



# [Ax-3] Muninn Mission

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## ESA Experiments Overview

Requirements Planning Lead for i70/Ax-3



# Ax-3 Muninn ESA Research Overview



## HUMAN RESEARCH

ARED Kinematics (Software update)  
Bone Health  
Brain-DTI (G)  
Cardio Deconditioning (G)  
DNAAge (G)  
EchoFinder

## TECH DEMONSTRATIONS

Anita-2  
Life Support Rack (Maintenance)  
Surface Avatar  
VR-OBT 2

## DK CONTRIBUTIONS WANDT MISSION

DK Sleep in Orbit  
DK Thor Davis  
EPO DK Astro Bit

## FACILITY/MAINTENANCE

Biolab  
MyotonPRO battery charging

## MATERIAL SCIENCES

MSL Batch 3a (Calibration Run)  
PK-4 Science Campaign

## SNSA CONTRIBUTIONS WANDT MISSION



MemoBC (ICE Cube)  
Orbital Architecture

## FLUID PHYSICS

FSL FOAM C

## OTHER NATIONAL CONTRIBUTIONS

CIMON (DLR)  
Lumina (CNES)

## EDUCATION

EPO Generic Videos Wandt

G: Ground experiment



# Human Research

## HUMAN RESEARCH

ARED Kinematics (software update)  
Bone Health  
Brain-DTI (G)  
Cardio Deconditioning (G)  
DNAmAge (G)  
EchoFinder



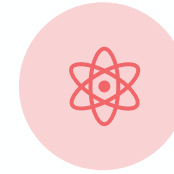
## SCIENTIFIC BACKGROUND

- 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

- The estimation of internal forces during exercises with ARED during spaceflight is fundamental to improve the daily exercises effectiveness. Without such knowledge, exercise programs may not be as effective as possible in protecting the physiological systems from long-term microgravity exposure.
- Current exercise prescriptions are based on the knowledge obtained during ground-based research. It is possible that differences in gravitational environments influence the acute loading that occurs during resistance exercise.
- This investigation, therefore, is crucial to allow the most effective exercise programs to be developed and prescribed for future long-term space exploration.



## SCIENTIFIC BACKGROUND

- Bone loss from the lower extremities is a well-known consequence of exposure to microgravity. Experimental bed-rest is accepted as a ground-based model for simulated microgravity in humans. Regarding the musculoskeletal system, one should expect bone losses to stop and to be reversed after immobilization has ended. However, and quite counter-intuitively, bone loss continues after re-ambulation. The observation is hard to explain by our current grasp of bone biology.
- The team performed the ISS-experiment EDOS2, to confirm that post re-entry bone loss (PREBL) would occur in long-term human spaceflight. Strikingly, however, an interim analysis in ten long-mission crew members suggests absence of PREBL. Notably, the one short-duration mission crew member studied did exhibit PREBL. PREBL would then occur only in missions that are shorter than 6 months. However, this explanation would only be based on single case. We propose to take identical measures in the Bone Health study as in EDOS-2.



## SCIENTIFIC OBJECTIVES

1. The main objective is to explore the existence/non-existence of PREBL in short duration missions (up to 60 days). Closing this knowledge-gap is important for our view of related bone loss.
2. The secondary objective is to explore whether the divergence/non-divergence of PREBL is explained by differences in cellular bone dynamics. Practically, the idea is to obtain identical measures as in our EDOS2 study, and to obtain these measures at identical time points.
3. The specific aims, listed in order of importance are to assess:
  - a) bone mass and structure pre- and post-flight
  - b) bone resorption from urine samples pre- and post-flight
  - c) cellular bone adaptation dynamics from blood samples pre-, in- and post-flight
  - d) physical activity pre-, in- and post-flight
  - e) dietary intake pre-, in- and post-flight



## NEED OF SPACE

- Regarding bone micro-architecture, trabecular bone adapts to loading by developing structures that are closely parallel to the principle of stresses in bone tissue. Permanent changes in the gravitational field might therefore produce altered bone architecture.
- Importantly, it is still unknown whether the recovery of bone volume is uniform, or whether it is selective for the horizontal or vertical trabeculae.
- Although space is a unique environment, there are strong parallels between spaceflight, ageing processes and prolonged immobilization. Within the context of this proposal, we follow up changes in bone mass and bone strength before and after spaceflight. Hence, there is enormous potential to create new approaches which contribute to our understanding of bone ageing, osteoporosis as well as hospital-based immobilization, following diverse disuse situations such as surgery, injury, coma or paralysis.



## 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 débarquement, uncompensated peripheral lesions).



## NEED OF SPACE

- Space flight is a model where a 'controlled' and reversal stimulus is given to the human body. Almost no other ethically approvable situation provides such a clear but also immense stimulus to the human body as several months of microgravity.
- It is crucial to understand the adaptation and plasticity of the brain to tackle the countermeasure problems that currently still exist in human spaceflight. Fundamental knowledge of how and where microgravity-induced neuroplasticity takes place may provide key solutions towards countermeasures against the deleterious effects of microgravity.
- Next, it opens a huge domain of research that benefits the general public. Indeed, it is not possible, due to ethical reasons, to study the effect of vestibular disorders pre and post disease for example. Indeed, we can't impose in healthy subjects such a dramatic effect on the vestibular system as obtained by microgravity. Space flight serves as a unique model to gain fundamental insight in neuroplasticity.



