[Inc. 74] εpsilon Mission

ESA Experiments Overview

Requirements Planning Team Lead for i74

Increment 74 ESA Research Overview

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ASIM (Ext. Payload)
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G: Ground Experiment
RSA: Joint research Russian crew-time
N: Joint research NASA crew-time
↑: Upload only
↓: Download only
First time In-Orbit Execution

Human Research

HUMAN RESEARCH
ARED Kinematics
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Cartilage Degeneration (G)
Cervical in Space (G)
Sarcolab (G)

ARED Kinematics

SCIENTIFIC **BACKGROUND**

- During long duration spaceflight, astronauts suffer losses in bone, muscle, and cardiovascular health which require partial or complete solutions to allow for sustainable human exploration beyond the protective environment of Earth. The unloading of bones and muscles in microgravity results in a rapid deterioration of both. Exercise has been proven to be the most effective means at counteracting the physical deconditioning intrinsic to human spaceflight.
- Currently crewmembers perform resistive exercise on the International Space Station (ISS) using the Advanced Resistive Exercise Device (ARED). However, a major unknown is the internal bone and muscle forces developed during exercise in microgravity. In addition, squat and deadlift resistance exercise loads used in-flight have to be increased to account for the loss of body weight in microgravity and it is unknown how the level of body weight replacement (BWR) affects bone and muscle loads

SCIENTIFIC **OBJECTIVES**

1. To quantify the joint torque, muscle forces, and bone stresses that occur during exercise in microgravity.
2. The ARED-K session includes the following exercises: normal squat, single-leg squat, wide stance squat, and deadlift. Before this session, unless it is provided via data sharing, also an isometric mid-thigh pull assessment will be required to determine experimental exercise load levels.
3. Exercises will be performed with varying resistances to assess load magnitude upon performance.
4. To compare the dynamic and kinematic strategies between exercise in normal gravity and in microgravity during the ARED motor tasks.
5. To quantify adaptations in performance that may occur throughout a long-duration spaceflight mission.

NEED OF SPACE

Accurate estimation of internal forces during resistive exercise requires measurement under true microgravity, where gravitational loading, movement strategies and body-weight replacement conditions differ fundamentally from Earth. Ground-based analogues cannot replicate the biomechanical environment of inflight ARED exercise; therefore, only in-orbit measurements can reveal how microgravity alters joint loading and muscle activation, enabling the development of effective countermeasures for astronaut health on long-duration missions.

RETURN TO EARTH

Post-flight data collection is performed once, at R+45 (±1 week), to capture recovery biomechanics during a stable phase after re-adaptation begins. This session replicates the pre-flight protocol, allowing comparison of post-flight joint mechanics and movement strategies with pre- and inflight data, thereby helping determine the extent and time course of functional recovery after long-duration microgravity exposure.

Bone on ISS

SCIENTIFIC **BACKGROUND**

- Microgravity has severe effects on human physiology, and particularly on bone. The exposure to microgravity and the post-flight skeletal re-adaptation to 1G on Earth are responsible for changes in bone turnover, and subsequently in bone shape, density, microarchitecture, and mechanical integrity. Several of these changes cannot be recovered over several months to years in human tibia and vertebra. In addition to bone markers representing bone formation and resorption activities, the investigation aims to evaluate other markers of interest. These include muscle factors, Fibroblast growth factors, inflammation biomarkers and Osteocyte-derived factors.
- Changes in levels of molecular and physiological markers in blood and urine of crew will be correlated prior, during and post spaceflight on the international Space Station (ISS). This investigation is a follow-up of the EDOS (1 and 2) study, will also try to understand the bone long term recovery after flight, the crew inter-individual heterogeneity predisposing to bone fragility and the effect of repeated flights and recovery periods. The data gathered will also be computed together to develop a bone digital twin model able to predict the behaviour of bone structural parameters during recovery periods and to simulate astronaut-specific bone evolution.

SCIENTIFIC **OBJECTIVES**

1. Understand bone long term recovery.
2. Understand interspecific heterogeneity between subject population.
3. Understand bone recovery in recurrent exposure to microgravity.
4. Explore new biological mechanism related to bone loss by:
   a. Assessing selected miRNA expression patterns
   b. Assessing bone mineral metabolism
   c. Assessing pro and anti-inflammatory pathways
   d. Assessing mitochondrial multiplicity

NEED OF SPACE

Microgravity exposes the skeleton to a uniquely severe form of disuse that cannot be reproduced on Earth, fundamentally altering bone remodeling, mineral metabolism, and osteocyte signaling. Space-related bone loss has been described after space sojourns of several days up to 6 months duration. Only spaceflight enables assessment of how bone structure, density, turnover markers, and the FGF23–Klotho axis (a hormone produced mainly by osteocytes and osteoblasts in bone and a protein acting as a co-receptor for FGF23) evolve under true weightlessness, especially across long-duration missions.

The resulting dataset—including inflight blood markers and longitudinal High-Resolution peripheral Quantitative Computed Tomography HR-pQCT/ peripheral Quantitative Computed Tomography pQCT imaging—provides essential inputs for the bone digital twin and for improving countermeasures aimed at preventing bone loss during and after spaceflight.

RETURN TO EARTH

An improved understanding of the bone biology of immobilization is very important for the prevention and treatment of immobilization-related bone disorders.

Immunity Assay

esa

SCIENTIFIC **BACKGROUND**

- Assessing, monitoring and maintaining human health is a prerequisite for successful mission accomplishment. In the last decades immunology has also become a major topic in this regard. Research focuses on the analyses of specific cell functions ex vivo or in vitro to assess the changes in the human body and organisms when exposed to psychological/biological and physical stress factors during a long-term mission in space. As a result, the immune system is targeted by a multitude of hormones, hormone-like substances and radiation effects, leading altogether to an imbalance of immune functions which can potentially explain the higher risk of infection.
- Immunity Assay targets to investigate the impact of space-flight stressors on cellular immune functions ex vivo using a new in vitro DTH assay set-up, thereby mirroring key properties of the Multitest CMI but extending it by viral antigens and mitogens, and by analyzing the potential impact of stress hormones on the immune response.

SCIENTIFIC **OBJECTIVES**

The aim is to monitor crew cellular immunity ex vivo using an antigen- and mitogen-based approach. The readout of these complex and multidirectional pathways are pro and anti-inflammatory acting cytokines that are secreted in response to this ex vivo immune challenge. The impact of gravitation (0 G and 1 G) as well as the action of stress sensitive, immune-modulating drugs (e.g. glucocorticoids) will be analysed. Furthermore, measurement of parameters depicting T cell characteristics such as T-cell profile, growth factors or chemokines is essential.

NEED OF SPACE

The rationale of this assay is to monitor immune (dys-) functions in space and to test for the role of a stress hormone - here of corticoids - on the antigen/mitogen dependent immune responses. This study can only be conducted i) when the subject analyzed is subjected to μG condition for months and ii) when the incubation conditions allow to comparatively test for the effects of gravitation (μG vs. 1G).

Benefit for space and Earth applications: The test will be of benefit both for space and non-space applications helping hereby to assess the complex cellular immune functions by using a novel in vitro DTH assay set-up. This testing will further increase the understanding of gravitation dependent immune response pattern and its potential modulation through stress hormones. In conjunction with other blood samples and saliva collections, this test will provide a feasible approach to monitor stress related immune performance also on Earth.

RETURN TO EARTH

A post-flight session at R+0/1 is required because landing produces an acute stress response that can interact with long-duration immune dysfunction. Sampling within the first 24 hours captures these immediate immunological shifts and aligns the dataset with other ISS immune studies for harmonized comparisons. Additional post-flight BDCs at R+7 and R+25–30 track early recovery trajectories and help distinguish transient landing-related effects from persisting dysfunction following microgravity exposure.

Muscle Stimulation

SCIENTIFIC **BACKGROUND**

- Muscle atrophy and the associated rapid decline in exercise capacity are still a concern for crew-health and their operational proficiency during prolonged space missions. Despite the success of exercise to sustain astronaut health and performance in spaceflight, these countermeasures are time consuming and do not entirely prevent muscle wasting and weakness.
- Neuromuscular electrical stimulation (NMES) is a well-recognized efficient modality to potentiate muscle performance in athletes and healthy individuals, and to combat muscle atrophy during prolonged periods of disuse, immobilization, injury, or in patients affected by chronic diseases.
- NMES not only attenuates the loss of muscle mass, but also improves muscle power and endurance, which are known to be reduced in spaceflight. It thus represents a promising intervention to address both the problems of muscle weakness and loss of endurance during spaceflight.

SCIENTIFIC **OBJECTIVES**

The main objective of our proposal is to determine the effectiveness of bilateral NMES during the last period in-orbit to counteract the spaceflight-related decline in exercise capacity, muscle mass, neuromuscular function, muscle endurance of skeletal muscle.

Secondary objectives are to assess whether such effects are explicable by maintained aerobic energy metabolism and muscle oxygenation, increased neural drive, release of hormonal/trophic factors which are involved in the maintenance of muscle and mass, metabolism and attenuation of inflammation.

NEED OF SPACE

Space provides the only environment where human skeletal muscle is exposed to prolonged unloading in true microgravity, making it essential to study whether NMES can effectively reduce muscle loss under flight-specific physiological conditions. NMES may enable shorter exercise durations and lighter equipment requirements, reducing crew time and payload demands for future missions. The ISS environment also allows assessment of NMES benefits in combination with existing resistive and aerobic countermeasures, with direct implications for long-duration missions and future habitats on the Moon and Mars. If the present study shows that NMES is beneficial, it will not only improve the countermeasure programme for space travel, but it will also have useful applications in the clinical setting and elderly population.

RETURN TO EARTH

Post-flight testing must occur as soon as possible because both spaceflight-induced deconditioning and the effects of NMES can diminish rapidly after landing. To capture these acute changes, Muscle Stimulation requires neurophysiological, microcirculatory, MRI, and blood assessments within the first week after return (ideally R+0/1 for blood and microcirculation, and early for MRI to avoid fluid-shift artefacts). Early acquisition minimizes recovery-related bias, ensuring accurate evaluation of how well NMES mitigated muscle atrophy and functional decline during spaceflight.

RelaxPro

SCIENTIFIC **BACKGROUND**

- Astronauts routinely face sleep disruption and elevated stress in space—two behavioural risks tightly linked to performance and safety. Evidence from analogs and operational experience indicates that mind/body practices (relaxation training, diaphragmatic breathing, progressive muscle relaxation, and mindfulness) can reduce distress and improve sleep, and a NASA-commissioned review by the RelaxPro science team recommends structured training for astronauts. RelaxPro tests a space-tailored protocol delivered as brief audio narratives, introduced pre-flight and practiced in-flight, with one track focused on sleep promotion and another on stress reduction.
- The study pairs these practices with multidimensional measures—sleep/Hearth Rate Variability (HRV) monitoring, saliva biomarkers (e.g., cortisol, DHEA/DHEA-S), subjective sleep logs and affect ratings, and (for longer missions) hair endocannabinoids (e.g., anandamide, 2-AG) that index longer-term stress exposure. Together, these readouts allow RelaxPro to quantify both short-term responses (night-of and day-after) and mission-level adaptation to the intervention.

SCIENTIFIC **OBJECTIVES**

RelaxPro aims to test the efficacy of two guided relaxation protocols—one for sleep, one for stress—on astronauts' sleep quality and stress levels during ISS missions. Outcomes include subjective sleep and affect, actigraphy-derived sleep indices, heart-rate variability as an autonomic marker, and endocrine markers of stress from morning/evening saliva samples. A post-flight qualitative interview captures user experience and operational fit.

The study further seeks to link effects to mission context, examining how responses vary across session timing (Non-Relaxation Day/Relaxation session Day/Day After Relaxation blocks), mission duration, and individual factors. By quantifying acute and cumulative benefits, RelaxPro supports the development of non-invasive, low-resource countermeasures for behavioural health risks in current ISS operations and future exploration missions.

NEED OF SPACE

Spaceflight creates a unique stress–sleep environment shaped by disrupted schedules, isolation, workload, and physiological changes, making it essential to test relaxation countermeasures directly in orbit. RelaxPro's alternating sleep-promoting and stress-releasing sessions allow real-time evaluation of their effects on sleep quality, HRV, and hormonal rhythms under authentic conditions, while the ISS's structured NRD–RSD–DAR cycles across varying mission lengths provide dose–response and durability data unavailable on Earth—long-duration missions. critical for developing simple, autonomous, non-pharmacological tools for future long-duration missions.

RETURN TO EARTH

After landing, RelaxPro conducts a two-day post-flight block mirroring baseline assessments (sleep/HRV monitoring, sleep log, stress/emotions questionnaire, saliva; plus, a post-flight interview) to evaluate persistence of benefits, compare against pre-flight, and capture astronaut feedback on usability and mission integration—evidence that guides protocol refinement for longer future missions.

Brain-DTI – Ground only

esa

SCIENTIFIC BACKGROUND

- A recently developed MR technique called Diffusion tensor imaging (DTI) allows investigating brain tissue microstructure and connectivity, particularly in white matter. This non-invasive imaging method probes the diffusion characteristics of water molecules in biological tissue, like the human brain. This allows determining the neuro-anatomy of the brain since water molecules are subject to random thermal motion (‘Brownian motion’). This process causes these molecules to move in a translational matter and thus ‘to diffuse’.
- However, in biological tissue, such as the human brain, free motion of the water molecules is restricted due to natural barriers, so in this case, water will move more easily in one direction than the other, corresponding with the underlying organization of the tissue.
- Based on neuro-anatomical data and previous work from PET and fMRI studies, DTI can be used to find biomarkers of neuroplasticity.

SCIENTIFIC OBJECTIVES

1. To obtain knowledge on how astronauts adapt to microgravity at the level of the brain.
2. To use the model of microgravity to gain insight in which specific regions of interest are involved in space motion sickness (SMS), spatial disorientation, vertigo, and convergence of otolith and semicircular canal signals.
3. To link biomarkers of brain plasticity with clinical outcomes that are obtained by motion sickness questionnaires.
4. To use the obtained knowledge on this adaptation of the astronaut brain to microgravity as a starting point to optimize countermeasures against space motion sickness, spatial disorientation, vertigo and convergence of otolith and semicircular canal signals.
5. To use this knowledge as a starting point in the treatment of specific groups of vertigo patients (e.g. visual vertigo syndrome, mal de debarquement, uncompensated peripheral lesions).

NEED OF SPACE

Spaceflight provides a unique, controllable, and ethically unattainable stimulus that cannot be replicated on Earth, allowing researchers to observe profound vestibular and neuro-sensory adaptation processes in real time. Studying astronauts before and after long-duration missions therefore enables identification of neuroplastic mechanisms and biomarkers that cannot be investigated in healthy subjects on Earth, and facilitates comparisons between astronauts, healthy controls, and vestibular-disorder patients to advance both spaceflight and clinical neuroscience.

RETURN TO EARTH

Early post-flight assessments are essential because brain plasticity processes begin reversing quickly upon re-exposure to gravity, with substantial changes occurring within the first days after landing. Capturing MRI data as early as possible—especially the additional R+1 to R+3 session for European subjects—allows the experiment to better determine the time course of recovery and better understand how neuroplastic changes evolve during the initial re-adaptation period.

Exposome Signature – Ground only

SCIENTIFIC BACKGROUND

- Spaceflight exposes astronauts to multiple combined stressors—microgravity, radiation, confinement, isolation, circadian disruption, and environmental changes—that simultaneously impact immune, endocrine, metabolic, microbiome, virome, and redox systems. Prior missions show these effects can resemble mechanisms seen in chronic disease and accelerated aging on Earth, with low-grade inflammation (LGI) emerging as a key feature influenced by several space-related factors.
- The Exposome Signature project examines how these interconnected systems evolve before, during, and after missions by measuring a broad panel of neuroendocrine, metabolic, immune, redox, inflammatory, microbiome, and virome markers. To distinguish space-specific effects from those caused by isolation and operational stress, parallel measurements in Italian Navy submariners provide an Earth-based analog without microgravity or cosmic radiation, helping identify which physiological changes are uniquely space-induced.

