[Inc. 70] Huginn Mission

ESA Experiments Overview

Increment 70 ESA Research Overview

HUMAN RESEARCH
ARED Kinematics
Brain-DTI (G)
Epigenetic Adaptation (G)
Immunity Assay
Muscle Stimulation
Lumbar Pain in Space (G)
Sarcolab-3 (G)

EDUCATION
EPO Astro-Pi
EPO Task List
EPO Astro Bit
EPO Generic Videos Mogensen

FACILITY
Bartolomeo
Biolab Maint
Echo SW Update
EDR-2
EPM
ESA Power Bank
Everywear
PPFS

G: Ground experiment
R: Russian crew

TECH DEMONSTRATIONS
ACLS (Life Support Rack, LSR)
Anita-2
Metal 3D Printer
Surface Avatar
m-NLP

MATERIAL SCIENCES
EML Batch 3.3/4 (TBC)
MSL Batch 3a
PK-4 (R) Science Campaign(s)
Transparent Alloys (INPE)

ENVIRONMENTAL SCIENCE & RADIATION PHYSICS
ASIM (Ext. Payload)
DOSIS-3D

FLUID PHYSICS
Foam-C
PASTA

NATIONAL & COMMERCIAL CONTRIBUTIONS
ASI EVOO
CNES Cerebral Ageing
CNES Food Processor
CNES Lumina
CNES MatISS-3
DLR Concrete Hardening
ICE Cubes
Immune Cell Activation

DK CONTRIBUTIONS MOGENSEN MISSION
DK Aquamembrane-3
DK Circadian Light
DK Denmach
DK Earthshine from ISS
DK Sleep in Orbit
DK SpaceWear Monitor
DK Thor Davis
DK VR for Exercise
DK VR Mental Care

Human Research

HUMAN RESEARCH
ARED Kinematics
Brain-DTI (G)
Epigenetic Adaptation (G)
Immunity Assay
Muscle Stimulation
Lumbar Pain in Space (G)
Sarcolab-3 (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

- 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.

Brain-DTI – Ground

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

- 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.

Epigenetic Adaptation – Ground

SCIENTIFIC BACKGROUND

- The immune system is responsible for sensing pathogens and initiating immune responses against infections. Besides that, it is involved in the bidirectional interaction between the gut microbiota and the brain, and impacts tumour fate in different stages of the disease. Immune cells have complex signalling pathways which are tightly regulated at different levels by epigenetic factors.
- It is largely unknown how long-term space-flight influences changes in the epigenome. It is proposed to identify genome-wide changes of epigenetic modifications associated with enhancers1 acquired during flight in a defined subset of immune cells.
- The epigenomic changes induced by prolonged exposure to microgravity and cosmic irradiation will be compared to alterations occurring under normal gravity in control subjects. This approach will identify pathways involved in altered immune response during long-duration orbital space-flights and establish specific hypotheses concerning potential targets for therapeutic intervention.

SCIENTIFIC OBJECTIVES

It is proposed to investigate global changes in the enhancers responsible for coordinating intrinsic and extrinsic differentiation signals of immune cells after a long-term orbital space-flight.

The objectives are:

1. A mapping of the enhancer landscape pre- and post-flight in specific cell types of the immune system.
2. A correlation of the alterations in the enhancer landscape to changes in the transcriptome.
3. A comparative analysis of enhancer signatures identified across different subjects, which differs in the control subjects comparing crew's data to a control group.
4. A meta-analysis of space-flight associated enhancer signatures to a large cohort of publicly available dataset, aiming to identify commonalities of the space flight associated signatures to other known diseases.

NEED OF SPACE

- Epigenetic mechanisms allow an organism to respond rapidly to the environment through changes in gene expression. The extent to which environmental effects, especially extended orbital space-flights, can provoke epigenetic responses of immune cells represents a promising area of research for space exploration.
- The results of this project will further extrapolate to other cell types besides the immune system and will inform future studies aiming to prevent or control these epigenetic alterations. It will allow to develop countermeasures that help preventing disruption in the immune system and therapies to help treat diseases during spaceflight.
- Ultimately, by comparing the identified signatures to known diseases it might be possible to identify known and approved drugs, which could represent potential treatment options to counteract space flight associated aberrations of the immune system.