## SCIENTIFIC BACKGROUND

- Astronauts experience cardiac deconditioning upon return to Earth, with reductions in left ventricular mass and cardiac contractility, but these changes often recover within a few days.
- Head-Down (-6° ) Tilt Bed Rest (HDBR) is an analogue environment for spaceflight induced cardiovascular deconditioning. However, the longest duration of the recent HDBR (60 days) never approached the current duration of missions to the ISS (180 days). To this date, no studies investigated the accuracy of correspondence between the HDBR model with actual space flights, and no studies investigated the impact of mission duration on the extent of the cardiovascular changes.
- Deep space radiation exposure may lead to vascular endothelial cell dysfunction, potentially increasing the risk of cardiovascular diseases among astronauts. As space agencies, and/or commercial restart the Moon exploration as a gateway to Mars, we believe that it is urgent to document the cardiac function of the current astronaut corps.



## SCIENTIFIC OBJECTIVES

The objectives of the present study are:

1. Determine short-term changes after space flight in geometry, structure, and functionality of the cardiovascular system using state-of-the-art CMR, especially using T1/T2 mapping, strain, and 4D-flow sequences.
2. Establish a standardized CMR reference database for long-term follow up after space flight for determining late-onset changes and for determining the specific effects of the duration of spaceflights in low-Earth-orbit.
3. Elucidate the mechanism underlying the possible changes in cardiac size and left ventricular mass after long term space flight.
4. Compare the results from different space flight durations to determine the exposition duration effect.
5. Compare the results from actual spaceflight to the same CMR protocols performed during bedrest. This will serve as a validation



## NEED OF SPACE

- Understanding how normal gravity affects the cardiovascular system can benefit heart failure patients and cancer therapy patients, as it may help mitigate the impact of gravity and radiation on their health.
- This study can provide valuable data for space agencies, serving as a reference and database for investigating how spaceflight duration influences cardiovascular changes, particularly for deep-space missions versus low Earth orbit (LEO) missions.
- By using the same protocol as bedrest experiments, this study can validate the correspondence between the bedrest model and spaceflight-induced changes, benefiting both researchers and space agencies.
- Ultimately, this research has dual benefits, offering insights into managing cardiovascular issues on Earth and addressing the unique challenges of space exploration.



## SCIENTIFIC BACKGROUND

- Ageing is the single biggest risk factor for almost all human pathologies other than those caused by infections or due to congenital defects. Presently, the best understood cause of ageing is senescent cells. There are compelling evidence to suggest the existence of another force that drives ageing. This insight comes from careful analyses of modifications that occur on DNA that concluded that DNA methylation ageing is indeed an innate property of cells and tissues.
- It is proposed that this innate aging process is driven by a yet-to-be characterised "epigenetic maintenance machinery" that is thought to be augmented to counteract potential genomic instability that may be instigated by DNA damage.
- It is however a significant challenge to test the effect of DNA damage on epigenetic ageing in humans on Earth. It is an unrivalled opportunity to analyse the epigenetic ages of astronauts who are exposed to greater DNA-damaging cosmic radiation during prolonged space flight.



## SCIENTIFIC OBJECTIVES

1. Obtain genome-wide DNA methylation data from humans pre- and post-spaceflight.
2. Gain insight into the relationship between DNA damage caused by low earth orbit radiation and age-related epigenetic changes in humans including the epigenetic clock (Horvath, 2013).
3. Characterize DNA methylation changes associated with spaceflight.
4. Describe genome-wide epigenetic changes associated with spaceflight in humans that can contribute to explain DNAm changes.

The project aims to gain insight into how an epigenetic biomarker of aging is affected by the radiation exposure during prolonged spaceflight and test the hypothesis that DNA methylation age progression is associated with DNA damage. This will help to unravel the relationship between epigenetic changes and the aging process in humans.



## NEED OF SPACE

- During spaceflight at ISS, astronauts are exposed to increased levels of radiation (approximately 80 mSV of which approximately half are constituted by protons, which are much more damaging to DNA than terrestrial ionising radiation, which has negligible fraction of proton and are also at very much lower doses (~3mGy/year).
- Thus, astronauts are predictably exposed to increased DNA damage during spaceflight, making this setting unique for investigating the role of DNA damage in the progression of ageing as measured by the "epigenetic clock" and therefore DNAm age.
- This knowledge will be employed to exclude or corroborate potential effectors and variables. As such, the hypothesis that cosmic radiation can perturb epigenetic ageing can be securely tested and concluded but it can only be done as part of a space experiment with the participation of astronauts. The testing of this hypothesis is not only important as a genuine scientific question but also potentially useful for future manned space industries and programmes.