SCIENTIFIC OBJECTIVES

The Exposome Signature experiment aims to build a comprehensive multi-system profile of astronauts before, during, and after missions by measuring inflammation, immune function, oxidative stress, metabolism, neuroendocrine signaling, microbiome and virome activity, and circulating microRNAs. By including both short (<150 days) and long (≥150 days) missions, the study assesses immediate adaptations, long-term changes, and the persistence of physiological alterations after return to Earth. Another key goal is to identify biomarkers and predictive patterns that support astronaut monitoring and the development of targeted countermeasures. Comparing astronaut data with submariners helps distinguish microgravity- and radiation-specific effects from those caused by isolation and stress. These insights will inform medical planning for future exploration missions and guide improved diagnostic, monitoring, and therapeutic strategies in space and on Earth.

NEED OF SPACE

Spaceflight creates conditions—altered gravity, radiation, confinement, and shifts in microbiome and behavior—that cannot be reproduced on Earth and drive unique changes across immune, metabolic, endocrine, and microbial systems. Capturing these space-specific effects requires in-flight sampling, as many biomarkers change only under microgravity and evolve throughout the mission. Collecting data across different mission lengths helps identify which physiological alterations are temporary or persistent, supporting the development of effective health-monitoring tools and countermeasures for future exploration missions.

RETURN TO EARTH

Exposome Signature performs several post-flight sessions (R+0/1, R+7, R+21–30, R+4–6 months) to track immediate recovery, ongoing readaptation, and persistent changes across immune, inflammatory, metabolic, endocrine, microbiome, and virome profiles. These time points are essential for identifying lasting dysregulations and assessing potential health risks that may appear after mission completion, especially following longer flights.

Cartilage Degeneration – Ground only

SCIENTIFIC **BACKGROUND**

- Microgravity and long periods of unloading are known to negatively affect joint health, but the underlying mechanisms remain unclear. Previous ESA bed-rest studies and the earlier ESA "Cartilage" experiment showed early degenerative changes in knee cartilage after 4–6 months in space, consistent with ground findings that immobilization reduces cartilage thickness and alters metabolism. Because articular cartilage relies on regular mechanical loading and has a slow turnover due to its lack of vascular and lymphatic systems, even moderate unloading can cause shifts in its composition and structure.
- The CarDeg study uses MRI, HR-pQCT, and blood and urine biomarkers to better understand how microgravity affects cartilage and to identify individuals most at risk. By examining factors such as mission duration, activity levels, previous flight experience, and radiation exposure, the study aims to improve prediction of injury risk during long missions and deepen understanding of cartilage degeneration relevant to both astronauts and people on Earth.

SCIENTIFIC **OBJECTIVES**

The primary objective of the CarDeg experiment is to determine how long-duration spaceflight affects joint health, with a particular focus on knee cartilage. By assessing both cartilage morphology and biochemical markers of cartilage metabolism, the study aims to quantify how microgravity alters tissue structure and function. These insights will support early identification of astronauts who may be vulnerable to degeneration.

Beyond measuring changes, the experiment seeks to identify specific risk factors linked to cartilage deterioration, including mission duration, training history, in-flight exercise behaviour, bone quality, muscle morphology, and general health status. Understanding how these factors interact will help clarify why some individuals may exhibit greater degeneration than others after similar exposure. A further objective is to assess how microgravity-induced alterations may increase injury risk during future exploration missions, where mobility is essential. The study also aims to deepen understanding of how immobilization contributes to the development of osteoarthritis. Insights gained in space are therefore expected to support both astronaut health and terrestrial health challenges related to sedentary behaviour.

NEED OF SPACE

Microgravity offers the only environment where cartilage can be unloaded for months, allowing researchers to observe slow, early degenerative changes that cannot be detected in short-term or Earth-based models. This long-duration unloading helps reveal how healthy cartilage responds to reduced mechanical load and supports the development of countermeasures to protect astronaut mobility, while also improving understanding of joint degeneration in immobilized or sedentary individuals on Earth.

RETURN TO EARTH

After landing, CarDeg monitors how cartilage, bone, muscle, gait, and biomarkers change as astronauts readapt to gravity, using follow-up sessions at R+28, R+365, and R+730. Because cartilage recovers slowly, these long-term measurements help reveal whether joint health returns to pre-flight levels or shows lasting degeneration, providing essential insight for future mission health risks.

Cervical in Space – Ground only

SCIENTIFIC **BACKGROUND**

- Astronauts face a markedly increased risk of cervical Intervertebral Disk (IVD) herniation after spaceflight, but the mechanisms remain insufficiently understood. Unlike the lumbar spine—where hyperhydration was once considered the leading hypothesis—no in-flight data exist on cervical disc hydration, although short-term recumbency studies suggest it may increase. Additional factors such as impaired muscle and neurovestibular function after spaceflight may compromise cervical muscle control, while deep cervical muscles and fat infiltration patterns known from neck-pain research have never been systematically studied in astronauts.
- Cervical disc health may also be affected by microgravity-related changes in vertebral bodies and endplates, which supply nutrients to the disc. Bone loss could alter disc size, hydration, and loading, and endplate damage is linked to disc degeneration. These combined structural, muscular, and neuromuscular factors likely interact to elevate cervical herniation risk, warranting comprehensive investigation.

SCIENTIFIC **OBJECTIVES**

The study aims to assess anatomical, functional, and neuromuscular changes in the cervical spine before and after long-duration spaceflight. This includes MRI-based evaluation of disc morphology and hydration, 3D kinematic analysis of movement patterns, detailed measurement of muscle strength, endurance, and motor unit behaviour, and DXA-based assessment of cervical bone parameters. Collected data will also support in-vitro disc loading simulations and finite-element modelling to identify stress and strain profiles associated with cervical herniation risk. Expected findings include increases in disc volume and hydration, muscle atrophy and fat infiltration, reduced range of motion, altered motor control, and bone density changes—all of which may contribute to post-flight injury risk. Importantly, these results will help define requirements for targeted countermeasures to mitigate cervical herniation risk during and after future missions.

NEED OF SPACE

Spaceflight is the only environment that exposes the cervical spine to prolonged microgravity, fluid shifts, neuromuscular deconditioning, and loading changes that cannot be reproduced on Earth. Bed-rest studies have already proven inadequate for modeling cervical spine adaptations, making real astronaut data essential for identifying true space-specific mechanisms of disc and muscle change. Because herniation risk is highest immediately post-flight, only direct pre- and post-mission cervical measurements can reveal the underlying processes and inform effective countermeasures.

RETURN TO EARTH

After landing, astronauts undergo four post-flight sessions (R+1–7, R+8–14, R+45–90, and R+160–190 days) to capture early cervical changes when herniation risk is highest, and to track how disc morphology, muscle function, and kinematics recover over time. These sessions provide essential data on the timeline of readaptation, identifying which changes resolve quickly, which persist, and how they may relate to symptoms such as neck pain or reduced mobility.

Sarcolab-3 – Ground only

SCIENTIFIC **BACKGROUND**

- After a long-term exposure to microgravity, muscle function is highly altered due to loss of muscle mass, broad sensory disturbances, reduced contractile properties, and perturbation in motor control; as a consequence, a decrease in muscle force per unit of cross-sectional area (F/CSA) is observed.
- This phenomenon may not only be related to alterations in muscle architecture and in neural drive but also to tendinous and extracellular matrix changes affecting the mechanical output of the muscle and its ability to transduce mechanical signals into chemical processes driving protein synthesis. Contractile and elastic mechanical properties of the tendon-muscle unit are also profoundly modified notably its stiffness analysed in active or passive conditions.
- These structural changes are accompanied by (or partly due to?) reduction in muscle activation as indicated by EMGs studies in voluntary (maximal and submaximal) and reflex conditions, a way to demonstrate the changes in motor control.

SCIENTIFIC **OBJECTIVES**

1. To characterise reflex excitability of the disused muscles.
2. To characterize elastic and mechanical properties in active and passive states
3. To characterize muscle activation and muscle fatigability under voluntary (and electrically evoked) conditions by recording surface EMGs during maximal and submaximal isometric contractions (contractions produced without joint displacement) and maximal isokinetic contractions (contractions produced with joint displacement at a constant velocity).
4. To assess muscle architectural features.
5. To characterize soleus tendon mechanical properties before and after spaceflight.
6. To assess the intrinsic contractile properties and molecular pathways involved in the tissue adaptation
7. To assess dynamic motor control performance during a series of position-matching tasks with and without external loads

NEED OF SPACE

Ground-based unloading models cannot replicate true microgravity, where gravitational load and somatosensory input are fully removed. To understand the mechanisms behind muscle wasting, altered tendon mechanics, and disproportionate force loss, measurements must be made in a zero-gravity environment, making spaceflight the only setting that reveals the authentic drivers of myotendinous and neuromuscular adaptation.

RETURN TO EARTH

Early post-flight measurements are essential because neuromuscular and tendon adaptations begin reversing quickly once gravity is restored. Sarcolab-3 therefore performs reflex testing on R+1 and muscle–tendon assessments within the following days (R+3–5) to capture the most rapid phase of readaptation and determine which deficits persist as recovery progresses.

Biology

BIOLOGY

Lux in Space (Biolab)
Nemuco (Biolab)
Seed Vigour on ISS

Lux in Space

esa

SCIENTIFIC **BACKGROUND**

- Space radiation and microgravity both affect biological systems, yet their combined influence on cellular DNA repair remains insufficiently understood. Prior studies have shown altered gene expression and contradictory effects on DNA repair under microgravity, ranging from inhibition to enhancement, but results remain fragmented and sometimes inconsistent across organisms and experimental platforms. Because microgravity cannot be faithfully simulated on Earth, true gravitational effects on cellular radiation responses require in-orbit investigation.
- DNA is the primary biological target of radiation damage, and the bacterial SOS response provides a sensitive and well-characterized system to monitor such effects. Previous space experiments using bacteria, yeast, and human cells have shown that microgravity may alter repair pathways, but available data are insufficient to establish clear mechanistic insights. Lux in Space addresses this knowledge gap by tracking the full sequence from radiation-induced DNA damage to repair induction and kinetics under continuous microgravity

SCIENTIFIC **OBJECTIVES**

Lux in Space investigates whether microgravity alters the kinetics of enzymatic DNA repair following radiation exposure. Using genetically modified *Salmonella enterica* expressing SOS-regulated bioluminescence, the experiment measures DNA damage-induced luminescence and corresponding cell proliferation to determine microgravity-dependent repair responsiveness. Parallel 1-g controls generated via onboard centrifugation enable direct comparison of repair induction, dose response, and repair kinetics.

Specific objectives include culturing bacteria in 0-g and 1-g in parallel, inducing UV-C–mediated DNA damage at two doses, quantifying repair-associated luminescence over time, and assessing whether microgravity modifies dose-effect relationships. Combined analysis of irradiated and non-irradiated samples across gravity levels will reveal potential synergistic, additive, or antagonistic interactions between microgravity and radiation..

NEED OF SPACE

Microgravity cannot be reliably reproduced on Earth, making spaceflight essential to determine how it affects DNA repair pathways. Lux in Space must be performed in orbit to isolate true microgravity effects from ground-based artifacts and to study how microgravity interacts with elevated space radiation—critical knowledge for astronaut health, life-support microbiology, biosensor development, and planetary-protection considerations.

RETURN TO EARTH

Lux in Space returns no biological samples; instead, all optical-density, bioluminescence, temperature, and housekeeping data are downlinked for analysis. These datasets will define dose-response curves and reveal how microgravity alters DNA repair, supporting radiation-risk assessment for long missions, development of microbial biosensors, and evaluation of microbial stability in life-support systems, while also informing studies of more complex organisms..

Nemuco

SCIENTIFIC **BACKGROUND**

Prolonged microgravity causes structural and metabolic adaptations in skeletal muscle, including well-documented atrophy, reduced strength, and impaired neuromuscular performance. These effects are linked not only to changes within muscle fibers but also to altered neuronal recruitment patterns, suggesting that nerve terminals and neuromuscular signaling contribute significantly to muscle degradation in space. Prior studies show that microgravity and disuse produce similar neuromuscular junction (NMJ) alterations, including reduced synaptic vesicles, neurotransmitter content, axonal degeneration, and sprouting.

Although ultrastructural NMJ changes have been described in space-exposed animals, the molecular mechanisms that govern NMJ stability, signaling, and plasticity under microgravity remain poorly understood. Existing findings point to disrupted NMJ maintenance and remodeling in reduced activity conditions, but in-flight molecular data remain largely absent. NEMUCO addresses this gap by examining how microgravity affects NMJ formation, gene expression, and postsynaptic signaling components in a controlled in-vitro nerve-muscle co-culture model.

SCIENTIFIC **OBJECTIVES**

NEMUCO aims to determine how microgravity influences NMJ formation, stability, and molecular regulation using a 3D co-culture model of differentiating myotubes and α-motoneurons. The experiment seeks to identify NMJ-specific genes responsive to microgravity and assess whether microgravity alters spatial organization and timing of key postsynaptic components, including nicotinic acetylcholine receptor clustering and synaptic assembly processes.

Additional objectives include mapping global gene-expression changes, determining the hierarchical involvement of NMJ-related genes, and assessing the localization and regulation of Homer proteins—key scaffolding elements involved in neuromuscular signaling. The experiment will also explore whether specific interventions can restore Homer-dependent signaling pathways disrupted under microgravity.

NEED OF SPACE

Microgravity effects on neuromuscular junction (NMJ) stability cannot be reproduced on Earth, making in-orbit experimentation essential. NEMUCO enables direct assessment of how microgravity alters NMJ formation and remodeling—key to understanding space-induced muscle atrophy—and isolates microgravity-specific mechanisms that ground or animal studies cannot resolve.

RETURN TO EARTH

Fixed samples are returned to Earth for molecular and structural analyses, including RNA sequencing, ultrastructural NMJ assessment, and immunofluorescence of key synaptic proteins such as Homers. These data will clarify how microgravity disrupts NMJ assembly and gene regulation, supporting improved countermeasures for astronaut muscle atrophy and offering insights relevant to neuromuscular diseases.

Seed Vigour on ISS

esa

SCIENTIFIC **BACKGROUND**

- Earlier ISS research suggested seeds were largely unaffected by the station environment, but more recent work on Eruca sativa revealed reduced seed vigour, increased ageing sensitivity, and transcriptome changes after six months in orbit—even though viability remained intact. These findings indicate that subtle physiological effects can occur inside the ISS, but previous studies often lacked seed-biology expertise, adequate controls, or environmental monitoring, making interpretation difficult.
- Because seed vigour, longevity, and ageing responses differ widely across species, stress tolerances, and ploidy levels, the behaviour of a single species cannot be generalised. Improved environmental logging (temperature, humidity, and radiation) and side-by-side ground controls are therefore necessary to identify whether the ISS environment consistently alters seed performance, and whether certain seed traits (e.g., extremophily, polyploidy, genome size) confer resilience.

SCIENTIFIC **OBJECTIVES**

The activity aims to expose seeds from 6–9 crop and wild species to ISS conditions for at least six months to quantify how spaceflight affects seed vigour, ageing sensitivity, and viability. Each species will be compared against ground controls designed to isolate specific environmental factors—low-temperature storage, ISS-like temperature regimes, and mechanical disturbances matching transport to and from orbit.