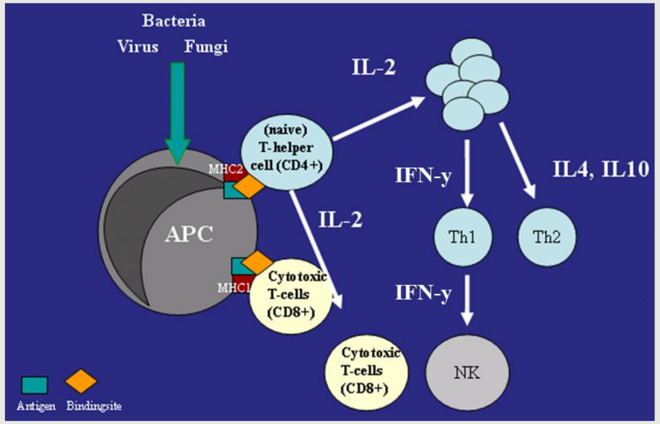
Immunity Assay

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 LAB

- 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.

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

1. exercise capacity,
2. muscle mass,
3. neuromuscular function,
4. muscle endurance of skeletal muscle.

Secondary objectives are to assess whether such effects are explicable by:

1. maintained aerobic energy metabolism and muscle oxygenation,
2. increased neural drive,
3. release of hormonal/trophic factors which are involved in the maintenance of muscle
4. mass, metabolism and attenuation of inflammation.

NEED OF SPACE LAB

- For humans in space, muscle wasting is a substantial problem that negatively affects the health of those travelling on long-term missions. NMES may be a promising tool to improve the training effects on muscle in-flight and to shorten the time required for daily exercise.
- In combination with resistive and aerobic exercise, NEMS could not only improve muscle function, but also allow for smaller and lighter exercise equipment, thus reducing the payload and overall weight on board, and be applied for future reduced gravity habitats as on the Moon or Mars. It is hoped that the information learned from this research study will help the scientific community learn more about human physiological changes for future space flight missions.
- 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.

Lumbar Pain in Space – Ground

SCIENTIFIC BACKGROUND

- Exposing humans to microgravity has severe implications on their health. Low back pain emerges in flight and impairs the performance of the astronauts substantially.
- It is assumed that microgravity induces a swelling of the lumbar intervertebral discs (IVD), which causes the low back pain. New reports are claiming, however, that mechanisms involved in stabilizing the spinal cord might be the main reason for the pain, rather than the disc swelling.
- Additionally, astronauts suffer motor control challenged when exposed to different spine loading/unloading. For maintaining the balance of the upright body and the ability to adapt to changes in gravity and/or additional loading, a healthy motor control of the spine is essential). Gravity plays a key role in this spinal motor control system
- Last but not least, it has been shown that movement kinematics change in response to decrease of microgravity but more research is needed to explain the processes behind those changes.

SCIENTIFIC OBJECTIVES

The objectives of this study are to elucidate the microgravity induced origin of low back pain in astronauts holistically. More specifically, this project aims at:

1. monitoring motion patterns of astronauts and determine the motor control of the spine under various loading conditions pre- and post-flight.
2. revealing the impact of microgravity exposure to the IVDs of the astronauts by conducting experiments on isolated bovine IVDs that have been exposed to similar conditions as the IVDs of the astronauts (Ground Reference Experiment).

This project will investigate the microgravity-induced changes on the human spine to understand in more detail the above-mentioned knowledge gaps. Measurements of lumbar spinal motor control (stiffness and motion patterns) and ultrasonic examination of the discs (with and without load) of astronauts will be performed before and after mission.