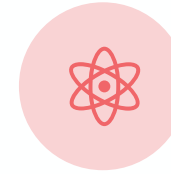
## SCIENTIFIC BACKGROUND

- Ultrasonography is a medical tool capable of addressing two-thirds of potential medical conditions on a spacecraft. It's non-invasive, cost-effective, and free from ionizing radiation, making it the primary imaging method for astronaut health monitoring.
- As space missions venture further from Earth, the communication delay makes real-time tele-operation impractical for astronaut medical monitoring and research.
- To address this challenge, an innovative solution based on augmented reality (AR) called "EchoFinder" has been developed. Before the mission, expert sonographers use this software to save the ideal 3D position and orientation of an ultrasound probe for specific individuals.
- In space, astronauts can recreate the pre-flight probe position using AR visualization, enabling them to perform high-quality ultrasound scans autonomously. These images are then transmitted to Earth for expert evaluation and diagnosis, ensuring astronaut health during space missions.



## SCIENTIFIC OBJECTIVES

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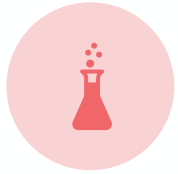
## NEED OF SPACE

- The EchoFinder protocol has undergone testing on Earth and during astronaut analogue missions, but it's crucial to assess its performance in the unique physiological conditions of space, including organ displacement and volume changes.
- EchoFinder has the potential to support medical operations and life sciences ultrasound imaging during future exploration missions by enabling non-expert astronauts to acquire clinical-quality images without external assistance.
- On Earth, ultrasonography is a valuable medical tool, but its widespread use is limited by the need for specialized expertise. EchoFinder aims to democratize ultrasound usage by removing the expertise barrier, making it accessible to a broader population, particularly in underserved or rural areas.
- In deep space exploration, where real-time communication with Earth is limited, EchoFinder becomes essential for astronauts to acquire high-quality ultrasound images independently.

# SNSA Contributions

## SNSA CONTRIBUTIONS WANDT MISSION

MemoBC (ICE Cube)  
Orbital Architecture



## SCIENTIFIC BACKGROUND

- Experiment name: Memo BC
- Organization: Prof. E. Kozlova, University of Uppsala

The experiment proposed by Prof. Elena Kozlova from the University of Uppsala will investigate the molecular mechanism of the “proliferating memory” effect, induced by the exposure to microgravity of boundary cap neural crest stem cells (BCs) and pancreatic beta cells. The experiment will use three batches of boundary cap neural crest stem cells (BCs):

- BCs previously flown on Maser 14 – V14BCs (when free-floating cells were able to keep proliferation capacity for 2 weeks after microgravity exposure in anaerobic and nontemperature-controlled conditions);
- BCs previously flown on Maser 15 – V15BCs (when cells seeded in 3D printed scaffolds were able to keep proliferation capacity for 3 weeks after microgravity exposure in anaerobic and non-temperature-controlled conditions);
- Fresh BCs (i.e., cells never exposed to microgravity before).

A total of 100 samples will fly to the ISS, with cell cultures exposed to ambient temperature ( $24^{\circ}\text{C} \pm 6^{\circ}\text{C}$ ) during all the phases of the spaceflight mission (i.e., from experiment handover on-ground to the launch authorities for integration into the launcher, launch, 2 weeks in-orbit execution within the Axiom-3 mission, download and return to the science team’s lab). The experiment does not need any intervention of the crew other than the placement and removal in/from the storage area on board the ISS.



## SCIENTIFIC OBJECTIVES

- Identify the effects of long-term microgravity on neural stem cell differentiation, proliferation, and function, including their possible delayed emergence. Determine the molecular basis for observed effects, focusing on possible stem cell-induced changes in their culture medium during microgravity, as well as on possible underlying genetic and epigenetic modifications.
- The findings may contribute to novel approaches to harvest microgravity induced beneficial properties of neural stem cells for future Space Applications, during flight and/or under extraterrestrial settlement conditions.
- The results of this investigation will identify hitherto unknown effects of microgravity on neural stem cell properties that may have the potential for translation to biomedical Earth Applications.



## SCIENTIFIC BACKGROUND

- Architecture significantly impacts physical and psychological well-being, especially in confined spaces like space habitats, making it crucial for longer missions and diverse astronaut selection.
- The study assesses architecture's effects on cognition and stress using methods like Heart Rate Variability (HRV) for stress and self-administered cognitive tasks. Brain activity and influencing factors like sleep, diet, and exercise will also be monitored.
- The study will consider astronauts' activity schedules during the mission to infer the architectural factors that may influence their performance and stress levels. Additional factors such as sleep quality, dietary intake, and exercise schedules will be observed.
- Data collected in the space environment will be compared with measurements and observations from ground-based space analogue missions. The focus of reporting will be on differences (deltas) between locations and conditions to protect the astronauts' privacy.

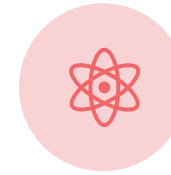


## SCIENTIFIC OBJECTIVES

This study aims to investigate the effects of architectural settings, and their properties to the user's cognitive performance, stress levels, and stress recovery rate. More specifically this activity wants to study if effects between the above-mentioned factors, observed in isolated and confined environments on earth, and especially in space analogue missions, are similarly observed in the environment of a space station.