A further objective is to determine which biological traits predict resilience to spaceflight. The study will assess whether extremophile species or polyploid species retain higher vigour, whether genome size or embryo-to-seed ratios influence outcomes, and whether species showing the strongest physiological changes also exhibit larger transcriptomic shifts, including radiation-responsive gene expression differences.

NEED OF SPACE

Spaceflight exposes seeds to environmental conditions—microgravity, ISS-specific radiation, and transport-related stresses—that cannot be fully replicated on Earth. Storing seeds inside the ISS is therefore essential to determine whether reduced vigour occurs consistently across species, to test which seed traits influence resilience, and to compare against well-characterised ground controls.

RETURN TO EARTH

Returned seeds, together with temperature, humidity, radiation, and acceleration logs, enable detailed analyses of vigour, ageing sensitivity, biophysical traits, and transcriptome changes. These results will identify traits linked to resilience in spaceflight conditions, guide crop and storage strategies for long-duration missions, and advance seed-banking science.

Material Sciences

MATERIAL SCIENCES

Colloidal Solids
EML Batch 3.5, 4.1 (N)
PK-4 (RSA)

Colloidal Solids

SCIENTIFIC **BACKGROUND**

- Colloidal Solids investigates how colloidal suspensions form crystals, glasses, and gels—states that mimic the phase behavior of complex molecular systems but are experimentally more accessible because colloidal interactions can be finely tuned. Central scientific challenges relate to solidification processes, including the glass transition in hard-sphere systems, the emergence of attractive glasses and gels through depletion interactions, and the formation of complex structures arising from the competition between short-range attraction and long-range electrostatic repulsion.
- Additionally, suspensions containing anisotropic particles (rods, ellipsoids, dumbbells) present rich phase behaviour and open questions regarding rotational and translational arrest, novel crystalline phases, and glassification mechanisms. These systems provide model materials for testing concepts in non-equilibrium statistical physics, such as aging, dynamical heterogeneity, and the coupling between structure and dynamics.

SCIENTIFIC **OBJECTIVES**

The experiment aims to characterize the dynamics and structural evolution associated with glass transitions, gelation, and aggregation in colloidal suspensions. Specific goals include quantifying dynamical heterogeneities, mapping phase diagrams across interaction regimes, and determining whether equilibrium glass states exist and what their steady-state properties are. The project also seeks to study irreversible aggregation processes and their connection to slowing dynamics, as well as to probe orientational and rotational behavior using optically anisotropic particles.

Furthermore, the research addresses how complex depletion forces shape the formation and structure of colloidal gels, and how anisotropic interactions influence phase behavior and crystallization pathways. All experiments rely on coordinated use of multi-angle Dynamic Light Scattering (DLS), Small-Angle Light Scattering (SALS), and Time-Resolved Correlation (TRC) to capture fast and slow dynamics and structural evolution throughout solidification processes

NEED OF SPACE

Microgravity is essential because gravity-driven sedimentation, convection, and density gradients distort the structure and dynamics of colloidal systems, even when buoyant forces are small. Past space experiments showed that systems remaining glassy for years on Earth can crystallize in microgravity. Eliminating gravity creates uniform, flow-free conditions that reveal the intrinsic phase transitions, nucleation processes, and structural length scales otherwise obscured on Earth.

RETURN TO EARTH

The Colloidal Solids experiment does not require physical sample return. All scientific information—correlation functions, scattering data, processed image-based diagnostics, and relevant housekeeping measurements—is acquired on orbit and downlinked. This eliminates the need for sample recovery while still providing all data necessary for post-flight analysis and model validation.

EML Batch 3.5/4.1 – EDR

SCIENTIFIC **BACKGROUND**

- The EML electromagnetic levitator is a multi-user facility that provides containerless melting and solidification of electrically conductive, spherical samples, under ultra-high vacuum and/or high gas-purity conditions. Each sample container will fit 18 samples, defined as a 'Batch'.
- Heating and positioning of the sample is achieved by electromagnetic fields generated by a coil system. The EML supports research in the field of meta-stable states and phases and measurement of high-accurate thermophysical properties of liquid metallic alloys in the stable and undercooled state. The max processing temperature is 1,950 ° C. The former field covers investigations of nucleation and solidification kinetics in undercooled melts and developing microstructure. Thermophysical properties include surface tension, viscosity, melting range, fraction solid, specific heat, heat of fusion, mass density and thermal expansion, and thermal transport properties as the total hemispherical emissivity and effective thermal conductivity.

SCIENTIFIC **OBJECTIVES**

EML Sample Batch 3 and 4 investigate a broad set of alloy systems to advance the understanding of nucleation mechanisms, fluid-flow effects, phase selection, and the links between liquid structure and solidification behaviour. The projects aim to obtain high-precision thermophysical properties for industrially relevant materials (e.g., Inconel alloys, metallic glasses, Ti-based biomaterials, Fe-based steels) and model alloys used to probe fundamental solidification pathways.

Both Batch 3 and 4 follow the standard EML sample-chamber capacity of 18 active positions (samples), with 3 backup samples. A swap between Batch 3 and 4 is planned for Spring 2026.

Across the Batch 4 selected samples, objectives include: determining the influence of convection on nucleation and growth; validating new nucleation models; characterising glass-forming ability; mapping growth velocities under controlled undercooling; and quantifying how chemical composition, oxygen content, or induced stirring modify liquid dynamics, phase transitions, and resulting microstructures. These results feed directly into improved modelling of casting, additive manufacturing, and rapid-solidification processes.

NEED OF SPACE

Microgravity suppresses convection, buoyancy, and hydrostatic pressure, allowing stable, spherical droplets and precise thermophysical measurements impossible on Earth. It enables deeper undercooling, reproducible nucleation, and controlled solidification while decoupling heating from positioning fields. These conditions provide the accuracy required to test solidification theories and fluid-flow models central to the EML Batch 4 investigations.

RETURN TO EARTH

Returned samples undergo structural and microstructural analyses—such as Scanning Electron Microscopy (SEM)/ Energy-Dispersive X-ray Spectroscopy (EDX), X-ray Diffraction (XRD), calorimetry, and hardness testing—to complement in-flight measurements. These data reveal phase selection, microsegregation, crystallisation pathways, and glass formation, enabling full validation of models and direct correlation between microgravity processing and resulting material structures.

PK-4 – EPM (with Russian crew support)

esa

SCIENTIFIC **BACKGROUND**

- Plasma Kristall-4 (PK-4) is an experiment for investigating complex plasmas. Plasmas are ionized gases produced by high temperatures, like in the sun, or by electric fields, i.e., low temperature discharge plasmas like in neon tubes. In the latter case the degree of ionization is small and a large amount of neutral gas is present. Complex or dusty plasmas are plasmas which contain beside electrons, ions, and neutral gas in addition micro-particles, e.g., dust grains. Due to the high mobility of the electrons (compared to the ions) in low temperature discharge plasmas the micro-particles collect a large number of electrons on their surface.
- For a particle with a diameter of a few microns this charge can be of the order of 10.000 electron charges. Therefore, the micro-particles interact strongly with each other, and complex plasmas are an example for strongly coupled plasma in which the interaction energy between the plasma particles (or at least of one component) is larger than the kinetic energy of the particles.

SCIENTIFIC **OBJECTIVES**

The main interest lies in the investigation of the liquid phase and flow phenomena of complex plasmas for which PK-4 is especially suited.

1. Microscopic properties of complex plasmas: charging of the particles, the external forces on the particles (e.g. ion drag), the fundamental interactions between the particles, agglomeration, and particle growth.
2. Macroscopic properties of complex plasmas: hydrodynamics (e.g. viscosity), thermodynamics (e.g. equation of state), and non-equilibriums aspects (e.g. lane formation, self-organisation) of complex plasmas.
3. Generic properties of classical many-body systems: Complex plasmas are ideal model systems for studying various problems of strongly coupled many-body systems in solid state physics, fluid physics, plasma physics, nano-technology and even nuclear physics because complex plasmas can easily be produced and observed in real time on the microscopic and kinetic level.

NEED OF SPACE

Due to the strong influence of gravity on the micro-particles, most experiments on complex plasmas are strongly distorted or even impossible on earth and require microgravity conditions. Hence dynamical processes can be investigated on the level of single particles which is not possible in most systems. Therefore, new insights in the dynamics of those processes can be provided. Typical examples are crystallization and melting, phonons in plasma crystals, dust waves, Mach cones, nozzles, turbulence, and nano-fluidics.

RETURN TO EARTH

PK-4 scientific recordings of particle motion, wave propagation, and phase-transition behaviour in complex plasmas are analysed to better understand fundamental physical processes. Beyond basic research, PK-4 results contribute directly to applied sciences. Knowledge gained from PK-4's plasma manipulation and control has already enabled the development of practical plasma-based technologies on Earth, including room-temperature plasma devices for disinfecting wounds.

Environmental Science & Radiation Physics

ENVIRONMENTAL SCIENCE & RADIATION PHYSICS

DOSIS 3D

Multi-Needle Langmuir Probe

DOSIS 3D

SCIENTIFIC **BACKGROUND**

- Radiation is one of the main health detriment for long-duration human space missions. Radiation levels far exceed the ones encountered on Earth for occupational radiation workers. Accurate knowledge of the physical characteristics of the space radiation field in dependence of the solar activity, the orbit parameters and the different shielding configurations of the ISS is needed.
- The aim of the DOSIS 3D experiment is to measure radiation field parameters such as absorbed dose, particle fluence and Linear Energy Transfer) LET spectra as well as dose equivalent at different locations inside the International Space Station ISS, using passive and active radiation measurement devices. The collected set of data will be used for the refinement of radiation transport calculations through realistic shielding distributions of the ISS and will provide baseline data for experiments conducted in the ISS, as well as (and in particular for) assessing the radiation exposure of the astronauts working on board.

SCIENTIFIC **OBJECTIVES**

The main objective of the DOSIS 3D experiment is the determination of the absorbed dose and the dose equivalent using a variety of active and passive radiation detector devices distributed throughout the ISS. To achieve the dose distribution in three dimensions (3D), DOSIS 3D aims to combine data acquired by ESA with complementary data from radiation detectors operated by JAXA, NASA and ROSCOSMOS/IMBP. Based on the combined output from passive and active detectors, an interactive database is under construction to serve the scientific community, holding essential information for the application of radiation protection standards for manned spaceflight and for any radiation sensitive experiment in space. A first version of the database designed for educational purposes is available within the so-called 'DOSIS Data Viewer'.

An additional scientific objective of the DOSIS 3D experiment is to determine the impact of ionizing radiation in LEO on plant seeds.

NEED OF SPACE

The radiation environment in space cannot faithfully be mimicked on ground, and definitely not including the complex shielding characteristics of the ISS. Due to its dynamics, is it not possible to make accurate predictions based on radiation data that have already been acquired on board of the ISS. The only approach to obtain reliable information is to permanently monitor the radiation environment in situ, on board of the ISS in different locations.

RETURN TO EARTH

Recovered passive detectors and Biostacks are analysed on the ground to determine absorbed dose, LET and charge spectra, neutron contributions, and biological effects in seeds. These data improve radiation models and transport calculations using real ISS shielding conditions. They support astronaut radiation protection, provide environmental dosimetry for ISS experiments, and form a long-term reference dataset. The results also feed an online international database that strengthens prediction tools for LEO and future deep-space missions.

m-NLP

esa

TECHNICAL **BACKGROUND**

- The outermost part of the Earth's atmosphere above about 80 km altitude consists of a mixture of electrically neutral and electrically charged particles. Generally, we call this mixture plasma, and specifically, this high-altitude region of the atmosphere we call the ionosphere. Due to its composition, the ionosphere displays nontrivial dynamics and is subject to electromagnetic forces.
- Plasma density variations on smaller scales (< 100 m) cause degradation of trans-ionospheric radio signals such as those used in modern global navigation satellite systems (GNSS). All aspects of Earth's near space environment that adversely affect technological systems have been grouped under the label "space weather effects". To be able to understand and ultimately predict GNSS signal degradation in a way we currently predict rain or air temperature, we are in desperate need of measurements that resolve these small-scale plasma density variations.

SCIENTIFIC **OBJECTIVES**

- The m-NLP (Multi Needle Langmuir Probe) is an instrument designed for monitoring ionospheric plasma densities, and hence it must be deployed in the ionosphere in order to fulfil its purpose.
- The experimental setup will be based on the boom system developed by the University of Oslo (UiO) for EIDEL with the GSTP contract 4000109398/13/NL/AK and the low-cost readout electronics developed by UiO for the BRIK-II CubeSat in combination with interface electronics for Bartolomeo compatibility which will be adapted from already existing EIDEL technology and products and incorporated into the m-NLP payload.
- The instrument will accommodate 3 cassettes with 2 probes each with a radial spacing of about 40 cm facing ISS ram direction.
- The m-NLP is a electron density and plasma potential instrument and its electronic board can interface up to 4 probes each. The EIDEL Remote Interface Unit (ERIU) is used to interface the instrument to Bartolomeo and to be able to accommodate a custom number of instruments up to 4.

NEED OF SPACE

Because m-NLP must directly sample ionospheric plasma, deployment in space is essential; Earth-based facilities cannot replicate ionospheric conditions. The ISS, orbiting near the peak plasma density at ~400 km altitude, provides an ideal platform due to its unique combination of orbital coverage, local-time sampling, high downlink bandwidth, and continuous power availability. These factors enable long-duration, high-resolution plasma density measurements and repeated sampling of geophysically critical local-time sectors needed to capture phenomena such as Sub-Auroral Ion Drifts (SAIDs) and Sub-Auroral Polarization Stream (SAPS).

RETURN TO EARTH

Returned probe tips are examined to verify instrument performance and improve calibration. The collected data—electron density, floating potential, and system health parameters—enhance models used to predict ionospheric disturbances affecting GNSS and communication systems. These results strengthen space-weather forecasting, support future small-satellite missions using m-NLP technology, and contribute to long-term datasets for understanding ionospheric behaviour across the solar cycle.

Fundamental Science

FUNDAMENTAL SCIENCE

ASIM (Ext. Payload)
ACES (Ext. Payload)

ASIM – External Payload

SCIENTIFIC **BACKGROUND**

- The Atmosphere-Space Interactions Monitor (ASIM) is an Earth observation facility located on the external payload platform on the Columbus module. The aim is the study of severe thunderstorms and their role in the Earth's atmosphere and climate. ASIM can measure high altitude electrical discharges in the stratosphere and mesosphere and intra-cloud lightening in the troposphere, gravity waves and the creation of high-altitude clouds.
- Also, the newly discovered "Transient Luminous Events" (TLEs) and "Terrestrial Gamma-ray Flashes" (TGFs). The observations of TLEs are of “sprites”, a manifestation of electrical break-down in the mesosphere, the “blue jet”, a discharge propagating upwards into the stratosphere from cloud tops, and the “elve”, a concentric ring of emissions from neutrals excited by a lightning electromagnetic pulse at the bottom edge of ionosphere. TGFs are from the atmosphere above thunderstorms, generally of duration shorter than 1 msec with energies from ~100 keV to tens of MeV.

SCIENTIFIC **OBJECTIVES**

ASIM aims to produce the most comprehensive global survey of TLEs and TGFs and to study the physics behind them, including how they relate to lightning, gravity-wave propagation, and high-altitude cloud formation. It also investigates how thunderstorms perturb the ionosphere and radiation belts, and contributes to the characterization of meteors, auroral emissions, and lightning-driven particle precipitation.

In addition, ASIM supports broader Earth-observation objectives by monitoring dust storms, pollutants from mega-cities, volcanic plumes, forest fires, and hurricane activity, particularly their influence on atmospheric electrification. Its multi-wavelength observing capability enables cross-disciplinary research connecting atmospheric physics, space weather, and climate processes.