NEED OF SPACE LAB

- It is anticipated that investigating the effects of changing gravity conditions and axial load on astronaut IVDs and spinal motor control will lead to an improved understanding of the stabilization mechanisms of the spine in general. Furthermore, by investigating isolated IVDs that experienced similar microgravity exposure like the ones of the astronauts (as part of the ground reference experiment), a more profound knowledge on potential degenerative processes on tissue as well as cell level can be obtained.
- The knowledge gained could help to control spinal stability during future space exploration endeavours, thereby potentially reducing the incidence of low back pain and IVD herniation of astronauts.
- New prevention and therapy programs can be developed for astronauts on long-term space missions. These new programs could also help astronauts in unexpected loading situations and improve spinal robustness.

Sarcolab-3 – Ground

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 LAB

- The evidence obtained so far on humans undergoing chronic disuse on Earth refers to conditions in which gravity has not been removed but simply shifted by 90 degree.
- Cellular signalling in response to changes in mechanotransduction are most likely to be different between conditions where gravity is practically zero (microgravity) and those in which gravity is still present but simply acting along a different axis.
- Hence in order to understand the mechanism of muscle wasting and disproportionate force loss in space, microgravity is the ideal condition where this experiment should be performed.
- Also, from a motor control point of view, the reduction in somatosensory stimulation observed during spaceflight as well as the full degree of physical unloading cannot be reproduced on Earth

Education

EDUCATION
EPO Astro-Pi
EPO Astro Bit
EPO Generic Videos Mogensen

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. Over 39 million Raspberry Pis have been sold between 2012 and 2021 making it the 3rd most popular personal computer in history after the PC and the Apple Macintosh.
- 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. This ensured continuation of Astro Pi operations, mitigated student software performance issues and added new science capabilities.

SCIENTIFIC **OBJECTIVES**

1. Perform a night photography investigation to determine if low-light photography of city lights is technically possible with the Astro Pi hardware.
2. If night photography is determined to be possible, perform a second investigation to identify optimal lens configuration for night photography.
3. Filming of Astro Pi VIS and IR at COL and Nadir window deployment locations using GoPro MAX 360 camera.
4. Fulfilment of European Astro Pi Challenge 2022-23 educational offer to students. Due to visiting vehicle traffic in April/May 2023, there is a real possibility of no nadir windows being available in Node 1 or 2 for Astro Pi deployments. Should this be the case, we would like to use the WORF rack, where both Astro Pi units could be deployed at the same time.
5. Astro Pi hardware remains on ISS, and powered on, for use in future educational activities until HW end of life or until download is requested by ESA Education programme.

NEED OF SPACE LAB

- The European Astro Pi Challenge provides opportunities for students to engage with coding activities in the context of space. The project uses computer coding as a means to do science investigations, and through this, stimulate the curiosity of students, nurture their skills and scientific competences, and motivate them towards further study of STEM subjects.
- The Agency is conscious that it can play a significant role in contributing to a scientifically literate and aware society, and that it has both a responsibility and a vested interest in doing so. The International Space Station (ISS) Education Programme makes use of human spaceflight and the ISS, as a means to capture the attention and the interest of students, to attract them to study, in particular, scientific and technical disciplines, and to appreciate and understand the benefits, challenges, and importance of space for Europe and as a member of a global economy.

EPO Astro Bit

SCIENTIFIC **BACKGROUND**

- Focus on STEM activities in Scandinavian schools has increased during the last years.
- One of the significant Danish initiatives is ‘the ultra:bit project’, in which 1,900 schools across Denmark have received special ultra:bit school sets containing the microcomputer BBC micro:bit and educational materials, with the aim of bringing technology and digital creativity into the classrooms in a structured, meaningful and sustainable way.
- For the occasion of the upcoming Huginn mission, ‘the ultra:bit project’ wishes to develop and facilitate a new national and Scandinavian educational challenge called ultra:space.
- In ultra:space, students design an experiment using coding and the BBC micro:bit. Five experiments will win the challenge. The winning experiments will then be tested in orbit by ESA astronaut Andreas Mogensen during the HUGINN mission

SCIENTIFIC **OBJECTIVES**

- The children are the researchers in this project. The primary objective of the project is to investigate known phenomena from an earth environment in a micro-G environment. The investigation must include the Astro Bit, a domestic BBC micro:bit on ground can run the same experiments for an Earth-based comparison.
- The experiment in orbit will be performed by ESA astronaut Andreas Mogensen during the HUGINN mission.
- Five winning experiments will be selected by ESA, DR and NRK, to be tested by Andreas Mogensen.
- The Astro Pi payload will provide operational support for space to ground data transfer to and from Astro Bit.