Briefly, what the team aims to achieve is:

- Monitor astronauts' cognitive performance, stress levels, and prefrontal cortex activity.
- Correlate their location and activities with the above measures.
- Assess perceived stress, sleep quality, and gather data on environmental parameters.
- Collect information on physiological health, nutrition, and exercise schedules.
- Conduct semi-structured interviews with astronauts to enhance findings.
- Analyze the station layout for context and analysis.



## NEED OF SPACE

- This activity focuses on studying how architectural properties affect human cognition and stress during space missions. It aims to validate the use of space analogue missions for such studies and explore how microgravity impacts cognitive performance, going beyond isolation and confinement conditions.
- The research in the space environment provides a controlled setup to examine indirect relationships between architecture and occupants. Novel design requirements developed for extraterrestrial missions may have applications on Earth, benefiting extreme isolated and confined environments like offshore platforms, mines, submarines, and polar stations.
- Ultimately, the research aims to generate requirement suggestions for future space missions, leading to better-designed space stations that enhance astronaut cognitive performance, stress management, safety, and mission success.

# DK Contributions

## DK CONTRIBUTIONS WANDT MISSION

DK EPO Astro Bit  
DK Sleep in Orbit  
DK Thor Davis



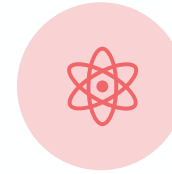
## SCIENTIFIC BACKGROUND

- Focus on STEM activities in Scandinavian schools has increased during the last years.
- HW was uploaded for the occasion of the Huginn mission and as part of 'the ultra:bit project' to develop and facilitate a new national and Scandinavian educational challenge called ultra:space.
- Astro Bit is an educational payload to facilitate programming, critical thinking, and digital skill development. Astro Bit is a modified BBC micro:bit, an open-source embedded system designed to strengthen the teaching of computer programming skills in young people.
- Astro Bit can be used in a hand-held configuration powered by batteries or being connected to the Astro Pi mark II which will provide operational support for space to ground data transfer to and from Astro Bit



## SCIENTIFIC OBJECTIVES

- During the Astro Bit Calibration activity, the crew will investigate the impact of microgravity on 11 built-in physical gestures that the micro:bit can be programmed to detect. It is expected that some will still work in microgravity, while others will not.
- Crew will use trial and error to see if some gestures can be counterfeited by performing certain movements.
- The experiment in orbit will be performed by ESA astronaut Marcus Wandt during the MUNINN mission.
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## NEED OF SPACE LAB

- The purpose of the project is to get Marcus Wandt to investigate space on behalf of the students.
- The Astro Bit's sensor package contains, among other things, an accelerometer, a magnetometer, a light meter and can give insight into mass versus weight, motion and inertia, acceleration and velocity – all in micro-G.



## SCIENTIFIC BACKGROUND

- Sleep is intimately related to our health, well-being, and cognitive performance. Living in zero gravity and in an artificial day-night cycle influences our circadian rhythm and sleep patterns. Poor sleep has immediate negative consequences on human's: attention, concentration, learning, memory, problem-solving, decision-making, creativity, emotional processing, and judgment. There is mounting evidence that in the long term, poor sleep increases the risk for cognitive decline and dementia.
- Sleep stages are per definition related to brain states and must be assessed based on electrical brain signals (EEG). Ear-EEG is a method to record EEG signals from electrodes placed in the ear. Ear-EEG based sleep monitoring has been thoroughly validated against gold standard and has proved to provide reliable and accurate sleep measurements. The crucial advantage of ear-EEG over alternative recording methods is, due to easy-of-use and minimal obtrusiveness to the sleep, that it can be used for long-term sleep monitoring.



## SCIENTIFIC OBJECTIVES

- The overall objective is to investigate quantitative physiological differences between sleep on Earth and sleep in space.
- The study comprises several nights recording before launch (Pre-Mission), several nights recording at the ISS (During Mission), and several nights recording after return to Earth (Post-Mission).
- The primary objective is to investigate if there are quantitative physiological differences between sleep on Earth and sleep in space.
- The secondary objective is to characterize any such differences.
- The third objective is to assess if any such differences have influence on astronauts' health (short and long term effects) and cognitive performance (short term effects).



## NEED OF SPACE

- This activity is based on a method for sleep monitoring, which have been thoroughly validated on Earth.
- There are two main reasons for applying the method in space:
  1. it has the potential to increase safety and reduce human errors in future space missions
  2. monitoring sleep in space provides a unique opportunity to study physiological manipulation of the brain's environment, which are relevant for neuro and health science.



## SCIENTIFIC BACKGROUND

- The technical purpose of THOR-DAVIS is to test a new camera concept in space for observations of thunderclouds and their electrical activity at up to 100.000 frames per second. The camera type is a so-called neuromorphic camera (or event camera) where pixels are read out asynchronously when the photon flux to a pixel changes. The goal is to understand, under realistic conditions, the use of such a camera for future use in space for observations of processes in severe electrical storms.
- The scientific purpose is to conduct video camera observations of thunderclouds and their electrical activity. The focus is on altitude-resolved measurements of activity at the top of the clouds and the stratosphere above.
- The neuromorphic camera must be uploaded. It will be operated with a coaligned normal camera already on the ISS.