NEED OF SPACE

ASIM requires a space-based platform to observe optical, X-ray, and gamma-ray emissions from thunderstorms globally—phenomena too faint and fast to detect from the ground. The ISS provides continuous global coverage, frequent nighttime passes, and unobstructed nadir viewing, enabling simultaneous multi-band measurements and coordinated triggering between optical and high-energy sensors.

RETURN TO EARTH

After downlink, ASIM optical, photometer, and high-energy data are calibrated at the ASIM Science Data Center and used to study thunderstorm electrodynamics, atmospheric coupling, and global TLE/TGF occurrence. The results support climate-related research, improve understanding of ionospheric and radiation-belt processes, and provide validation for future missions such as MTG-LI and TARANIS, enhancing global monitoring of lightning-related atmospheric phenomena.

ACES – External Payload

SCIENTIFIC **BACKGROUND**

- ACES (Atomic Clock Ensemble in Space) is an ESA fundamental physics mission operating a new generation of ultra-stable atomic clocks—PHARAO (cold-atom cesium clock) and SHM (Space Hydrogen Maser)—in the microgravity environment of the ISS Columbus External Payload Facility. The space-based environment minimizes gravity-related perturbations and enables optimal clock performance, producing an exceptionally stable 100 MHz reference distributed to Earth via microwave and optical links.
- The mission's design allows both space-to-ground and ground-to-ground clock comparisons using a global network of MWL and ELT terminals tied to national metrology institutes. This enables high-precision tests of general relativity, gravitational redshift, variations of fundamental constants, and geodesy applications that are not achievable with terrestrial setups alone

SCIENTIFIC **OBJECTIVES**

Primary objectives are to demonstrate the performance of space atomic clocks and high-precision time/frequency transfer links, compare ground clocks through the ACES Microwave Link, and perform fundamental physics experiments. These include testing general relativity, searching for variations in physical constants, and validating the ACES space time-scale.

Secondary objectives include long-term SHM stability assessment, ground-clock synchronization, contributions to the international atomic time scale, relativistic geodesy using MWL and the ELT optical link, and integration with GNSS-based comparison networks. These combined capabilities allow ACES to address a wide scientific portfolio in time metrology and fundamental physics.

NEED OF SPACE

Operating ACES in orbit is essential to achieve the clock stability and accuracy required for its scientific goals. Microgravity eliminates disturbances inherent to ground-based clocks, stabilizing cold-atom operation and enabling the combined PHARAO–SHM time reference. From the ISS, ACES also attains global visibility to multiple ground terminals, allowing precise, repeated space-to-ground and intercontinental ground-to-ground time transfer that cannot be performed from any Earth-based platform.

RETURN TO EARTH

ACES delivers space-to-ground time-transfer and clock-comparison data that, once processed and archived at CADMOS, support high-precision relativity tests, improved global timekeeping, GNSS enhancements, and relativistic geodesy. The results strengthen international time standards and advance next-generation timing technologies with applications in navigation, telecommunications, and Earth-science research.

Fluid physics

FLUID PHYSICS

FSL – Soft Matter Dynamics
Heat Transfer Host 2

Soft Matter Dynamics - FSL

SCIENTIFIC **BACKGROUND**

- Foams and emulsions can be formed and stabilized only in the presence of well selected additives, such as surfactants, polymers, proteins and their mixtures. By the addition of surfactants or polymers, the properties of the particles' surface can be modified, and in turn the free energy of their attachment to a liquid interface. This will allow us to tune the stabilizing or destabilizing action of a particle/surfactant system, depending on the demands of a respective application.
- The work proposed in the Particle STAbilised Emulsions and Foams (PASTA) project follows the line from characterizing the surface properties of particles via a complex analysis of the properties of layers at liquid/gas and liquid/liquid interfaces to studying the behaviour of liquid films and finally to model real foams and emulsions. The work comprises the application of available knowledge to the preparation and characterization of particle stabilized emulsions, produced by adapting to the SOFT MATTER DYNAMICS instrument.

SCIENTIFIC **OBJECTIVES**

The scientific state of the art provides only general principles for the present subject and many questions are yet open. Understanding of special systems has been established but generic mechanisms do not exist yet. Therefore, taking advantage of the existing expertise of the participating teams significant progress will be achieved in this old and simultaneously very new scientific and technological field. This will also cover the further improvement of insight into the generic mechanisms of foam and emulsion stabilization.

The experiments will address the following topics:

1. Evaluate the characteristic time for the droplet coalescence as a function of the formulation
2. Identify and investigate specific dynamic regimes for droplets dynamics (for example Brownian vs. Capillary driven) during emulsion destabilization.
3. Test and develop models for emulsion stability/destabilization prognosis.

NEED OF SPACE

Gravity strongly distorts the intrinsic behaviour of foams, granular matter, and emulsions by inducing drainage, sedimentation, and creaming—processes that mask the internal dynamics the experiment aims to study. Microgravity eliminates these effects, enabling observation of wet-foam coarsening without drainage, granular cooling without sedimentation, and emulsion destabilization driven solely by coalescence. Long-duration, low-disturbance microgravity is essential to produce homogeneous conditions, collect statistically robust datasets, and compare results directly with theoretical models that assume the absence of gravitational body forces.

RETURN TO EARTH

Foam and granular sample cells are returned to Earth to verify liquid fractions, check for leakage, and support interpretation of the optical-diagnostics data. For particle-laden emulsions, only the data—correlation functions, images, and housekeeping parameters—are downlinked for ground analysis. Together, these datasets enable extraction of coarsening, rearrangement, granular-dynamics, and coalescence parameters needed to validate the scientific models.

Heat Transfer Host-2

SCIENTIFIC **BACKGROUND**

- The Heat Transfer Host 2 (HTH-2) facility provides the controlled thermal environment, heating capability, diagnostics access, and operational infrastructure required to accommodate inserts like Condensations on Fin (CoF) and Marangoni in Films (MiF) and enable high-precision heat-transfer experiments in microgravity.
- While the CoF experiment is currently ongoing (started in i73 across i74) the MiF insert is planned to be uploaded in Spring 2026.
- Previous laboratory investigations and simplified microgravity tests have demonstrated that substrate-induced Marangoni effects can enhance mixing, alter evaporation rates, and generate intricate interface shapes. However, these earlier studies were often restricted to pure liquids, simple geometries, or two-dimensional configurations. MiF extends this work by exploring more complex substrate designs, additional liquids and mixtures, and coupled phenomena such as chemical patterning or nanoparticle self-assembly, providing a comprehensive dataset to refine theories of interfacial transport and instability formation.

SCIENTIFIC **OBJECTIVES**

The **CoF** experiment aims at investigating the liquid film thickness distribution, the average and local heat transfer coefficient and the effect ofsurface roughness during film-wise condensation on an axisymmetric cold fin. Themain experiment goal is to evaluate the heat transfer coefficient along a curvilinear finon top of which condensation takes place. Potential applications of this investigationinclude film evaporation in cooling applications, distillation, powder production,coating and printing.

MiF aims to characterise Marangoni convection, evaporation behaviour, and pattern formation in thin liquid films on substrates with tailored structural, thermal, or chemical modifications. It will measure key parameters—film thickness evolution, interface deformation and rupture, heat transport, and vapour-phase concentration—to reveal how substrate properties and surface-tension gradients govern film dynamics.

By varying substrate geometry, liquid type, and ambient vapour conditions, the experiment will determine their influence on flow stability, evaporation rate, and heat-transfer performance.

NEED OF SPACE

Microgravity is indispensable for isolating thermocapillary forces from gravity-driven convection, buoyancy-induced vapour stratification, and hydrostatic stabilization of the interface. These gravity-dependent effects significantly distort film-rupture behaviour, vapour distribution, and the evolution of complex topological patterns on Earth. Only long-duration, low-disturbance microgravity aboard the ISS enables accurate observation of intrinsic Marangoni convection, evaporation-limited dynamics, and pattern-formation mechanisms over the extended timescales required.

RETURN TO EARTH

The resulting datasets will underpin strategies to control film hydrodynamics via substrate engineering and provide validated benchmarks for theoretical and numerical models of Marangoni-driven phenomena. They are essential for comparing results to ground-based reference experiments.

Tech Demo

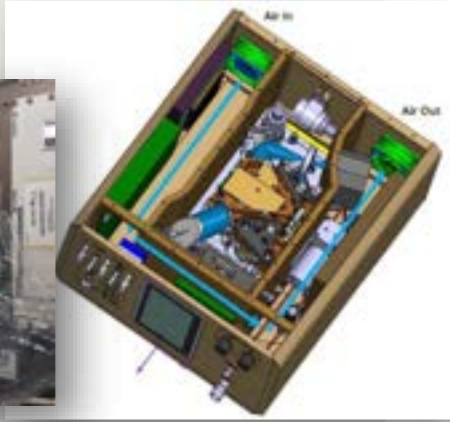
TECHNOLOGY DEMONSTRATIONS

Anita-2
E4D
Metal-3D Printer

Anita-2 – Docking vehicles

TECHNICAL **BACKGROUND**

- The Analyzing Interferometer for Ambient Air-2 (ANITA-2) is a compact gas analyser which can analyse and quantify 33 trace contaminants in the atmosphere aboard the International Space Station (ISS) automatically. ANITA-2 can also detect the presence of unknown substances which can be evaluated later on the ground. This investigation aims to demonstrate the capabilities of the device and provide a resource for on-board atmospheric analysis for use by ISS crew.



SCIENTIFIC **OBJECTIVES**

Monitor the concentration of a series of compounds for a minimum period of three months. The lifetime of ANITA-2 is at least 8000h, i.e. one-year continuous operation.

The long-term perspectives for ANITA2 are:

- Demonstrate the robustness of the improved technology at the ISS in a representative operational environment: ISS as a test bed for technologies for future exploration.
- Develop small European niches in the area of life support based on state-of-the-art technology.
- Reiterate the NASA interest in the European technology for air contamination monitoring (no match in the US).
- For ESA to include ANITA2 technology in future cooperation with the IPs for long duration human exploration activities either as recurring items or improved ones.

NEED OF SPACE

Atmosphere monitoring is important in closed environments. It is an essential function for human exploration systems. The ANITA-2 technology demonstration is part of the European Space Agency's (ESA) preparation for future human space exploration missions. Autonomous, automatic air monitoring is a must for long term space missions. ANITA-2 is advantageous for long term exploration missions as it does not require any consumables. Its operation on ISS is necessary as a technology demonstrator before scaling up to other platforms.

RETURN TO EARTH

ANITA-2 technology can be applied in environmental monitoring, and in the monitoring of air quality in closed environments, like for example, clean room facilities, hospitals, submarines and other enclosed spaces.

E4D

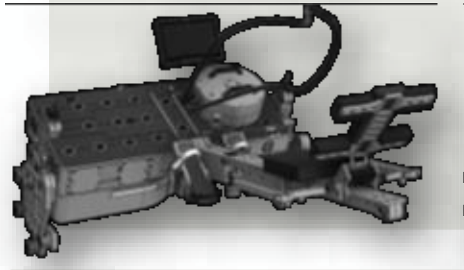
TECHNICAL **BACKGROUND**

- In-flight exercise is a critical component of human spaceflight, mandated for long-duration ISS missions to prevent physiological deconditioning. The European Enhanced Exploration Exercise Device (E4D)—developed alongside NASA's Vibration Isolation System (VIS)—was conceived to expand the ISS exercise capabilities by offering novel exercise modes and a compact, modular, multi-modal device suitable for future exploration missions where mass and volume are constrained.
- The ISS technology demonstration aims to evaluate the feasibility, safety, and user acceptance of new exercise modalities that have never been performed in microgravity, while systematically commissioning both new and "classic" exercise modes. The effort supports raising E4D's Technology Readiness Level toward becoming a nominal ISS countermeasure device and a precursor for exercise systems on spacecraft such as Lunar Gateway and Orion.

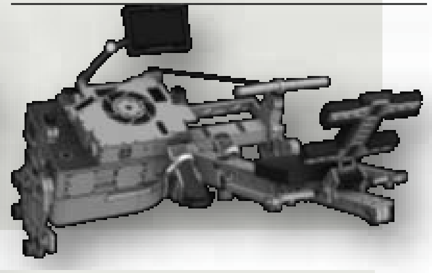
SCIENTIFIC **OBJECTIVES**

The primary objective is to collect engineering data and qualitative feedback from multiple crew members to determine whether E4D can serve as an acceptable single multi-modal countermeasure device, capable of providing the necessary resistive, aerobic, and movement-quality requirements currently covered by multiple ISS exercise systems. This includes validating load/watt outputs, range of motion, movement quality, comfort, and user acceptance.

Additional objectives include assessing the feasibility and movement quality of all E4D exercise modes; implementing a graduated commissioning process to reach Technology Readiness Level 9 (TRL-9); understanding reliability and maintainability in operational conditions; and evaluating E4D's suitability for deep-space vehicles. Collected operational knowledge will guide hardware refinements for exploration-class missions.



E4D in rope pulling configuration



E4D in Rowing configuration

NEED OF SPACE

E4D must be tested in microgravity because its design relies on operation together with a Vibration Isolation System, and its functional behaviour cannot be reproduced in gravity. Only the ISS offers extended microgravity exposure to validate technical performance, user experience, vibration behaviour, and feasibility of exercise modes. This testing is necessary to optimize E4D for use as a countermeasure system in deep-space habitats, where conventional ISS-class hardware cannot be accommodated due to strict mass and volume constraints.

RETURN TO EARTH

E4D hardware is not planned for return to Earth after the technology demonstration. Only specific components—such as the motion capture system—may be returned if a failure investigation requires it. At the end of the activity, ESA and NASA will determine whether to relocate E4D within ISS, transfer subsystems for continued use, repurpose components for follow-on studies, or dispose of the hardware.

Metal 3D Printer

TECHNICAL **BACKGROUND**

- Additive Manufacturing (AM - also referred to as 3D printing) is a fast evolving and very competitive technology domain which is revolutionising the approach to conceiving and manufacturing parts. When considering space exploration missions, such a technology will allow realisation of in-orbit manufacturing and repair, as well as new designs, tailored to a micro/reduced gravity environment (i.e. without launch loads). This may entail a major departure from how design, pre-flight qualification and testing is performed today for space hardware.
- While initiatives have recently materialised to install and operate 3D printers on the ISS, these are currently limited to using polymers. As these have limited use for functional engineering parts, ESA is currently assessing AM technologies using other materials, such as engineering plastics.
- A logical evolution is to expand the manufacturing capabilities to metallic materials processing and printing in Space.

SCIENTIFIC **OBJECTIVES**

The Metal 3D hardware consists of a sealed box containing the Additive Manufacturing machine, and an

electronic box. The integrated sealed box and electronics box shall be accommodated in the EDR2 FM in

ISS/Columbus. The mission aims to:

- develop a Metal 3D Printer Technology Demonstrator, based on Additive Manufacturing, that will demonstrate the capabilities of this technology to perform metal deposition in 3D under sustained microgravity conditions and manufacture test specimens.
- demonstrate the complete chain of the in-orbit manufacturing process, including handling by crew, supported by ground operator.
- demonstrate the concept of in-situ part manufacturing and repair.

Sealed Printer

NEED OF SPACE

Whereas 3D printing is an established technology on Earth, the use in spaceflight is still in an early stage. Metal printing in space brings challenges, such as the printing process and material composition with lack of gravity, as well as operational constraints (as opposed to 3D printing on Earth). In order to understand the impact of microgravity on the printing process and the operations of a Metal 3D Printer within the constraints of a space habitat, operation in a space environment is needed.