NEED OF SPACE LAB

- The purpose of the project is to get Andreas Mogensen to investigate space on behalf of the students. The students submit their experiment ideas in the form of questions about whether something that works on earth will work in the same way in space (LEO) along with their computer program to test the expereiment. A BBC micro:bit must be included in the experiment. The concept is thus based on natural science phenomena that amaze the students.
- The students can pose a question, that we know beforehand will not work in micro-G as there is important learning in Andreas explaining why this doesn’t work. Andreas Mogensen should be seen as the students' helper, who can make them more aware of the conditions in space. Andreas Mogensen tests the winning entries at the ISS in a USOS module. And tells, based on the students' experiments, why it can be done or not, and which natural forces or phenomena are at play. The competition gives students a completely unique opportunity to test their hypotheses in space.

EPO Generic Videos Mogensen

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. The programmes usually target various academic levels and include inflight calls between the crew and students of various ages.
- 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 Danish Rumrejsen Consortium and ESA in support of the upcoming Huginn mission of Andreas Mogensen 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**

1. Filming on ISS with Andreas Mogensen, downlink and delivery to ESA/Rumrejsen Consortium of:
   a. IFCs Back-up(1 video, filmed in EN & DA)
   b. Astronaut logbook and Humans in Space exhibition (EN & DA) – 4 videos

2. Capture of imagery on ISS by Andreas Mogensen, downlink and delivery to ESA/Rumrejsen Consortium of:
   a. Earth from Space Quiz with Andreas (10 images)
   b. Paxi art competition: Favourite place on Earth (up to 9 images)
   c. Astronaut logbook with Andreas (2 images)

3. Capture of diary text:
   a. Five astronaut logbook diary entries in English emailed directly to PIs via crew personal email (one separate entry to accompany each video and image) as agreed with Andreas Mogensen on 8 May 2023.

NEED OF SPACE LAB

From ESA Education Office's point of view, the education programme supporting Andreas Mogensen’s Huginn 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 Denmark is a part – Andreas is an ESA astronaut,
- the importance and the benefits of making use of Andreas Mogensen’s crew time and of the International Space Station as an educational platform, achieved thanks to the partnership between ESA and the Rumrejsen Consortium for education activities,
- the importance of STEM education both for ESA and the Rumrejsen Consortium, and their sharing of educational objectives.

Tech Demo

TECH DEMONSTRATIONS
ACLS (Life Support Rack, LSR)
Anita-2
Metal 3D Printer
Surface Avatar
m-NLP

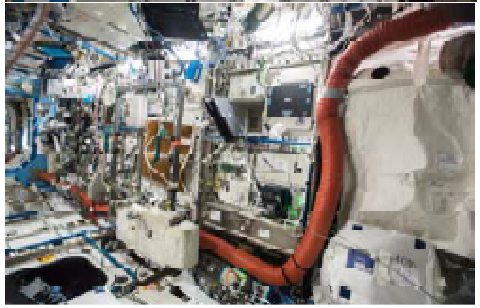
Life Support Rack (LSR) – Maintenance

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 (CO2) from the ISS atmosphere in concurrence with ISS ECLS and
  - converts hydrogen (H2) with CO2 to methane (CH4) and water (H2O)
  - is able to provide the CO2 removal function and the O2 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 CO2 removal, O2 production, and H2O 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.



Anita-2 – Docking vehicles

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.

Metal 3D Printer

esa

SCIENTIFIC **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 objective of this activity is 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.
- The activity aims to demonstrate the complete chain of the in-orbit manufacturing process, including handling by crew, supported by ground operator.
- Production samples will be returned to Earth for in-depth analyses, including mechanical and microstructural evaluation. In addition, the activity intends to analyse and, at a level commensurate with the present possibilities offered by the technology, to demonstrate the concept of in-situ part manufacturing and repair.