## SCIENTIFIC OBJECTIVES

- RO1: Evaluate the use of neuromorphic cameras for thunderstorm observations from future space platforms. By conducting observations of electrical activity of thunderstorms with such camera provided by a collaborator.
- RO2: Secure high-speed observations in three spectral bands of cloud top lightning with the neuromorphic camera.



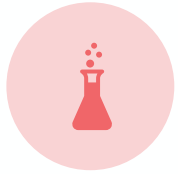
## NEED OF SPACE

- Some of the very intense thunderstorm regions are in the tropical and subtropical regions that are difficult to access and therefore pose significant logistical challenges. Here, on the other hand the ISS offers an almost complete coverage of Earth's thunderstorms with its orbit inclination of 51.6°
- In addition, the ISS is the platform that has the lowest orbit available and therefore brings us as close as possible to the phenomena we want to observe.
- We are particularly interested in corona discharges observed in the near-UV band. These occur at the top of storm clouds and are difficult to observe from ground or aircraft.

# Education

EDUCATION

EPO Generic Videos Wandt



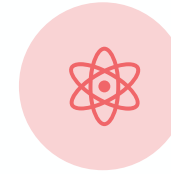
## SCIENTIFIC BACKGROUND

- The ESA Education Office (TEC-XE), in close collaboration with the Directorate of Human Spaceflight and Robotics Exploration (HRE) runs an educational programme for each ESA astronaut on their long duration missions to the ISS.
- TEC-XE develops material which can be used in the classroom to support the teaching of STEM subjects throughout ESA Member State schools. This activity will provide material for a number of education and outreach programmes that are being run by the ESA Education Office and European Space Education Resource Centre (ESERO) Sweden\*, and in concurrence with the Swedish National Space Agency (SNSA) in support of the upcoming Muninn mission of Marcus Wandt to the ISS. The activities related to this project are intended to encourage and strengthen the teaching of science curriculum, and through this, stimulate the curiosity of students and motivate them towards further study of STEM subjects.



## SCIENTIFIC OBJECTIVES

- Filming on ISS with Marcus Wandt, downlink and delivery to ESA/ESERO Sweden of:
- a. Space for Everyone: Interview part of a video production on showcasing careers within the space field
  - b. Welcome to Wisdome: introduction to the dome shows, presentations, and/or space activities of the Wisdome Project
  - c. Mission X: a healthy mind and body: part of the *train like an astronaut school project challenges*; space exercise demonstrations and Q&A about physiological and anatomical changes in microgravity
  - d. REXUS/BEXUS: kick-off and welcome to students involved in the project Rocket Experiments
  - e. Spaceship Earth Sustainability Message: about closed-loop systems, like Earth, and conserving, reusing, and recycling resources to support life
  - f. Life in Weightlessness: simple demonstrations to showcase effects of microgravity
  - g. Paxi on ISS: Space Menu: introduction for pre-primary and primary school children to space through food and nutrition



## NEED OF SPACE LAB

- From ESA Education Office's point of view, the education programme supporting Marcus Wandt's Muninn mission to the ISS is a means to attract and involve students in STEM activities and, in doing so, create awareness about:
- the existence of a European space programme of which Sweden is a part – Marcus is an ESA astronaut,
  - the importance and the benefits of making use of Marcus Wandt's crew time and of the International Space Station as an educational platform,
  - the importance of STEM education both for ESA and the SNSA, and their sharing of educational objectives.

\* ESERO Sweden is an initiative of ESA and the SNSA, run by KTH Royal Institute of Technology in collaboration with the Wisdome project's five science centres: Tekniska museum, Malmö Museum, Universeum, Visualization Center C and Curiosum. 18

# Tech Demo

## TECH DEMONSTRATIONS

Anita-2  
Surface Avatar  
VR-OBT 2



## TECHNICAL BACKGROUND

- ANITA-2 (ANalyzing InTerferometer for ambient Air) is a FTIR (Fourier Transform InfraRed) spectrometer that has the capability to monitor simultaneously 32 gaseous compounds, with a high time resolution (i.e. one sample every 5 minutes).
- ANITA flew on ISS as a technology demonstrator in summer 2007 with successful measurements and operations the mission lasted 11 months in total.

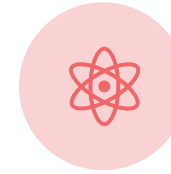


## SCIENTIFIC OBJECTIVES

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

- Demonstrate the air monitoring capabilities under realistic conditions in a space habitat, including the dynamic variation of air contaminants caused by astronaut activities, scientific experiments, degradation of space hardware over time, microbial activity etc.
- ANITA is a highly sensitive FTIR air contaminant analyser which in future evolution will allow automatic monitoring of air quality in open atmosphere and closed habitats.
- 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.



## SCIENTIFIC BACKGROUND

- ACLS stands for Advanced Closed Loop System and includes a regenerative physico-chemical life support system which:
  - provides breathable oxygen for a crew of 3
  - reduces carbon dioxide (CO<sub>2</sub>) from the ISS atmosphere in concurrence with ISS ECLS and
  - converts hydrogen (H<sub>2</sub>) with CO<sub>2</sub> to methane (CH<sub>4</sub>) and water (H<sub>2</sub>O)
  - is able to provide the CO<sub>2</sub> removal function and the O<sub>2</sub> generations function independently from each other in so called stand-alone operational modes.



