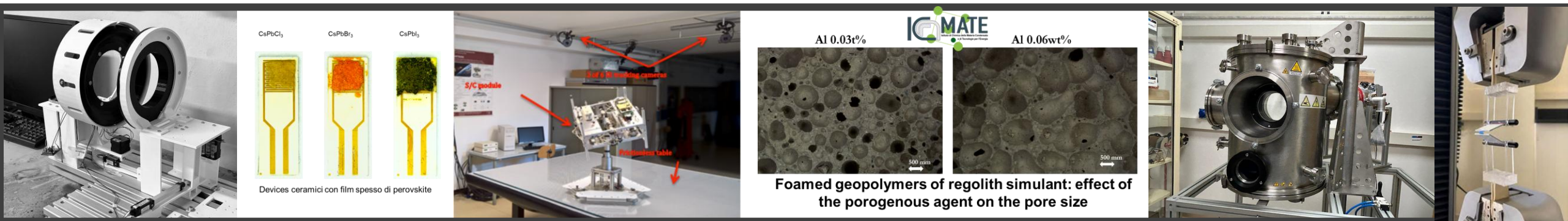
# Development of enabling systems and technologies for extraterrestrial habitats



## WP 8.5 - Latest results

- ❑ **Radiation protection and space health (INAF, UNIBO, ENEA, UNIFI, UNIROMA1, ALTEC)** – Development and validation of advanced radiation sensors and dosimeters based on polymers, perovskites, DLC, and composite technologies, supported by irradiation campaigns, numerical simulations, and comparison with flight data (Artemis I). Biological effects are investigated through UVC-based viral inactivation studies, reinforcing links between radiation, materials, and crew health. → **Session M3**
- ❑ **Advanced materials for habitats and protection systems (UNIROMA1, UNIROMA2, CNR-ISSMC, CNR-ICMATE, CIRA, ENEA, UNIBO, UNIFI, UNIPD)** – Research on ISRU-derived, sustainable, and multifunctional materials for shielding, dust mitigation, and structural applications, including regolith-based composites, foamed geopolymers, recycled carbon fibers, thin films, and micrometeoroid impact sensors, with attention to manufacturing and material optimization. → **Session M3**
- ❑ **Inflatable and deployable structures (POLITO, UNINA, POLIBA)** – Structural and multibody analyses of deployable systems; development of origami-inspired folding concepts, auxetic structures, and advanced self-healing joining techniques for pressurized habitats. → **Session M3**
- ❑ **Task integration and coordination (UNIBO)** – Identification and consolidation of interfaces, dependencies, and synergies across Tasks, supporting coordinated development and progressive integration of habitat technologies, protection systems, and inflatable modules.

# Experimental research for advanced space exploration



## WP 8.6 - Latest results

- ❑ **Experimental testbeds and simulation of space environments** – Advancement of experimental and theoretical frameworks to replicate lunar and planetary conditions, including dust chambers, dust dynamics and transport modeling, planetary analogue studies, and laboratory investigations of water–rock interactions. Task 8.6.1 supported these activities through the establishment of dedicated experimental facilities and the acquisition of advanced mechanical, electrical, optical, and chemical instrumentation across Spoke 8. → **Session M3**
- ❑ **Prototyping and experimental validation** – Prototyping and testing of components and subsystems for robotic and human lunar and Martian exploration, spanning sensing technologies, autonomous navigation, deployable and pressurized structures, communications and navigation systems, thermal control, space agriculture, advanced materials, dosimetry, and rad-hard electronics. Activities include testing in simulated extraterrestrial environments and breadboarding of complex systems such as the Lunar Pressurized Rover/Ants. → **Session M3**
- ❑ **Digital modeling, human factors and TRL assessment** – Integrated experimental, analytical, and simulation activities supporting mission design and validation, including advanced digital simulation tools, multi-method laboratory data analysis, and theoretical modeling of lunar and planetary environments. Human-centered research combines neurophysiological measurements, biological samples, behavioral observation, and VR-based mobility platforms, while Task 8.6.3 provides ESA-compliant data validation and TRL assessment to guide technology maturation. → **Session P2**