RETURN TO EARTH

Production samples will be returned to Earth for in-depth analyses, including mechanical and microstructural evaluation. Lessons learned from 3D printing in space conditions will be used for the development and improvement of Metal 3D Printing by additive manufacturing on Earth.

CNES Contributions

CNES CONTRIBUTIONS
ADENOT MISSION

* CNES Bone Ultrasonography (G)
* CNES ECHOFinder2
* CNES Eurosuit
* CNES MATISS-4
* CNES Food processor
* CNES Multi Imager System (Inc. 75)
* CNES PhysioTool

Bone Ultrasonography – Ground only

SCIENTIFIC BACKGROUND

- Bone perfusion plays a key role in maintaining bone metabolism, yet it is difficult to measure in humans. A newly developed intraosseous ultrasound technique can visualize internal bone structure and quantify pulsatile blood flow—capabilities not possible with traditional ultrasound. This advanced system has been validated in volunteers and now enables assessment of bone quality (via ultrasound wave speed) and bone perfusion using matrix-array transducers and programmable hardware.
- Spaceflight causes rapid bone loss and vascular alterations, especially in the lower limbs. Microgravity reduces mechanical loading and impairs vascular function, potentially affecting blood flow inside bones—something never measured in astronauts. Combining this new ultrasound method with High-Resolution Peripheral Quantitative Computed Tomography (HR-pQCT) / Peripheral Quantitative Computed Tomography (pQCT) provides a unique opportunity to evaluate both bone structure and perfusion changes associated with weightlessness.

SCIENTIFIC OBJECTIVES

The experiment aims to evaluate structural and vascular changes in the tibia through innovative pre- and post-flight ultrasound, measuring ultrasound wave speed as an index of bone quality and pulsatile blood flow during arterial occlusion to assess perfusion and vascular reactivity. Because the tibia is one of the bones most affected by spaceflight unloading, these measures sensitively capture spaceflight-related bone deterioration. A second aim is to validate ultrasound-derived bone structural metrics by comparing them with HR-pQCT or pQCT measures of bone density, cortical thickness, porosity, and trabecular microarchitecture. By correlating ultrasound changes with CT-based findings across pre-/post-flight sessions, the study evaluates whether the new ultrasound technique can become a practical and flight-compatible tool for monitoring bone health on future missions. Two core goals guide the protocol:

Objective 1 — Vascular: assess tibial vascular reactivity via ultrasound perfusion measurements.

Objective 2 — Structural: compare ultrasound-based bone structural indices with HR-pQCT/pQCT outcomes.

NEED OF SPACE

Microgravity causes accelerated bone loss and vascular changes that cannot be reproduced on Earth. Determining whether reduced blood flow inside bone contributes to this deterioration requires measurements directly linked to spaceflight. Because these structural and vascular effects occur only in microgravity, pre- and post-flight assessments are essential to isolate spaceflight-induced changes. The new ultrasound technology also provides the first opportunity to assess intraosseous blood flow and may eventually support in-flight bone monitoring. Conducting the experiment around an ISS mission is therefore critical to understand bone demineralization mechanisms and validate this tool for future exploration missions.

RETURN TO EARTH

Early post-flight sessions (R+2/3 and R+10) capture rapid changes in bone perfusion and structure before readaptation begins, while later sessions track longer-term recovery. This schedule ensures a complete picture of acute effects and long-term remodeling following spaceflight

ECHOFinder-2

SCIENTIFIC **BACKGROUND**

- Ultrasound is the only medical imaging modality currently available on the ISS, enabling non-invasive, real-time monitoring without radiation. Two-thirds of medical conditions relevant to spaceflight can be assessed with ultrasound, making it essential for crew health management. Today, high-quality imaging on orbit relies on ground-based specialists who tele-operate scans, but increasing exploration distances will introduce communication delays that make real-time telemedicine impossible.
- EchoFinder-2 provides a new autonomous solution combining augmented reality (AR) and artificial intelligence (AI). During pre-flight Baseline Data Collection, an expert saves the exact 3D probe position and orientation for each organ. In-flight, astronauts reproduce these positions using AR guidance, while the AI automatically detects organ views and saves clinically usable images. This approach enables non-expert crew to perform sonography independently—a critical capability for deep-space missions

SCIENTIFIC **OBJECTIVES**

The primary objective is to demonstrate that astronauts can acquire high-quality ultrasound images without any real-time guidance from Earth. EchoFinder-2 evaluates whether AR-assisted probe positioning and AI-based organ detection function reliably in microgravity, allowing crew members with no sonography background to capture clinically valid images.

A second objective is to validate the robustness and minimal-hardware approach of EchoFinder-2—using only a tablet, QR-code tracking, and the ISS ECHO ultrasound system. The study also assesses how microgravity-induced organ shifts affect the accuracy of pre-recorded probe positions, informing future Earth-independent medical operations.

Figure 1: One QR Cube is placed on the ultrasound probe and one on the chest of the subject using a bespoke chest support. The EchoFinder software tracks the QR Cube to save the position and orientation of the ultrasound probe in relation to the reference QR Cube on the chest.

NEED OF SPACE

Long-duration spaceflight causes anatomical shifts and physiological changes (e.g., organ displacement, fluid redistribution) not observable on Earth. These differences must be quantified to ensure EchoFinder-2 can deliver reliable probe guidance under true exploration conditions. Moreover, as tele-operation becomes impossible on missions to the Moon or Mars, validating an autonomous, crew-operated ultrasound system in microgravity is essential for future medical support and science imaging.

RETURN TO EARTH

EchoFinder-2 does not include post-flight sessions; all scientific value depends on comparing expert-acquired pre-flight probe positions with astronaut-acquired in-flight images. The BDC session establishes individualized anatomical references, while in-flight runs reveal how microgravity affects both anatomy and operator performance. The comparison between pre-flight and in-flight data is therefore key to assessing the system's reliability for deep-space medical autonomy.

EuroSuit

SCIENTIFIC **BACKGROUND**

- Spacesuits, together with launch systems and life-support infrastructure, are core elements of human spaceflight capability. An Intra-Vehicular Activity (IVA) suit is worn during critical mission phases such as launch, docking, and landing, providing protection in case of fire or depressurization while still allowing the astronaut to operate spacecraft systems effectively. A first European IVA suit concept was developed in 2023–2024, with ergonomics as the primary focus, including the requirement that the suit must be donnable unassisted within two minutes.
- As Europe advances toward autonomous crewed access to space, validating its own IVA suit is a necessary step toward sovereignty and future independent spaceflight. Before finalizing the flight-ready suit, an intermediate model made with materials exhibiting similar behavioUr (flexibility, elasticity, strength) is required for evaluation in microgravity. Testing this prototype on the ISS allows realistic assessment of donning, mobility, comfort, and operational usability before the full suit design is locked for ground completion in 2027.

SCIENTIFIC **OBJECTIVES**

The first objective is to validate whether astronauts can don the EuroSuit autonomously within the required two-minute limit in microgravity. This includes donning Layer 0, followed by donning the full suit (Layer 1 plus helmet), and verifying that mobility and closure mechanisms function correctly in weightlessness. A complete operational sequence—donning, performing movement tasks, manipulating objects, and doffing—is video-recorded to support detailed analysis by the design team.

A second objective is to collect astronaut feedback through structured questionnaires, capturing their assessment of ergonomics, comfort, ease of movement, ease of donning/doffing, and usability of gloves, helmet, and integrated features. User feedback, combined with observed performance trends across multiple sessions, will feed directly into refining the European IVA suit design toward a future flight-qualified model.

Figure 1 - Euro Suit Layer 1 front (on the left) and back (on the right) side

NEED OF SPACE

The suit must be validated in microgravity because donning and mobility requirements differ significantly from ground conditions. Only in weightlessness can designers confirm that the ergonomics, material behavior, and donning sequence truly meet operational constraints. The ISS therefore provides the only environment where the two-minute autonomous-donning criterion can be realistically tested.

RETURN TO EARTH

Although EuroSuit requires no post-flight data collection, all design conclusions rely on comparing ISS session performance and astronaut feedback with ground expectations. Microgravity-specific challenges—such as floating limbs, reduced friction, and different movement mechanics—will be identified from the recorded sessions and questionnaires. This evidence will inform Earth-based redesign efforts and guide development of the final European IVA suit to be completed by 2027.

MATISS-4

SCIENTIFIC **BACKGROUND**

- Matiss (Microbial Aerosol Tethering on Innovative Surfaces in the international Space Station) is a family of experiments that started in 2015, in the context of the first space mission of Thomas Pesquet, Proxima. Matiss initial versions aimed to demonstrate that surfaces with hydrophobic properties could be a possible answer applicable at spacecraft scale by limit surface wettability and reduce contamination contact area.
- MATISS-4 extends this effort by exploring new materials and analytical approaches to improve spacecraft hygiene and mitigate risks to crew health and equipment performance. Existing sample holders allowed only morphological analyses via light microscopy, limiting identification of the nature and composition of deposited particles. MATISS-4 introduces new internally redesigned holders enabling deeper post-flight investigations using nano-XRF and Raman spectroscopy. This upgrade supports the development of next-generation antimicrobial surfaces for spacecraft, contributes to European cooperative R&D efforts, and strengthens cross-sector innovation for contamination control technologies.

SCIENTIFIC **OBJECTIVES**

MATISS-4 aims to evaluate new antimicrobial and hydrophobic surface coatings by exposing them to the ISS cabin environment over extended periods (8–16 months). By focusing on droplets carrying individual microorganisms, the study investigates how modified surfaces influence droplet adhesion, particle settlement, and contamination patterns in microgravity. The experiment uses upgraded sample holders incorporating diamond and quartz windows to enable high-resolution compositional analysis.

The objectives include:

• Proof of concept for the new surface-testing prototype adapted for ISS use.

• Demonstration that nano-XRF imaging can resolve single microbial particles collected in-orbit.

• Development of correlative imaging, combining visible-light microscopy with nano-XRF for systematic particle identification.

• Comprehensive post-flight analysis of microbial contamination across surfaces exposed for different durations, informing future antimicrobial surface design for exploration missions.

NEED OF SPACE

Microgravity fundamentally alters how droplets, aerosols, and microorganisms behave, making ground-based simulations insufficient to capture real contamination dynamics. Airflow patterns, droplet transport, particle adhesion, and environmental factors such as radiation and confined-habitat circulation differ significantly from Earth conditions. MATISS-4 therefore requires in-orbit exposure to gather authentic, non-reproducible data essential for validating antimicrobial surface performance in spacecraft environments.

RETURN TO EARTH

Understanding contamination patterns relies entirely on post-flight laboratory analysis. After exposure, each holder must be uninstalled, downloaded within 30 days, and transferred to the PI's laboratory within 10 days to prevent alteration of samples by terrestrial conditions. Returned holders are then analysed using nano-XRF and Raman spectroscopy, allowing researchers to identify microbial particles, map contamination profiles, and compare the effectiveness of different coatings. This Earth-based phase is critical to validating MATISS-4 hypotheses and guiding future antimicrobial surface development.

Food Processor

esa

SCIENTIFIC **BACKGROUND**

- The Food Processor is part of CNES's Advanced System for Space Food (ASSF) project, which aims to develop autonomous, safe, and nutritionally optimized food-preparation capabilities for future exploration missions. Long-duration crews will require equipment able to manage food stocks, process fresh or shelf-stable ingredients, and adapt recipes to individual nutritional needs. The ISS provides a unique platform to validate such technologies, which must function reliably under microgravity constraints such as fluid behaviour, workspace restrictions, and hygiene requirements.
- Beyond nutrition, food is central to crew well-being, providing sensory pleasure, psychological comfort, and social interaction. Microgravity often alters taste and smell, and packaged ISS foods can become repetitive or lose quality over long storage. Future missions—especially to Mars—will require more diversified, fresh, and appealing menus while maintaining strict food safety standards. The Food Processor contributes to this strategic evolution by demonstrating that cooking processes such as rehydration, beating, mixing, and ingredient preparation can be performed safely and effectively in orbit.

SCIENTIFIC **OBJECTIVES**

The first demonstration (1st Demo) aimed to validate the Food Processor prototype by executing a complete recipe, chocolate mousse, using three primary cooking functions: rehydration, beating egg whites, and controlled mixing. The demonstration assessed whether textures, foams, ingredient incorporation, and intermediate steps could be achieved under microgravity, and whether the equipment (body, bowls, tools) performed as intended. Astronaut feedback on texture, taste, homogeneity, and usability was collected via the EveryWear app.

The second demonstration (2nd Demo) evaluates whether the Food Processor can prepare recipes using ingredients that could be grown on board, such as eggplant, legumes, and herbs. The selected recipe, Mediterranean Duo, tests delicate mixing with plant-based ingredients and assesses whether fresh, space-grown components can be incorporated safely and appetizingly. The activity also aims to identify design improvements for the future ASSF system that will support autonomous cooking on deep-space missions.

NEED OF SPACE

The Food Processor must be validated in real microgravity because cooking processes such as mixing, beating, rehydration, and ingredient flow behave fundamentally differently in weightlessness. The equipment must ensure safety—avoiding floating droplets or debris—while enabling astronauts to prepare fresh, nutritious meals and reduce reliance on resupply. Demonstrating the feasibility of cooking operations in orbit is essential for future habitats where food autonomy and on-site production will be critical.

RETURN TO EARTH

The Food Processor demonstrations rely primarily on crew feedback, imagery, and on-board observations, with no hardware returned to Earth. Analysis on Earth focuses on the downlinked photos, video, and reported sensory evaluations collected through the EveryWear app. These results inform the refinement of future ASSF prototypes and guide the development of food-processing technologies for exploration missions.

Multi Imager System

SCIENTIFIC **BACKGROUND**

- Surface biocontamination poses significant risks in spacecraft, where microorganisms grow more readily under microgravity and can form biofilms that damage equipment, degrade materials, and threaten crew health. Past incidents on MIR demonstrated how biofilms can corrode structural elements and electrical systems, while ISS operations require labor-intensive cleaning that still leaves difficult-to-reach areas untreated.
- Existing terrestrial techniques—multispectral imaging and point spectroscopy—have proven effective at detecting organic residues, microorganisms, and early-stage biofilms. Building on earlier CNES Matiss activities, the Multi Imager System aims to bring such detection capabilities directly onboard the ISS to enable early identification of contamination, prevent microbial proliferation, and reduce wasteful, time-consuming manual cleaning.

SCIENTIFIC **OBJECTIVES**

The experiment seeks to detect organic traces, particles, abnormal deposits, and early biofilm formation across representative ISS surfaces using multispectral reflectance imaging (420–1000 nm), fluorescence imaging (365 nm excitation), and point spectroscopy. These data allow identification of contamination signatures, including differentiating between types of microorganisms based on spectral profiles.

A secondary objective is to assess how contamination evolves over time, including before and after partial cleaning, and to validate the operational usability of the instrument in microgravity. This includes evaluating measurement quality, ergonomics, acquisition timelines, and the instrument's ability to guide more targeted and efficient cleaning processes.

NEED OF SPACE

True microgravity is essential for studying biocontamination because organic deposits, microbial growth, and biofilm formation behave differently in weightlessness. The ISS provides the only operational environment with unique materials, confined spaces, airflow patterns, and a long-established microbial ecosystem needed to validate detection performance, ergonomics, data acquisition, and cleaning-support procedures. Key operational factors—such as illumination, camera stability, and contaminant behaviour—can only be assessed in orbit.

RETURN TO EARTH

This investigation will enhance biocontamination detection and characterization for terrestrial applications such as food production, pharmaceuticals, medical settings, and industrial maintenance. Its contactless, light-independent multispectral approach is especially useful where lighting cannot be altered or surfaces are hard to access. Insights from observing contamination in space will also refine monitoring standards and cleaning strategies on Earth.