## SCIENTIFIC OBJECTIVES

- The Advanced Closed Loop System (ACLS) rack is a European Space Agency (ESA) designed life support rack that will demonstrate technology in CO<sub>2</sub> removal, O<sub>2</sub> production, and H<sub>2</sub>O production.
- The goal set by the ESA and the ECLS SMT is to achieve 1 year of cumulative operations in the first 2 years ACLS is installed. This run-time is desired to prove the reliability of the technology for potential use in future exploration missions.
- Upon successful demonstration of the ACLS technology, all hardware is expected to remain on-orbit for the duration of the ISS available to provide an operational function in agreement with the ISS Vehicle Office. ESA is responsible to manage procurement & upload of spare parts and the disposal of consumables, and it will be under system allocation.





## SCIENTIFIC BACKGROUND

- Robotic assets for exploration and infrastructure development on heavenly bodies avoid dangerous and time-consuming EVAs and lowers the barrier to entry to the planet surface. Effective command of these assets from orbit is essential: an operator should be able to control semi-autonomous robot teams, but at the same time also be able to “dive inside” a particular robot and control them as an avatar. This is possible from orbit but not from earth, due to the time delay and hence stability/transparency issues.
- The concept of commanding on these different levels and seamlessly transitioning between them is called “Scalable Autonomy”. From previous experiments we have seen the need for this in space teleoperation. Having reached the limits of the insights that can be gained on earth, many questions still need answering before we can deploy and control robots on a heavenly body from orbit.



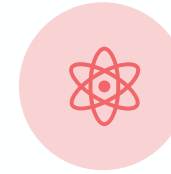
## SCIENTIFIC OBJECTIVES

Multi-modal, holistic user interface (UI) command of individual dissimilar robots at changing scales of autonomy.

- A UI used for commanding a variety of robots at various scales of autonomy should therefore be holistic: switching command between two robots, between different scales of autonomy, and between planning and commanding, should be easy and transparent.

Extending multi-modal UI command to team(s) of dissimilar robots.

- Having multiple, dissimilar robots work together on a task increases the range of tasks that can be performed. Commanding multiple robots, however, should introduce as little additional complexity in the UI for the crew as possible. In order for telerobotic exploration, building and maintenance to be practical, a single human operator will need to manage a team of robots without excessive physical or mental workload.



## NEED OF SPACE

It was reached a barrier with respect to the insights that can be gained from terrestrial research. This is due to two main reasons:

- The first is the physical conditions in which the operator works. Not only does the communication channel between the robot and operator have high latency, low bandwidth and poor quality, but the astronaut must remain in a confined space with limited company. Their only communication is with the scientists and engineers responsible for the system, many of whom they have not met or only met briefly a long time prior.
- The second is the known fact that sensorimotor performance is degraded in microgravity even after long acclimatisation. This makes it imperative to investigate and draw insights for teleoperation with haptic feedback in microgravity, with operators who have had time to acclimatise themselves (i.e. not on a parabolic flight). In addition, the difference between gravity on earth and microgravity in space may create a cognitive dissonance.



## SCIENTIFIC BACKGROUND

- On-board training (OBT) materials are essential for space missions and can include renders and animations of complex tasks and hardware. With the focus on destinations beyond LEO, the need for efficient and effective on-board training is increasing.
- Virtual reality (VR) offers a unique advantage, allowing users to interact with and observe complex 3D objects and data. VR has the potential to play a crucial role for future training in space exploration.
- In 2021, a technology demonstration called VR-OBT tested the effectiveness of using Virtual Reality for on-board training. However, the initial attempt faced issues with the hardware, specifically the Virtual Reality Head Mounted Display (HMD), which couldn't withstand the space environment.
- VR-OBT-2 is a repeat of the earlier experiment, but with a different HMD that has been tested for compatibility with the space environment during parabolic flights and has shown promising results. If successful, this technology could be applied to other experiments requiring on-board training.



## SCIENTIFIC OBJECTIVES

1. Precisely quantify the compatibility of the new VR HMD with the ISS environment
2. Evaluate the capability of the experiment and its communication infrastructure to support real-time space and ground collaboration in VR.
3. Evaluate the efficiency of OBT delivered via a VR HMD in terms of the time required to carry out the OBT and the time and resources required to develop the VR OBT content relative to 'standard' OBT content



## NEED OF SPACE

- The effectiveness of VR as a training medium on board the ISS is to be confirmed. It presents unique challenges in the space environment, including user motion tracking in microgravity and ensuring safety when using opaque Head-Mounted Displays (HMDs).
- VR-OBT-2 aims to advance the state-of-the-art in space-based VR training, contributing to the knowledge base for designing valuable VR training applications in areas like hazardous material handling, surgery, and heavy equipment operation on Earth.
- In space, crew members face complex and potentially hazardous tasks, making VR a tool for understanding three-dimensional information. VR HMDs can provide a more immersive experience, conveying complex 3D models, motion, and interactions in ways that traditional digital media cannot.
- VR's immersive nature can help astronauts become more familiar with unexperienced environments and tasks, particularly as missions venture beyond low Earth orbit, where greater autonomy is expected of astronauts.