NEED OF SPACE

- Whereas 3D printing is an established technology on Earth, the use in spaceflight is still in an early stage. Initial operation of 3D printers in space – i.e. International Space Station -, focus on printing using polymers. This covers only a limited use.
- Metal 3D Printing in space is expected to be complementary to printing polymers. However, metal printing in space also 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. As the process of printing metal parts by additive manufacturing is in the order of days2, a long duration flight opportunity such as ISS/Columbus is imperative.

Surface Avatar – Stand-alone

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.

m-NLP

SCIENTIFIC **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 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 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

- The ISS orbits at an altitude of around 400 km, near the peak plasma density of the ionosphere; additionally, it has – compared to standard satellite platforms – a large data downlink bandwidth combined with a large availability of electrical power. The ISS is therefore the ideal platform to host the multi-needle Langmuir probe (m-NLP) which is, to our knowledge, currently the only instrument in the world capable of resolving ionospheric plasma density variations at spatial scales below one meter.
- The placement of the m-NLP on board the ISS is justified by its two main purposes:

1. The m-NLP will gather valuable data from the equatorial and mid-latitude ionosphere, allowing us to study dynamical processes in this region in unprecedented detail; and
2. The m-NLP will act as a reference for other m-NLP instruments deployed on satellite platforms, allowing us to cross-validate and cross-calibrate the instrument across various platforms

Material Sciences

MATERIAL SCIENCES

EML Batch 3.3/4

MSL Batch 3a

PK-4 (R) Science Campaign(s)

Transparent Alloys (INPE)

EML Batch 3.3/4 – 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**

The aims of the Batch 3 experiments covers 12 individual projects.

Topics are: morphology of chill-cooled industrial steel, thermophysical properties of supercooled Ti-Zr- Ni liquids of different composition, solidification, thermophysical properties and electrical conductivity in liquid of the eutectic system formed by the phases CoSi and CoSi2, metastable phase formation of magnetic alloys, study of nucleation, microstructure investigation and determination of the growth velocity of Al-Ni, Al-Fe, Al-Cu and Si-Ge samples, influence of melt convection on phase selection in technically important peritectic alloys, thermophysical properties and electrical conductivity of liquid Si-Ge semiconductor alloys, thermophysical property (specific heat, density, surface tension and viscosity, electrical conductivity) measurements of industrial alloys, influence of melt convection on phase selection in technically important eutectic and peritectic alloys, nucleation and supercooling of glass- and quasicrystal-forming alloys, thermofluid and magnetohydrodynamic effects in liquid metal samples.

NEED OF SPACE

All sample systems have been tested in numerous Parabolic Flight Campaigns using the TEMPUS Parabolic Flight Facility of DLR in preparation for the EML missions.

MSL Batch 3a – MSL facility

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.

PK-4 – EPM (with Russian crew support)

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.

Transparent Alloys - INPE

SCIENTIFIC **BACKGROUND**

- **SETA**. The aim of this experiment is to study the pattern formation during univariant eutectic reaction in directional solidification in transparent ternary alloys. This pattern formation process shall not be affected by wall effects or by convective contributions to the heat and mass transport during the phase formation.
- **SEBA**. The aim of this experiment is to study the morphological instabilities of directionally solidified, transparent binary eutectic alloys under purely diffusive conditions.
- **METCOMP**. The aim of the METCOMP project is the research on layered structures in peritectic systems by in-situ observation.
- **CETSOL**. the ultimate objective of the CETSOL research programme is to significantly contribute to the improvement of integrated modelling of grain (crystal) structure in industrially important castings.

SCIENTIFIC **OBJECTIVES**

- **SETA**. Observation of the microstructure formation in univariant two-phase eutectic growth along the different eutectic grooves, study nucleation of eutectic phases on pre-existing phases in transient growth,o bservation of the origin of fault lines in eutectic structures and changes of the faultless eutectic structure.
- **SEBA**. Study of the formation and the relaxation of topological defects in rod-like structures, the rod-to-lamellar transition of eutectic growth patterns, the forcing effects of distortions of the thermal gradient.
- **METCOMP**. Study of the influence of gravitational effects on the microstructure evolution by comparing 1g and µg, experiments to pinpoint the effect of gravity, determination of microstructure selection maps, correlated to particle size, growth dynamics and fluid flow process parameters.
- **CETSOL**. The experiments have the objective of characterising the columnar and equiaxed solidification and columnar-to-equiaxed transition in transparent alloys.