PhysioTool

SCIENTIFIC **BACKGROUND**

- PhysioTool builds on the need to understand how the absence of gravity leads to systemic physiological deconditioning. Microgravity affects cardiovascular regulation, muscular activity, respiratory patterns, brain perfusion, and neuro-sensory and cognitive functions in ways that are only partially mitigated by existing countermeasures. Because these systems interact, an integrative multiparameter dataset is required to understand how deconditioning unfolds and affects astronaut health.
- Recent advances in ambulatory physiological monitoring now enable continuous, spontaneous 24-hour measurements during real astronaut activities, greatly expanding previous capabilities. The project also incorporates neurosensorial assessment to quantify mental workload, cognitive performance, and sensorimotor responses synchronized with physiological recordings, allowing unprecedented multimodal correlation of physical and cognitive processes in space.

SCIENTIFIC **OBJECTIVES**

PhysioTool aims to continuously monitor cardiovascular, respiratory, muscular, and perfusion parameters over 24 hours, establishing correlations between these systems throughout typical ISS daily cycles—including day/night variations. It seeks to characterize patterns of brain and muscle oxygenation, track changes across early, mid, and late mission phases, and better understand how physiological rhythms adapt during long-duration spaceflight.

A second core objective is to quantify cognitive load and psychological states through structured neurosensorial tasks, while recording response times and psychophysiological markers (EDA, heart rate, perfusion).

Pre- and post-flight stand tests complement the in-flight sessions, enabling the team to quantify cardiovascular deconditioning, orthostatic intolerance, and multisystem adaptation upon return to gravity.

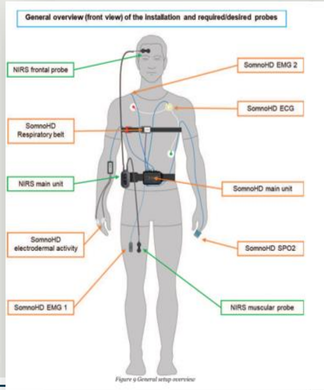


Figure 9 General setup overview

NEED OF SPACE

Microgravity causes physiological and psychological changes that cannot be fully reproduced by terrestrial analogues such as bed rest or dry immersion, which still preserve gravity-dependent cues like proprioception and fluid shifts. Long-duration exposure in orbit is therefore essential to capture the cumulative effects of microgravity on integrative physiology. Only the ISS enables continuous collection of combined physiological, cognitive, and psychological data under true space conditions, allowing a comprehensive assessment of human functioning in orbit.

RETURN TO EARTH

This work will enhance understanding of gravity-dependent physiological interactions and support medical challenges on Earth, including orthostatic intolerance, sleep and circadian disturbances, mental-load–related cardiovascular effects, and stress regulation. Its multimodal monitoring approach and technological advancements—particularly improved ambulatory polysomnography—could translate into new tools for healthcare, professional performance, education, and physical training, enabling more effective individualized assessment and intervention strategies.

Other National Contributions

NATIONAL CONTRIBUTIONS

CNES Euro Material Ageing
CNES Lumina
DK Circadian Light
DK Earthshine from ISS
DLR Easymotion-2
DLR Granular Sound
DLR T-Mini
PL Cube #25 LeopardISS
PL Scalable Radiation Monitor
PL Stability of Drugs

CNES Euro Material Ageing

SCIENTIFIC **BACKGROUND**

- The Low Earth Orbit (LEO) environment exposes materials to a combination of harsh factors—atomic oxygen, UV/VUV radiation, thermal cycling, contamination, and micrometeoroids—that cannot be faithfully reproduced simultaneously in laboratory facilities. Ground testing typically isolates these conditions, leading to limitations in predicting the real ageing and degradation behaviour of spacecraft materials. This affects both the development of new materials for satellites and the study of astrochemically relevant compounds, whose photochemical evolution is difficult to simulate under true Solar UV flux, especially below 200 nm.
- Euro Material Ageing (EMA) addresses these constraints by exposing a wide variety of passive and active material samples (SESAME) and organic/mineral astrochemistry specimens (IR-COASTER) directly to the LEO environment on the Bartolomeo platform. This mission builds on decades of heritage from CNES THERME experiments and ESA/CNES astrobiology exposure facilities, while providing improved representativeness and, for IR-COASTER, in-situ infrared spectral monitoring throughout exposure.

SCIENTIFIC **OBJECTIVES**

SESAME aims to characterise the behaviour, degradation, and contamination of space-exposed materials to support the development of future spacecraft. Its objectives include improving thermal control technologies, quantifying inflight contamination, validating environmental models (e.g., ATOX and UV fluence), and comparing in-flight vs. ground performance to refine predictive ageing tools. SESAME also evaluates both passive materials and active sensors (e.g., ATOX detectors, microbalances) that measure environmental parameters directly in orbit.

IR-COASTER focuses on the evolution and long-term stability of organic and mineral compounds relevant to small Solar System bodies or planetary surfaces such as Mars, Titan, or comets. It investigates degradation pathways under real Solar UV exposure, using in-situ IR spectroscopy to capture changes throughout the mission. This enables improved understanding of prebiotic chemistry in space and supports future autonomous astrobiology missions

NEED OF SPACE

True representativeness of the LEO environment cannot be reproduced on Earth: Solar UV photons below 200 nm, atomic oxygen flux, temperature cycles, vacuum, and contamination all act simultaneously in orbit but only sequentially in laboratories. This non-replicability leads to inaccurate degradation kinetics for both materials and organic compounds. Space exposure is therefore essential to obtain reliable ageing data, validate environmental models, and observe real-time physicochemical processes that cannot be captured using ground-based simulations.

RETURN TO EARTH

After exposure, SESAME and IR-COASTER are returned to CNES and LISA for detailed analyses. Because samples continue to age after retrieval, strict limits apply to stowage, download, and delivery (maximum 5 weeks before download begins and 12 weeks to reach CNES/LISA). The returned samples undergo thermo-optical measurements, contamination and erosion assessments, IR spectroscopy, and comparison with ground controls to accurately characterise space-induced changes.

CNES Lumina

esa

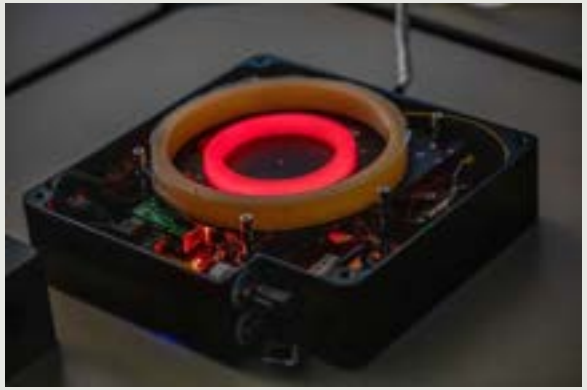
SCIENTIFIC **BACKGROUND**

- Fiber-optic Active Dosimeter (Lumina) is an active fiber dosimeter that monitors (at an acquisition rate of 1Hz) the received radiation dose by exploiting the radiation induced attenuation (RIA) phenomenon in real-time, to monitor the Total Ionising Dose (TID). RIA corresponds to a decrease of the radiation-sensitivite fiber transmission capacity caused by radiation damages absorbing the light. The higher the dose, the more is attenuated the light signal injected in the fiber is at the end of the fiber.
- A pre-calibration of the optical fiber on Earth allows precise evaluation of the radiation dose through loss monitoring on the International Space Station (ISS). Lumina measures the optical losses in two different optical fibers of different lengths: in the visible domain for the first 2-km channel, and in the infrared domain for the second one using 7-km fiber coil. This is achieved by using a specific sensor architecture comprising of two lasers and several photodiodes, optimized to measure low RIA and then to deduce low dose levels. Among the advantages of fiber-based dosimetry, Lumina performances are independent of the temperature of irradiation and of the dose rate. Furthermore, it has been demonstrated that the dosimeter provides reliable dose measurements in complex environments, such as the ones associated with electrons, protons, and gamma-ray or X-ray photons or neutrons.

SCIENTIFIC **OBJECTIVES**

1. To demonstrate the ability of a fiber-based dosimeter to measure, in real-time, the radiation dose on the ISS under realistic space conditions, that includes: particle spectrum (in terms of type of radiation, flux, energy), volume constraints, mechanical levels, remote operation (reliability, limited bandwidth required), power consumption, and interface.

2. To increase scientific knowledge regarding the fiber behavior in the visible and infrared domains when exposed at a low radiation dose rate for extended periods of time in space.



NEED OF SPACE

Monitoring of the ionizing radiation is a key topic for future space exploration. An embedded, robust fiber-based dosimeter that provides a real-time measurement of the fluctuation levels of ionizing radiation could allow for the ability to anticipate radiation flares and react properly to these dangerous events. The ISS platform is a magnificent opportunity to test this technology in the space environment.

RETURN TO EARTH

This kind of fiber-based dosimeter has promising applications in the medical and the nuclear industries.

DK Circadian Light

SCIENTIFIC **BACKGROUND**

- Spaceflight studies demonstrate significant impacts from sleep loss, circadian misalignment, and monotony in space, leading to reduced performance and well-being. To tackle these challenges, we propose an automated and varied lighting system (referred to as the “SAGA panel”), which will serve as a crew health countermeasure for circadian rhythms, sleep, performance, and well-being.
- The SAGA panel follows a natural daylight schedule, mimicking sunrise, sunset, daylight, etc. Notably, the panel automatically changes between various lighting settings and this happens gradually over time, just like one experiences real sunlight on Earth.
- The proposed panel transitions automatically between different colour temperatures and light intensities to best fit the circadian rhythm of the user. The panel also incorporates pseudo-randomized variation into the “sunrise” and “sunset” periods to create variation for the user and combat monotony.

SCIENTIFIC **OBJECTIVES**

Technical Objectives:

- Assembling and uploading a new LED panel, the SAGA panel, which improves on the current Lights by introducing automation, gradual changes in the light spectrum, and variation from day-to-day, to better mimic the variable nature of natural lighting found on Earth.

Scientific Objectives:

- Measure the effectiveness of the SAGA panel on circadian rhythm regulation, sleep, and stress.
- Measure the effectiveness of the SAGA panel on cognitive performance and well-being.
- Qualitatively explore the SAGA panel’s impact on crewmember well-being and monotony

NEED OF SPACE

One of the biggest challenges for well-being in space is sleep deprivation. The most frequently consumed medicine on the ISS is sleep medication. Going forward to the Moon, and eventually Mars, mission durations and distances will increase. In addition to this, larger quantities of commercial astronauts will fly in this decade and beyond.

Lighting is a key part of any spacecraft and habitat, aiding sleep, performance, and combatting monotony, all of high importance in the missions of today and tomorrow. In turn, testing an automated and varied lighting system in a real microgravity environment is valuable, and necessary in researching countermeasures for sleep deprivation.

RETURN TO EARTH

Insights from this study can guide wider adoption of dynamic lighting systems in hospitals, workplaces, and homes, especially for people exposed to limited natural light, such as patients, shift workers, or those in high-latitude regions. Broader implementation could enhance well-being and productivity while supporting future commercial applications.

DK Earthshine from ISS

SCIENTIFIC **BACKGROUND**

- Earth's climate is changing, and the best measurements of the changes are needed for timely adaptation; better observational data help improve climate models which are used to project expected climate change into the 21st century. The investigators are suggesting a complementary and independent method for Earth observation.
- Pictures of the Moon from space can help determine whether the earthshine method for determining Earth's albedo can benefit from the absence of an atmosphere.
- The 'earthshine method' consists of performing relative radiometry on images of the lunar disk which is illuminated by sunshine reflected from Earth. At the core of the 'earthshine method' lies obtaining images of the whole lunar disc from which the brightness of areas in the earthshine-illuminated side as well as the sunshine-illuminated side can be extracted. The ratio of the two numbers is proportional to the quantity sought, namely Earth's reflectivity or albedo.

SCIENTIFIC **OBJECTIVES**

The main objective is to obtain two sets of 100 correctly exposed images of the Moon during optimal lunar phases (1–3 days around New Moon) when earthshine is most measurable. Correct exposure must avoid saturating the bright side while keeping the dark side adequately visible. These images will allow precise determination of the brightness ratio between lunar hemispheres—directly linked to terrestrial albedo. Partial and minimal success thresholds exist, but high-volume image acquisition is the scientific target.

A further objective is to evaluate the scattered-light halo around the Moon, a key limitation of the earthshine method. By aligning and co-adding many raw 14-bit images, the experiment seeks to derive the halo profile and slope, compare it with ground-based data, and quantify improvements gained from observing outside Earth's atmosphere. These results inform calibration methods and shape the development of future space-based albedo-monitoring systems.

NEED OF SPACE

Ground observations of earthshine suffer from atmospheric variability, which reduces measurement precision even at exceptionally clean sites. Conducting the experiment from the ISS removes atmospheric disturbances entirely, enabling a quantitative assessment of how much variability is eliminated and providing critical validation for upcoming earthshine instruments under development at DTU Space and IRS Stuttgart.

RETURN TO EARTH

The experiment will help determine whether earthshine observations from space can serve as a cost-effective and independent method for monitoring Earth's albedo—an essential climate variable. Improved albedo data enhance long-term climate observations and strengthen climate-model constraints used to predict future climate conditions. Because earthshine instrumentation is significantly less costly than Earth-observing satellites, successful validation offers strong scientific and economic benefits for future climate-monitoring missions.

DLR EasyMotion-2

SCIENTIFIC **BACKGROUND**

- Human locomotion and exercise on Earth rely on body stability and neuromuscular control, but these functions degrade significantly in microgravity, contributing to muscle atrophy, reduced strength, and impaired performance. Current inflight countermeasures (ARED, T2, CEVIS) help mitigate these effects but remain only partially effective due to microgravity-related challenges such as limited loading forces and unknown long-term neuromuscular adaptations.
- Whole-body ElectroMyoStimulation (WB-EMS) is a non-invasive method that stimulates muscle contractions via transcutaneous electrical impulses. It has shown promising effects on muscle tone, strength, and neuromuscular function in clinical, rehabilitation, and sports settings on Earth. Preliminary ISS data from the first EasyMotion demonstration (Cosmic Kiss mission) suggest EMS may preserve muscle tone and stiffness in key muscle groups during long-duration missions, but further evidence with more participants is required.

SCIENTIFIC **OBJECTIVES**

The experiment aims to evaluate whether a 3–4-week inflight EMS-assisted exercise block can improve or maintain muscle tone, stiffness, and functional strength at five predefined skin measurement points (Multifidus, Splenius Capitis, Deltoideus Anterior, Rectus Femoris, Infrapatellar Tendon) compared with existing MYOTONES baseline data from astronauts who exercised without EMS. Measurements will be collected using Myotonometry, supported by dynamometry, surface Electromyography (sEMG), and structural Magnetic Resonance Imaging (MRI).

A second objective is to assess whether EMS can serve as an efficient “add-on” to nominal exercise by enhancing neuromuscular activation, reducing muscle deconditioning, and potentially shortening required exercise duration. The study also evaluates operational feasibility, tolerance, and the practicality of EMS protocols in microgravity, including use of personalized template suits to ensure accurate, repeatable muscle measurements.

NEED OF SPACE

Microgravity uniquely challenges neuromuscular stability and muscle loading in ways that cannot be fully replicated on Earth or in analog environments. Testing EMS directly in space allows assessment of its effects unmasked by gravity, and enables comparison with extensive MYOTONES inflight datasets to determine whether EMS can meaningfully improve countermeasure efficiency during long-duration missions. The space environment is therefore essential to evaluate EMS as a realistic operational tool for future Moon- and Mars-class missions.