# Spoke 8 @ SIU! Days

## Posters ☐ Speeches (Sessions M1, M3 & P2)

1. E. Santini et al. (CNR-ICMATE) Porous materials for space habitats: building elements from regolith simulants geo-polymerization and multiscale materials for photocatalytic filtering
  2. A. Cemmi et al. (ENEA) R&D of ionizing radiation sources and detectors for space radiation at ENEA
  3. P. Pinillos et al. (UNIBO) Microwave, millimeter wave and NIR spectroscopy for measuring compounds of interest into the atmosphere or on the surface
  4. L. Pradetto Battel et al. (UNIPD) Total Ionizing Dose Tolerance of CNN-Enabled Microcontrollers for Space Applications
  5. V. Mariani et al. (UNIROMA1) Positioning accuracy of a lunar polar lander
  6. S. Viviani et al. (UNIFI) Design Exploration on a modular Moon Mobile Habitat System for long-term human permanence
  7. C.L. Blengini et al. (POLITO) Multi-robot autonomous transport system in complex environments
  8. A. Caiazzo et al. (UNINA) Surface-Based Lunar Habitats with Inflatable and Deployable Features: A Conceptual Design and Numerical Feasibility Study
  9. M. Fantino et al. (LINKS/POLITO) Improving GNSS-based navigation in space by means of a radionavigation lunar beacon
  10. N. Calisi (UNIFI) Resin–Regolith Composites and Perovskite-Based Wearable Dosimeters for Lunar Surface Applications
  11. E. Pertile & C. Bettanini (UNIPD) The Mars Micro-Glider concept for atmospheric Analysis
  12. K. Lima (GSSI) Engineering Software for Robotics Space Exploration
  13. S. Enzo (UNIPD) Artificial Gravity Through Tethered Spinning Systems: From Mission Concepts to Laboratory Experimental Validation
  14. C. Franceschini et al. (POLITO) Development of computationally efficient multi-fidelity models for space systems
  15. A. Garro (UNICAL) A formal fragmentation of the RAMSAS (Reliability, Availability, Maintainability, and Safety Analysis via Simulation) method
  16. G. Luccisano et al. (POLITO/CIRA) Space It Up! project: Human Exploration Mission Design
  17. D. Modenini et al. (UNIBO) Development of a Robotic HIL Testbed for Vision-Based Spacecraft Navigation
  18. A. Cellai et al. (POLITO) Debonding and rebonding-on-demand Bio-Based Epoxy CANs composites joints
1. V. Lippiello - ***Lunar Ants***
  2. G. Notarstefano - ***Distributed autonomy, positioning and navigation***
  3. A. Merlo - ***Lunar Pressurized Rover***
  4. S. Caporali - ***3D printing, geopolimers***
  5. C. Porto - ***Simulation chambers and dust dynamics***
  6. C. Bettanini - ***EDL, Artificial Gravity module (tethered systems)***
  7. E. Zappino - ***Habitat & deployable/inflatable structures***
  8. M. Fracasso - ***Magnetic shielding***
  9. S. Laurenzi - ***Materials & Smart Composites***
  10. A. Desiderio - ***Vegetable Ideotypes for Fresh Food Production and Astronaut Diet***
  11. M. Pondrelli - ***Analog environments***
  12. N. Grasso - ***Soilless system for fresh food production for a balanced astronaut diet***
  13. G. Borghini - ***Individual and Crew's Human Factors Measurement***
  14. B. Fraboni - ***Radiation effects and monitoring sensors for closed-loop systems***
  15. C. Ciminelli – ***Engineering a Lunar Pressurized Rover Thorough Modeling and Simulation***
  16. G. Palmerini – ***GNSS-like navigation in space exploration***





AULA MAGNA GIOVANNI AGNELLI