NEED OF SPACE

- **SETA**. The experiments under microgravity shall for the first time enable the observation of the dynamics of the pattern formation in an univariant two-phase eutectic alloy.
- **SEBA**. Observations would be strongly sensitive to convective motions in the liquid, which, in ordinary conditions on Earth, entail a detrimental redistribution of the solute on a scale comparable to the container size. Such convective motions are suppressed in microgravity.
- **METCOMP**. The comparison of the experimental results, in space and on Earth, will allow evaluation of the influence of natural convection on the microstructure evolution.
- **CETSOL**. The major aim using transparent model alloys will be to identify growth regimes (columnar or equiaxed or mixed) and physical mechanisms in dependence of the experimental parameters (solidification velocity, temperature gradient) for diffusive heat and mass transport and without gravity effects.

Environmental Science & Radiation Physics

ENVIRONMENTAL SCIENCE &
RADIATION PHYSICS
ASIM (Ext. Payload)
DOSIS-3D

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**

1. Atmosphere and Climate: provide the most comprehensive global survey of TLEs and TGFs, study the physics of TLEs and TGFs, how TLEs and TGFs are related to lightening, quantify effects of gravity waves on the mesosphere, study high-altitude cloud formation, determine the characteristic of thunderstorms that make them effective in the perturbation of the high-altitude atmosphere.
2. Space Science: study effects of thunderstorms on the ionosphere and the radiation belts, determine the distribution of meteors in the Earth's environment and quantify their effect on the atmosphere, lightening-induced electron precipitation and relativistic electron precipitation, aurora borealis.
3. Earth Observation: dust storms and their effect on cloud formation and electrification, mega-cities and the effect of pollutants on cloud formation and electrification, forest fires and volcanoes and the relation to cloud formation and electrification, intensification of hurricanes and its relation to eye-wall lightning activity.

DOSIS 3D – Stand alone

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 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**

1. 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 radiationsensitive experiment in space. A first version of the database designed for educational purposes is available within the so-called 'DOSIS Data Viewer'.
2. 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.

Fluid Physics

FLUID PHYSICS
Foam-C
PASTA

Foam Coarsening 2-3 - FSL

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~Sqrt[time], such that R 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).

PASTA - 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

- Microgravity conditions provide a unique environment to investigate emulsion destabilization under the sole effect of coalescence. In fact, on ground conditions segregation (creaming) is coupled with coalescence in an intricate way.
- Coalescence is however the real process triggering the destabilization in low viscosity emulsions. In fact micrometric (or sub-micrometric) droplets in the absence of coalescence would remain uniformly dispersed under the effect of Brownian motions.
- Specific microgravity experiments are therefore able to provide evidences of the relations between the properties of the interfacial layers of droplets and their coalescence, allowing testing all existing models and develop innovative approaches.
- The latter will respond to the request of prognosis tools to help the formulation of emulsifiers and de-emulsifiers in a wide range of industrial applications.

National and Commercial Contributions

NATIONAL AND COMMERCIAL CONTRIBUTIONS

ASI EVOO
CNES Cerebral Ageing
CNES Food Processor
CNES Lumina
CNES MatISS-3
DLR Concrete Hardening
ICE Cubes
Immune Cell Activation

ASI EVOO

SCIENTIFIC **BACKGROUND**

- The Extra Virgin Olive Oil (EVOO) in Space investigation studies the effects of exposure to the extra-terrestrial environment on extra virgin olive oil. The physicochemical, sensorial and nutritional characteristics of veiled and filtered extra virgin olive oils are compared to those from controls kept on the ground.
- Physicochemical, sensorial, nutritional and microbiological analyses will be carried out on extra virgin olive oils before and after flight to determine any changes from exposure to the space environment (mainly: free acidity, peroxide index, UV absorption, phenols content and profile by tandem mass spectrometry, fatty acids analysis by HRGC, tocopherols analysis by HPLCFD; microbiological contamination by in vitro culture and metagenomic analysis; and sensory analysis by virgin olive oil tasting panels).