RETURN TO EARTH

EMS is already used in sports, rehabilitation, and clinical care on Earth. Results from EasyMotion-2 may support improved EMS-based protocols for injury recovery, post-surgery rehabilitation, and neuromuscular maintenance in ageing or sedentary populations. By better understanding muscle responses in extreme unloading conditions, the experiment could inform more effective EMS applications and contribute to broader health-maintenance strategies.

DLR Granular Sound

SCIENTIFIC **BACKGROUND**

- Granular materials—collections of macroscopic particles such as sand—behave very differently from classical solids, liquids, or gases. Sound propagation in these systems depends strongly on packing structure, inter-particle forces, and stress networks, leading to pressure-dependent sound speeds, nonlinear wave behaviour, and strong scattering.
- Existing models like Effective Medium Theory predict relations such as v ∝ p^1/6, but ground experiments show significant deviations at low confinement pressures, where nonlinear and shock-like effects emerge and scattering dominates). Near the transition to mechanical instability (jamming), continuum assumptions fail, wave speeds decrease, and acoustic behaviour becomes increasingly complex.
- Factors such as particle shape, material properties, and electrostatic forces in vacuum further influence sound propagation. To build a reliable foundation for understanding more complex granular media—including regolith-like materials—the experiment focuses on controlled measurements using precision glass spheres. Conducting these studies on the ISS removes gravity-induced pressure gradients, enabling measurements impossible to achieve on Earth.

SCIENTIFIC **OBJECTIVES**

The experiment aims to systematically characterize acoustic wave propagation in granular sphere packings across a wide range of confinement pressures. Objectives include preparing well-defined low-pressure packings in microgravity, generating plane waves of various strengths and frequencies, and measuring sound speed using synchronized accelerometers and piezo sensors. These data will allow accurate determination of linear and nonlinear wave-speed relations, including transitions where sound propagation depends on signal amplitude rather than only pressure.

Further objectives include quantifying sound attenuation, characterizing scattering via the incoherent “coda” signal, and measuring long-term evolution of packings under low pressure. Repeated or extended measurements will reveal how force-chain networks evolve in time, how attenuation decomposes into absorption vs. scattering contributions, and how mechanical stability changes near the jamming threshold. These results will answer open questions in granular physics and help validate theoretical models.

NEED OF SPACE

Gravity on Earth introduces unavoidable static pressures and vertical pressure gradients in granular packings, making it impossible to create truly low-pressure, well-defined conditions for sound-propagation studies. Short-duration microgravity platforms only allow limited parameter testing. The ISS provides the sustained, stable microgravity environment needed to prepare low-pressure packings and perform systematic measurements across a wide range of pressures and excitation settings.

RETURN TO EARTH

A better understanding of sound propagation in granular materials will support many Earth-based applications that rely on non-intrusive acoustic probing. Fields such as bulk material handling, soil stability assessment, landslide prediction, and seismic analysis depend on accurate models of granular behaviour, especially near the point where materials lose rigidity. The experiment's results will help refine diagnostic methods and improve the safety, handling, and predictive modelling of granular systems on Earth.

DLR T-mini

SCIENTIFIC **BACKGROUND**

- Long-duration spaceflight alters human thermoregulation, with astronauts showing elevated core body temperature (CBT) at rest and during physical strain, as documented in earlier ISS experiments such as THERMOLAB and CIRCADIAN RHYTHM. These changes are accompanied by altered circadian rhythms, increased thermal discomfort in microgravity, and reports of heat sensations in the head and upper body—especially during exercise, EVA, launch, and re-entry.
- Existing monitoring systems used in previous studies were large and cumbersome. T-Mini is a miniaturized, lightweight successor to the Thermo-Mini system, designed to provide continuous, non-invasive CBT measurements with improved comfort, sensor accuracy, and future integration into multisensor health-monitoring networks for deep-space missions and lunar Gateway operations.

SCIENTIFIC **OBJECTIVES**

The experiment aims to demonstrate the performance and usability of the new miniaturized T-Mini hardware, including automated data transfer, long-duration recording capability, and improved headband design. By collecting continuous 36-hour CBT, skin temperature, and actimetry data before, during, and after spaceflight, the study evaluates the device's ability to accurately capture circadian rhythm patterns and respond to varying physiological conditions. Scientifically, the investigation seeks to characterize how microgravity, varying gravitational loads, environmental changes on the ISS, and operational stressors influence thermoregulation. It will also assess CBT responses to acceleration phases (launch, re-entry) and to early adaptation during the first days in orbit. The results will provide insight into circadian changes, heat strain, and physiological adjustments critical for crew health in future exploration missions.

NEED OF SPACE

Human missions to the Moon and Mars expose crews to long-term microgravity, headward fluid shifts, isolation, altered light cycles, and increased radiation—all of which affect CBT regulation and circadian rhythm. These physiological changes cannot be fully replicated on Earth. Reliable in-orbit measurements using a miniaturized sensor system are therefore essential to understand thermophysiological adaptation, identify risks such as hyperthermia, and develop countermeasures for missions where real-time terrestrial support is limited.

RETURN TO EARTH

The T-Mini technology builds on earlier non-invasive heat-flux sensors already applied in clinical and occupational health settings. Findings from the space experiment can advance Earth-based applications by improving monitoring tools for firefighters, military personnel, and other heat-exposed professionals. The method's potential to prevent hyperthermia and enhance physiological monitoring makes it valuable for medicine, sports science, and safety-critical work environments.

PL LeopardISS – Experiment Cube #25

SCIENTIFIC **BACKGROUND**

- This investigation includes placing a piece of hardware, Leopard DPU, on the ISS, to become an extension of the *Smart Mission Lab (SML)* project (previously executed at ESA), allowing interested entities to perform verification and testing of their algorithms and softwares in space conditions. The idea for SML is to enable clients to test their algorithms from the ground, using remote access to the hardware without acquiring it physically, in the form of a subscription. It is considered a crucial step before their utilization in real satellite missions.
- Further motivation for the activity is to expand the existing Leopard DPU solution and gain additional space heritage for the hardware. In addition, the investigation will focus on developing tools required for deep space exploration (The Terrae Novae programme), with emphasis on performing 3D mapping and reconstruction of a scene based on image data required for space exploration (for instance spacecraft manoeuvring support, fully autonomous robotic exploration of exoplanets and moons or spacecraft situational awareness). During the activity, it will be demonstrated that the usage of ROS-2 on Leopard DPU is possible and effective.

SCIENTIFIC **OBJECTIVES**

1. Creation and verification of the onboard platform (Leopard DPU) for algorithms' testing in space conditions. The algorithms will be run on the DPU, onboard ISS, to test the hardware's robustness and remote operations.
2. Enabling clients to obtain flight heritage for their algorithms. – this is considered by algorithms' developers as a valuable step in proving that their AI/ML solutions are ready to be utilized on orbit.
3. Extension of KP Labs' Smart Mission Lab. – moving Earth-based solution for AI algorithms verification into ISS, proving its applicability and feasibility for clients as well as accelerating on-board processing as an important step for the upstream and downstream sector.
4. Advancing GPU-based solution that is already available on ISS (AI-Box) – towards FPGA AI-based on-board processing in future deep space environment.
5. Promotion of on-board processing of data and its benefits – to expand the market for data processing on board satellites and accelerate the development of this part of the space sector as well as raising awareness of the benefits of on-board data processing in comparison to SOA solutions.

NEED OF SPACE

The ISS platform serves as an environment that efficiently combines the features of both SML and an Earth-based server room applications, giving customers (companies and institutions) the opportunity to test their AI algorithms in space to obtain flight heritage on real hardware. In addition, some limitations in the communication time and sessions available may be an introduction to the real behaviour of the satellite in orbit. Additionally, on-board data processing is gaining popularity, so the promotion of its benefits shall accelerate its development and encourage more companies to be interested in this topic.

RETURN TO EARTH

With the development of faster and more efficient processing units, together with AI-based solutions and neutral network-based analysis as well as in-orbit data processing, the data downlink speed from satellites can be reduced up to 100 times, enabling much faster communications.

PL Scalable Radiation Monitor (RadMon-on-ISS)

esa

SCIENTIFIC **BACKGROUND**

- Radiation environment in orbit (LEO and beyond) requires specific radiation monitoring especially going beyond the Van Allen belts. This radiation causes malfunctions of electronic systems and impact the health of astronauts.
- Future lunar and deep-space missions will rely on high-performance computing systems that must withstand radiation-induced faults. Modern processors offer strong capabilities but are more susceptible to ionizing radiation, creating the need for adaptive architectures that adjust their operation based on real-time radiation levels. Radiation-aware supervision is therefore key to enabling safe, autonomous spacecraft systems.
- Scalable Radiation Monitor, developed at CERN, measures total ionizing dose and single-event effects to provide real-time radiation information. Calibrated in multiple CERN facilities, it can support system-level decisions such as switching between high-performance and redundancy modes. Deploying this payload on the ISS is a crucial step toward transitioning the technology from high-energy physics into operational spaceflight.

SCIENTIFIC **OBJECTIVES**

The experiment aims to characterize Scalable Radiation Monitor's response in the low-Earth-orbit radiation environment over extended periods and to correlate its measurements with radiation sensors already aboard the ISS, such as ISS-RAD and Timepix, as well as computational radiation models. This will establish calibration baselines and validate the instrument's ability to quantify both long-term and instantaneous radiation effects.

Additional objectives include acquiring spaceflight heritage for the sensor both inside the ISS and, in later phases, externally. The project also seeks to link ISS radiation measurements with those recorded in CERN facilities, enabling cross-environment calibration and supporting future applications where Scalable Radiation Monitor operates as an autonomous supervisor for high-performance computing systems in space.

NEED OF SPACE

Radiation effects are a defining element of the space environment and cannot be reliably simulated on Earth. Deploying Scalable Radiation Monitor on the ISS enables long-duration exposure to real LEO radiation conditions while providing correlation with well-characterized onboard reference sensors. This is essential for validating its performance, calibrating its measurements, and evaluating how the device functions in both shielded (internal) and more exposed (external) ISS locations—key steps before using the technology in future autonomous spacecraft systems or commercial constellations.

RETURN TO EARTH

Returned datasets—including continuous measurements of total ionizing dose, single-event upsets, and latch-ups—will refine space-radiation models, calibrate Scalable Radiation Monitor for orbital use, and demonstrate its suitability for adaptive spacecraft computing. The results will support applications in autonomous systems, satellite constellations, and broader radiation-environment research, with data shared through publications and later open access.

PL Stability of Drugs

esa

SCIENTIFIC **BACKGROUND**

Previous scientific studies have shown that the shelf life of commercially available drug delivery systems (DDS) for therapeutic substances in the form of tablets and lozenges stored on board the International Space Station is limited. The experiment aims to evaluate the stability of polymeric controlled drug release systems under conditions on the ISS.

The influence of microgravity on the diffusion of selected active substances by the polymer carrier, the effect of increased radiation levels on the degradation of biodegradable polyesters and the effect of shielding drugs against cosmic rays by the polymer matrix will be investigated. The use of this type of controlled release systems can be very beneficial during spaceflight, as they allow the patient to maintain effective concentrations of the active substance for a longer period of time, reducing the frequency of subsequent doses at well-defined intervals and eliminating the possibility of missed doses. It is possible to deliver the active substance both systemically and locally, bypassing the digestive and circulatory systems, decreasing the amount of the drug needed to achieve a specific clinical effect, while reducing the likelihood of side effects.

Polymer drug delivery systems can be used both internally in the form of an implant or subcutaneous or intramuscular injections, as well as externally, in the form of transdermal systems and dressings, which, due to their ability to bioresorption, can be absorbed by the body, which simplifies medical waste disposal procedures. These types of systems are therefore a universal solution, allowing for many types of therapy.

SCIENTIFIC **OBJECTIVES**

The aim of the experiment is to investigate whether it is possible to extend the usefulness of active substances during long-term storage in low Earth orbit conditions by introducing them into a polymer carrier.

NEED OF SPACE

Low Earth orbit is the best test point available to study the effect of elevated levels of radiation on the stability of drug structures, which has already been examined by other scientists. However, it is possible to investigate whether introducing them into the polymer matrix will improve their durability under mentioned conditions. The space environment provides a multi variable scenario in which cumulative effects of synergizing radiations can be studied and cannot be modelled or replicated on Earth.

RETURN TO EARTH

Obtained information concerning the shelf-life of polymer DDS containing drugs with various therapeutic effects may be also useful regarding their storage and usage on the Earth's surface conditions.

Education

EDUCATION

EPO Astro-Pi
EPO Task List
* EPO Adenot (ChlorISS + Generic Videos)

EPO Astro-Pi

SCIENTIFIC **BACKGROUND**

- The Raspberry Pi Foundation is a British charity whose mission is to promote the uptake of computer programming skills in young people and adults, using affordable and versatile computers that have reached global popularity. Its introduction to the ISS began during Tim Peake's Principia mission, where Astro Pi units equipped with sensors were used to run student-written experiments, demonstrating how space-based coding activities can meaningfully engage young learners.
- Since then, the European Astro Pi Challenge has grown into a continent-wide annual initiative supported by ESA, enabling over 163,000 students to design experiments executed on ISS hardware. The education and didactic support for the European AstroPi Challenge involves ESA Education procuring a set of Astro Pi kits which are shipped to registering schools. These kits contain equivalent hardware to the Astro Pi computers onboard the ISS and are used by the participating student teams to develop and test the software for their experiments.
- ESA Education uploaded new/improved replacement hardware in 2021 on SpaceX-24, ensuring the programme remains relevant to evolving STEM education needs.

SCIENTIFIC **OBJECTIVES**

EPO AstroPi aims at the fulfilment of European Astro Pi Challenge 2025-26. The challenge aims to provide authentic space-based coding and experimentation opportunities to European students. Student teams create software that interacts with Astro Pi sensors and camera systems, capturing environmental or Earth-observation data for later analysis.

Two formats drive these objectives:

- Mission Zero, a simple coding task where students display pixel art and sensor readings using AstroPi IR, ensuring every valid code submission runs on the ISS;
- Mission Space Lab, where students compute the ISS orbital speed using image-based methods. This mission uses Astro Pi VIS in two possible deployment locations - either at a nadir window (upon availability in Node 1 or 2, depending on visiting vehicle traffic) or in the WORF rack (where both Astro Pi units could be deployed at the same time) to acquire Earth imagery.

Astro Pi hardware remains on ISS, operational and connected for ongoing and future STEM engagement activities until HW end of life or until download is requested by ESA Education programme.

NEED OF SPACE

Running student-written code directly on ISS hardware is essential to the challenge's purpose. The space environment provides unique conditions—microgravity, orbital dynamics, real sensor inputs, and Earth-observation opportunities—that cannot be replicated on the ground. The authenticity of executing experiments in orbit and receiving real imagery and sensor data back on Earth, is fundamental to motivating students and enabling them to conduct meaningful scientific investigations.

RETURN TO EARTH

The Astro Pi Challenge strengthens scientific literacy and coding skills across Europe, supporting ESA's mandate to inspire and prepare future generations for STEM careers. By using space as a context for learning, the programme helps students appreciate the value of science and technology and encourages participation in fields vital to Europe's knowledge-driven economy.

EPO Adenot - ChlorISS

SCIENTIFIC **BACKGROUND**

- ChlorISS is an educational experiment designed to show how gravity and light influence seed germination and plant growth. By conducting the activity simultaneously on Earth and aboard the ISS, the project introduces young learners to fundamental biological and physical concepts related to plant development in microgravity versus under terrestrial gravity. The experiment uses Arabidopsis and Mizuna, two well-characterized model species, including a mutant Arabidopsis line (PGM) known to have impaired gravity perception, allowing students to observe how genetic differences affect responses to environmental cues.
- The activity builds on a long lineage of educational space-biology projects, such as Kuipers' Delta mission (2004) and Pesquet's Ceres experiment (2017), during which thousands of students across Europe performed the same seed-growth tasks on the ground and compared their results with space-based observations. ChlorISS leverages this heritage to continue inspiring and motivating students aged 10–18 across France and other ESA Member States to explore STEM topics through real experimental inquiry connected to an astronaut mission.