# Material Sciences

**MATERIAL SCIENCES**

MSL Batch 3a  
PK-4 (R) Science Campaign



## SCIENTIFIC BACKGROUND

- The MICAST and CETSOL projects aim at directional solidification of metallic alloys to identify the gravity-induced solidification phenomena and to develop analytical and advanced numerical models.
- Using the comparison of ground-based and microgravity experiments will pinpoint the effect of gravity and increase the accuracy of these computer models. MICAST focusses on solidification of AlSi-based alloys with different compositions, studying dendritic growth and the formation of intermetallic phases, eutectic growth and primary Si-phases in diffusive conditions and with forced melt flow. Within CETSOL, the columnar growth and the columnar-to-equiaxed transition as well as fragmentation effects will be investigated in refined AlCu alloys applying diffusive boundary conditions in microgravity without melt flow and sedimentation.
- The experiments of Batch 3a will make use of the Low Gradient Furnace (LGF) and the Solidification and Quenching Furnace (SQF).



## SCIENTIFIC OBJECTIVES

1. MICAST. The project is dedicated to (1) systematic analysis of the effect of convection on the evolution of the microstructure in technical Al-alloys, (2) investigate flow effects on binary and ternary variants of technically important aluminium casting alloys, and (3) combine advanced theoretical and experimental research methods on ground and in space.
2. CETSOL. The project is dedicated to deepen the quantitative understanding of the physical principles that govern microstructure formation with particular attention paid to the columnar-to-equiaxed transition (CET) in technically relevant cast alloys by directional solidification experiments.



## NEED OF SPACE

- In order to perform experiments in space, those projects will make use of the Materials Science Laboratory (MSL). The Materials Science Laboratory (MSL) is part of the Materials Science Research Rack 1 (MSRR-1), which is housed (since Aug 2009) in the US “Destiny” Module on the International Space Station to perform unique experiments in the field of high temperature materials research under significantly reduced gravity conditions.
- The MSL consists primarily of a Process Chamber accommodating both the Furnace Insert (FI) and the individual experiment cartridge, hereafter referred as a Sample Cartridge Assembly (SCA). Various FIs and SCAs will allow different types of materials science experiments to be performed. These experiments will include research into alloy solidification, crystal growth and the measurement of thermophysical properties, over a wide range of temperatures and with different experimental profiles.



## SCIENTIFIC BACKGROUND

- 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.

# Fluid Physics

FLUID PHYSICS

FSL FOAM C



## SCIENTIFIC BACKGROUND

- Foams are dispersions of gas into liquid or solid matrices. The behaviour of foams in micro-gravity and on earth are very different, because the process of drainage is absent in micro-gravity conditions. Drainage is the irreversible flow of liquid through the foam (leading to the accumulation of liquid at the foam bottom, and to a global liquid content decrease within the foam). Micro-gravity offers the opportunity to investigate the so-called "wet" foams, which cannot be stabilized on earth because of drainage (drainage gets faster as the foams gets wetter).
- The Hydrodynamics of Wet Foams (FOAM) project studies aqueous and non-aqueous foams in microgravity. The objective of FOAM coarsening is the study of the quiescent coarsening of foams as a function of the liquid fraction. It focuses on very wet foams which cannot be studied on ground, due to drainage effect. Conductimetry and multiple light scattering measurements provide measurements of the liquid fraction, of the bubble structure and dynamics of the material during coarsening.

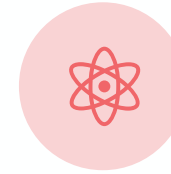


## SCIENTIFIC OBJECTIVES

The role of gravity on quiescent wet foams can be captured in 2 key questions:

1. Is the growth law for average bubble size  $R \sim \sqrt{t}$ , such that  $R \frac{dR}{dt}$  is a constant? If so, what is the liquid-fraction dependence of this rate?
2. How do the rate and the nature of the bubble rearrangement dynamics change as the liquid fraction is increased to the point of un-jamming?

Both questions require prolonged microgravity to capture the dramatic changes expected for the very wet foams. Answers to both represent baseline knowledge of structure/dynamics upon which flow and rheology must be interpreted. While this program can be usefully carried out for a single surfactant, it is also very interesting to examine different types of surfactants and different additives such as polymers and particulates.



## NEED OF SPACE

- Gravity plays an important role in the formation of foam and its subsequent evolution. Its primary effect is to cause excess liquid to drain rapidly away. When the foam is stable enough, it becomes dry and the gravitational force is balanced by a vertical pressure gradient in the liquid (and hence a vertical profile of liquid fraction). This restricts ground experiments to stable dry foams, and indeed the idealized theoretical models are largely confined to the dry foam limit. The present trend of the subject is therefore towards wet foams as well as dynamic effects.
- A micro- or zero-gravity study of wet foam hydrodynamics enables one to overcome the limits imposed by various instabilities experienced under normal gravity. This broader experimental characterization and corresponding insight will provide a scientifically valid alternative for the necessarily conservative empiricism currently employed to estimate the operational window and design for foam handling in industrial processes (such as gas/liquid contacting, flotation and pumping).