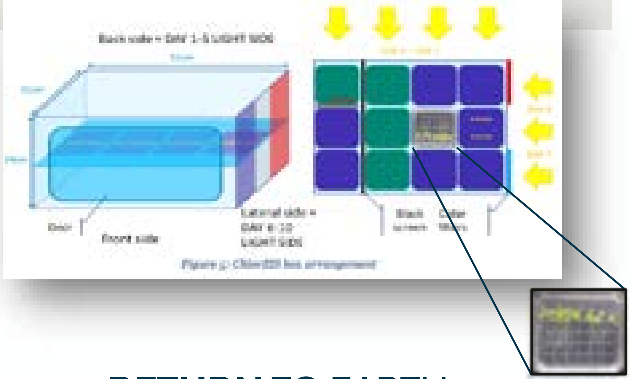
SCIENTIFIC **OBJECTIVES**

The primary objective is to:

- Run a synchronized plant-growth experiment in which the astronaut performs the space trial on the ISS while students execute the same protocol on Earth, enabling like-for-like comparison between microgravity and 1-g conditions.
- Use Arabidopsis and Mizuna seeds, including a PGM (phosphoglycerate mutase-like) Arabidopsis line with impaired gravity perception, to highlight how genotype and environment shape germination success, root/shoot orientation, and growth direction under different light intensities, orientations, and colours. In orbit, the hardware is placed near a Columbus light source and then rotated 90° after ~120 h to intentionally change the light vector, generating pre-/post-rotation datasets (day ~1–5 vs. ~6–10) that make the role of directional light evident in microgravity. Daily close-up imaging of each Petri dish (with visible passive temperature and humidity indicators) provides time-series data for classroom analysis and Earth–ISS comparisons

NEED OF SPACE

ChlorISS is an educational activity, whose use of space conditions is justified by the unique ability of microgravity to visibly alter plant growth direction, allowing students to observe clear differences between Earth-gravity and space-gravity germination in a way that enhances STEM learning.



RETURN TO EARTH

The main Earth benefit is the enrichment of STEM education. Comparing ground and in-orbit observations helps teachers illustrate fundamental biological and physical principles, supporting classroom instruction and strengthening students' scientific literacy and curiosity.

EPO Generic Videos Adenot

SCIENTIFIC **BACKGROUND**

- The ESA Education Office (TEC-XE), in close collaboration with the Directorate of Human Spaceflight and Robotics Exploration (HRE) develops educational programmes for each ESA astronaut on their long duration missions to the ISS, using spaceflight as a powerful context to engage students across Member States. The programmes usually target various academic levels and include inflight calls between the crew and students of various ages.
- For Sophie Adenot’s εpsilon mission, a suite of generic educational videos will be recorded on the ISS to support and expand outreach initiatives. These videos aim to spark curiosity, strengthen STEM teaching, and motivate students by showing authentic astronaut-led demonstrations and messages connected to ESA Education activities.

SCIENTIFIC **OBJECTIVES**

The activity aims to record a broad collection of video messages and demonstrations with Sophie Adenot aboard the ISS, supporting ESA Education and CNES outreach programmes. These include motivational messages (Mission X celebration, ESERO 20th anniversary), career-focused stories (“Making a mission”), science-based demonstrations (“Emulsions in microgravity,” “What’s your space height”), and thematic activities such as role-play mission scenarios and STEM-focused celebrations (Astro Pi anniversary). Together, they provide mission-authentic material for classroom use across Europe. A key objective is to leverage the ISS environment to illustrate scientific concepts that cannot be demonstrated on Earth in the same way. These demonstrations give teachers concrete examples to support lessons in physics, biology, engineering, and space science.

The activity also produces imagery supporting forthcoming ESA Education teaching resources, including AI/image-classification and medical-imaging classroom activities.

Two live in-flight calls further connect students directly with the astronaut.

NEED OF SPACE

Sophie Adenot’s εpsilon mission creates a unique opportunity to inspire students by leveraging the authenticity of the ISS environment. Filming in space enhances STEM learning by providing real microgravity demonstrations, genuine astronaut perspectives, and compelling storytelling that cannot be replicated on Earth. The ISS setting also raises awareness of space’s societal value and highlights the diverse career pathways connected to human spaceflight and science.

RETURN TO EARTH

The videos and imagery will become educational assets used across Europe to strengthen scientific literacy and support teachers delivering STEM curricula. These resources reinforce ESA’s long-term mission to cultivate an informed, technologically capable future workforce.

Commercial

COMMERCIAL
Green Bone (Kubik)
Laplace
Ice Cubes (#MediaSet Mk2, #23 SmallBoi, #34 CRA)

Green Bone

SCIENTIFIC **BACKGROUND**

- Bone tissue continually adapts to mechanical forces, and loss of loading—such as that caused by disease, aging, or trauma—reduces bone quality and complicates orthopedic treatments. Conditions like severe osteoporosis lead to high fracture risk, compromised bone regeneration, and poor outcomes for implants or scaffolds. Existing biomaterials often perform poorly in these environments due to reduced osteoblastic activity and diminished metaphyseal bone substance.
- Green Bone's biomimetic scaffold has already demonstrated full regeneration of critical-size defects in animal models, outperforming allografts and showing strong vascularization. With promising clinical experience from >500 non-osteoporotic patients and ongoing pre-market and post-market studies, the next step is to validate the scaffold's performance specifically for osteoporotic patients—an increasingly urgent need given aging demographics and rising osteoporosis prevalence.

SCIENTIFIC **OBJECTIVES**

The experiment aims to validate Green Bone's scaffold for use in orthopedic surgery in osteoporotic patients by exploiting microgravity as an accelerated model of osteoporosis. Human mesenchymal stem cells seeded onto the scaffold will be cultured in microgravity and 1g controls to assess attachment, differentiation, and overall scaffold support under osteopenia-like conditions.

RNA sequencing of microgravity-exposed and ground-based samples will reveal gene-expression signatures related to bone metabolism, extracellular matrix formation, and stress responses. Comparing microgravity, in-flight 1g, and ground controls will determine whether the scaffold supports regenerative processes even under conditions mimicking severe osteoporosis.

NEED OF SPACE

Microgravity induces rapid bone loss and osteopenia-like remodeling, providing an ethically preferable and physiologically relevant environment that closely mirrors critical aspects of osteoporosis. The ISS enables a controlled, accelerated model of bone degeneration that Earth-based systems cannot reproduce. Testing human bone cells on the GreenBone scaffold in this environment allows meaningful pre-clinical validation without additional animal studies and directly informs regulatory submissions for future clinical trials in osteoporotic patients.

RETURN TO EARTH

Returned samples will undergo RNA-seq and functional analyses to assess scaffold performance and cell behaviour under osteoporosis-like conditions. The results will directly support ethics submissions and CE-marking for upcoming clinical studies targeting severe osteoporosis, helping enable safer and more effective orthopedic treatments and reducing off-label graft use. The data will also strengthen Green Bone's commercial development and advance scientific understanding of bone-loss mechanisms relevant to astronaut health.

Laplace

SCIENTIFIC **BACKGROUND**

- Laplace focuses on understanding the earliest stages of planet formation by studying how micron-sized dust particles behave, collide, and agglomerate under protoplanetary-disk-like conditions. The experiment examines dust–dust, dust–gas, and dust–light interactions, providing insight into how planetesimals—the precursors to planets—emerge from freely moving dust clouds.
- Its scientific setup includes a vacuum chamber, particle-injection system, thermal-control infrastructure, and multiple high-resolution imaging tools (OOS and LDM), enabling precise tracking of particle motion and aggregate evolution. These subsystems recreate relevant physical forces such as thermal creep and photophoresis, allowing controlled study of phenomena otherwise inaccessible on Earth.

SCIENTIFIC **OBJECTIVES**

Laplace aims to determine how planetesimals form by analysing collision outcomes, mass-frequency distributions, and agglomeration rates of dust particles under microgravity. It systematically studies the effects of particle size, mixtures, material properties, density, gas pressure, injection methods, and turbulence-like forcing on aggregate formation.

Additional objectives include characterising dust–gas dynamics in transitions between gas-dominated and dust-dominated flow regimes, and quantifying the role of thermal creep and photophoresis in dense dust-gas mixtures. Across ~100 experiment runs, Laplace builds a comprehensive dataset that constrains key physical mechanisms governing early planetary growth.

NEED OF SPACE

Microgravity is essential for Laplace because only in weightlessness can dust particles remain freely suspended without sedimentation, replicating the low-gravity environment of protoplanetary disks. This allows pure Brownian motion, controlled collisions, and long-duration aggregate evolution that cannot be reproduced on Earth. The ISS also provides a stable vacuum, nitrogen environment, and continuous power/data resources required for high-precision imaging and frequent experiment runs.

RETURN TO EARTH

Laplace generates ~35 TB of compressed scientific data over its mission, stored on internal and external drives that are periodically returned to Earth for analysis. These datasets—including high-speed and high-resolution imagery of particle collisions—will advance models of planet formation and improve understanding of dust-aggregate physics. The results support planetary-science research, refine computational simulations of protoplanetary disks, and contribute to broader astrophysical studies on how planetary systems emerge.

Media Set Mk2

SCIENTIFIC **BACKGROUND**

- The Media Set Mk2 builds on the experience gained from the Media Set Mk1 flown during the Axiom-1 mission, incorporating crew feedback to enhance usability, audio quality, visual capabilities, and system flexibility. Crew-identified needs—such as louder audio, support for Bluetooth headsets, and access to an auxiliary display—motivated the redesign.
- The upgraded system is conceived not only as a communication tool but also as a multifunction platform capable of supporting on-orbit demonstrations. By adding real-time video upload, improved hardware interfaces, and edge computing capability, the Mk2 allows broader use across scientific, operational, and commercial applications proposed for ISS users.

SCIENTIFIC **OBJECTIVES**

The primary objective is to enhance the ISS Media Set to support real-time video uplink, improved audio, and visualization of payload activity both inside and outside the ICE Cubes Facility. These upgrades increase communication performance and interactive capability for crew and ground teams.

A second objective is to expand experimental and technology-demonstration opportunities by enabling device control, monitoring, and onboard Artificial Intelligence (AI) / Machine Learning (ML) edge computing via an integrated Nvidia Jetson Orin NX module. This capability supports diverse use cases, from biomedical sensing to digital-twin creation and facial-expression analysis as indicated by interested institutions and companies.

NEED OF SPACE

The Media Set Mk2 must be tested and utilized in the ISS environment because its purpose is to support crew operations, payload monitoring, and real-time communication in microgravity within the Columbus module. Its integration with the ICE Cubes Facility requires in-orbit validation of hardware behaviour, crew usability, audio and video performance, and edge-computing functionality under spaceflight conditions.

RETURN TO EARTH

Although the Media Set Mk2 is designed as a permanently hosted ISS asset, its operational outputs—live video streams, payload monitoring data, edge-processed results, and PAO/communication content—are transmitted to users on Earth for scientific, commercial, and outreach applications. These capabilities support technology demonstrations, user payload operations, astronaut–ground collaboration, and data-driven services such as AI-assisted sensing and digital-twin modelling, enabling new commercial and research opportunities derived from ISS operations.

SmallBoi – Experiment Cube #23

SCIENTIFIC **BACKGROUND**

- BioOrbit's Small Boi mission conducts an in-orbit demonstration of a crystallisation manufacturing system designed to exploit microgravity to improve crystal formation processes. The experiment investigates how the reactor, oscillatory flow mixing system, and fluidics behave in microgravity, where sedimentation and convection are reduced, offering conditions favorable for structured and uniform crystal growth.
- Microgravity has long been used to enhance crystallisation quality by eliminating buoyancy-driven disturbances that exist on Earth. Small Boi aims to determine whether its hardware can reliably generate crystals in this environment, validating performance for future commercial microgravity-enabled material production.

SCIENTIFIC **OBJECTIVES**

The primary objective is to demonstrate that Small Boi's reactor can feasibly produce crystals in space and operate safely and efficiently in microgravity. This includes confirming that the oscillatory flow mixing system performs as intended and that the crystallisation process proceeds cleanly and predictably under reduced-gravity conditions.

The mission also seeks to gather operational and structural data on hardware behaviour—vibration interactions, thermal control stability, fluid handling performance, and reactor responsiveness—to support future optimization and readiness for commercial microgravity manufacturing services.

NEED OF SPACE

Microgravity provides an environment free from sedimentation and density-driven convection, enabling crystal growth that cannot be replicated on Earth. For Small Boi, testing in space is essential to validate whether its crystallisation reactor can leverage these unique conditions to improve crystal formation. The ISS also provides the necessary operational infrastructure—ICE Cubes facility access, stable power, communication links, and controlled handling of potentially vibration-sensitive hardware.

RETURN TO EARTH

The crystals generated in orbit will be returned to BioOrbit for detailed analysis, enabling assessment of crystal structure, purity, and production viability under microgravity. These data support the development of commercial crystallisation services, informing reactor design, refining process parameters, and demonstrating feasibility for future customers. The insights gained may contribute to advanced materials manufacturing, improved reaction engineering, and the broader expansion of space-enabled industrial processes.

CRA – Experiment Cube #34

SCIENTIFIC **BACKGROUND**

- Emulsification—the mixing and stability of immiscible fluids such as water and oil—is strongly influenced by gravity-driven effects like buoyancy, sedimentation, and convection. On Earth, these effects shape droplet formation and phase separation, making it difficult to isolate the intrinsic fluid–fluid interaction behaviour. Microgravity provides a unique environment to observe emulsification without these dominant terrestrial forces.
- Thailand Innovative G-Force varied Emulsification Research for Space Exploration (TIGERS-X) from the Chulabhorn Royal Academy (CRA) focuses on understanding how emulsions form and remain stable when gravitational disturbances are removed. By examining oil–water mixtures under controlled low-flow conditions in microfluidic chips, the activity aims to generate fundamental insights relevant to fluid handling, food science, pharmaceuticals, and space-based manufacturing processes where reliable mixing behaviour is essential.

SCIENTIFIC **OBJECTIVES**

The primary objective is to study how microgravity affects mixing dynamics, droplet formation, homogeneity, and stability in water–oil emulsions. The experiment continuously pumps paired fluids through four microfluidic chips under very low flow rates, enabling fine observation of the emulsification process. Optical modules capture slow-motion video and still images to document how droplets behave in microgravity.

A secondary objective is to compare in-orbit results with ground-based experiments, using real-time telemetry from the ISS to replicate the exact operating conditions on Earth. This allows the science team to quantify gravity-driven differences in mixing behaviour, contributing to improved understanding of emulsions for future applications in microgravity manufacturing, life-support systems, and industrial processes..

NEED OF SPACE

Microgravity removes buoyancy- and sedimentation-driven forces that strongly influence fluid mixing on Earth, making it the only environment where intrinsic emulsification behaviour can be observed without gravitational bias. The ISS provides stable long-duration microgravity, precise environmental control, and real-time telemetry, enabling TIGERS-X to isolate microgravity effects on emulsion formation and to generate data that cannot be replicated through terrestrial simulations.

RETURN TO EARTH

The ICE Cubes unit containing the microfluidic system will be returned to Earth after the mission, providing the customer with recorded slow-motion videos, images, and sensor data for full post-flight analysis. These results will support the development of improved emulsification processes for space-relevant industries and may inform applications in food technology, pharmaceuticals, and fluid-handling systems requiring stable mixing in reduced-gravity environments.