# Other National Contributions

## OTHER NATIONAL CONTRIBUTIONS

CIMON (DLR)  
Lumina (CNES)



## SCIENTIFIC BACKGROUND

- Optical Fiber Dosimeter experiment is an active dosimeter based on optical measurements on different types of optical fibers.
- The Lumina sensor includes two optical fiber coils of several hundred meters which are used as an active dosimeter. These fiber coils are cylindrical and conduct light with minimum internal attenuation, allowing the signal of incident particles to easily reach the sensor (photo diode). When exposed to space radiative environment, optical fibers experience Radiation Induced Attenuation. Measurement of this attenuation (comparison between two optical path from a laser diode used as a source and a photodiode as a light receiver) is directly linked to the total ionizing dose.
- Dose monitoring is active as the light source remains permanently ON. For a given set-up, sensitivity of the apparatus is governed by the length of the fiber coil. The longer the fiber, the more sensitive the dosimeter.



## SCIENTIFIC OBJECTIVES

1. The main objective is to consolidate the concept of RIA measurement as a TID indicator in realistic space conditions: particle spectrum (in terms of type, flux, energy), volume constraints, mechanical levels, remote operation (reliability, low band width required), power consumption, interface.
2. The second objective is to increase scientific knowledge on fiber behaviour when exposed to low dose rate for a long time in space.

ISS measurements will provide precise indication on the performance of fibers in space. The first information is the actual sensitivity of fibers to the space radiation spectrum, compared to laboratory models. Another output of the mission is the stability of the RIA response over time. As the experiment will remain onboard for a relatively long duration at a low dose rate, measurements will give a feedback on the dosimeter performance evolution. This might be useful to prepare instruments dedicated to interplanetary exploration missions.



## NEED OF SPACE

- A thorough understanding of radiation exposure is a key issue for space exploration. The principle of RIA measurement on optical fibers as an indication of the total ionizing dose (TID) has been validated many times on particle accelerators and radioactive sources on Ground.
- The method was proven to be very reliable and sensitive to all sources of particles (electrons, protons, photon X and Gamma, neutrons) at various energies. Yet the environment encountered in space is unique. It is very dependent on the orbit, the solar activity, the spacecraft shielding etc. These conditions cannot be reproduced on earth, hence the need for a flight proven RIA dosimeter concept is needed.
- Fiber dosimeters are destined to monitor and detect dose variations on various types of satellites. The experiment on the space station will be exposed to a real radiative environment providing data in space conditions.



## SCIENTIFIC BACKGROUND

- Studies conducted in isolation environments like Mars500 and Antarctic winter-over, as well as short-term microgravity experiments, have revealed the intricate connections between stress, behavior, cognitive skills, and bodily functions.
- Psychological factors, such as peer pressure and groupthink, can arise during deep space missions, affecting communication and decision-making within the crew. Successful interplanetary missions will depend on individual adaptation, crew interactions, and effective psychological countermeasures.
- Airbus has initiated a study to address the technical and psychological challenges of deep space missions by creating the Crew Interactive MObile companioN (Cimon), an intelligent artificial companion. Cimon aims to improve crew-ground control relations and reduce the groupthink effect by providing a communication link between space and Earth, utilizing IBM's "Watson" AI system for clever conversations and information provision to the crew.

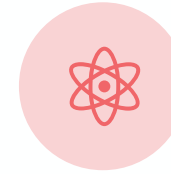


## SCIENTIFIC OBJECTIVES

The goals and objectives of are two as follows:

1. Technology demonstration of free flying unit: Cimon shall demonstrate in two different objectives regarding feasible autonomy as a free flying unit
2. Human Interaction with an Artificial Intelligence and Cimon: the astronauts on board the International Space Station ISS are living and working under very special conditions: a small team in a limited accessible space working on multiple complex tasks. Cimon shall demonstrate the feasibility - how and to which extent a "mobile companion" can support the crew in their daily tasks (Assisted crew activity/Maintenance), perform mobile video documentation and assist during complex science tasks (Science Support), facilitate training of specific motor skills (Skill Training), promote educational outreach programs

The implementation of the above-mentioned goals/objectives can be broken down into simple operations as a first step then progressively tackle more complex tasks in the time ahead.



## NEED OF SPACE

- Cimon represents one of the early steps toward achieving an intelligent mobile crew assistant with potential manipulating capabilities. While testing individual technologies within Cimon might not require a space experiment, it serves as an integrated technology demonstrator, assessing its performance in the real space environment under microgravity conditions and interaction with astronauts.
- Cimon's design is tailored for free flight in space, making it unique in the space environment. Cimon's role includes assisting with complex activities during missions, providing guidance, allowing for easy navigation between procedure steps, and even verifying hardware compliance with procedures. In the future, it may serve as an intercom to communicate with ground personnel and work independently on visual control tasks or experiments, making in-flight evaluations crucial to identify potential challenges and areas where Cimon can excel.