SCIENTIFIC **OBJECTIVES**

The objectives of the olive products in space investigations are:

- To study the impact of exposure to the space environment (microgravity and radiations) conditions aboard the International Space Station (ISS) on extra virgin olive oil physicochemical, sensorial, nutritional and microbiological characteristics.
- To observe the composition of olive secondary metabolites, such as phenols and tocopherols (vitamin E) as affected to microgravity conditions.
- To gather new information concerning olive oil composition and shelf-life to new environmental conditions.

NEED OF SPACE

- The consumption of EVO oil is certainly beneficial for astronauts' health during long term space missions. It would therefore be important to understand whether EVO oils would retain their properties when stored into spacecraft exposed the space environment for long period of time. This is even more important when considering the future long duration mission for extra-terrestrial exploration. There are no on-ground facilities capable of reproducing the specific space environment (micro-g and radiations), especially for a duration of time relevant for long-term space missions, therefore these tests need to be performed in real space conditions.
- It is also important the EVOO samples, even though they are considered a scientific experiment, are uploaded following the nominal logistics of astronaut food, to include also the overall environmental conditions and the nominal timeline usually the standard food follows. For this reason, it is highly recommended the EVOO Sample are uploaded in the food tray prepared for the astronaut meals.

CNES Cerebral Ageing

SCIENTIFIC **BACKGROUND**

- Culturing living human cells in the space is limited because of the need to passage the cell cultures under sterile conditions that are difficult to maintain in micrograviy. Therefore, analysis is restricted to a few days of culture of these cells. Moreover, these cultures are limited to the 2D conditions that are poorly representative of the physiological state.
- To overcome these limitations and provide human-derived material to analyse in space, we propose to use 3D cerebral organoids (= minibrains = MBs) derived from human healthy individuals or from patients.
- These organoids are complex structures that recapitulate human brain development in a dish and can be maintained in culture for several months. We plan to study the ageing process in MBs derived from normal individuals and from aptients with accelerated ageing/neurodegeneration and/or displaying hypersensitivity to UV irradiation similar to the one which are exposed living organisms in space.

SCIENTIFIC **OBJECTIVES**

To molecularly test human ageing in space to answer the following questions:

1. Do human cerebral organoids (MB) display earlier signs of ageing in space, and to what extent are these signs dependent on irradiation and/or microgravity?
2. Is this effect enhanced in MB originated from progeroid cells, and is this enhancement due to irradiations/oxidative stress and/or microgravity?

For the following analyses will be conducted:

i) MB sections for histology analysis

ii) MB sections for immunofluorescence analyses (cell type, molecular markers of the progeroid pathways, senescence)

iii) Protein extraction for WB analyses (progeroid pathways, senescence, autophagy, DNA repair markers, protein damage linked to ageing)

iv) RNA extraction (for transcriptome)

v) Maintenance of fixed samples for further analyses

vi) Assess markers of Alzheimer's disease in MB supernatant

NEED OF SPACE

- Longer periods in space are foreseen for astronauts in future trips (more distant planets, longer missions). The impact of the "space conditions"(irradiation, microgravity) on ageing is only starting to be investigated for human models. Only biochemical and molecular analysis can be performed from human material collected during human space flights (mainly or human waste). Molecular analysis is also limited for several tissues that are particularly affected during ageing, such as the brain, which cannot obviously undergo molecular analysis, let alone during the period in space. Therefore, human derived MBs represent a unique tool to test molecular changes linked to ageing during an increasing time in space.

CNES Food Processor

SCIENTIFIC **BACKGROUND**

- The Food Processor project is part of a more global project, the Advanced System for Space Food (ASSF) project, part of the CNES roadmap "Nutrition for Exploration", whose goal is to develop an equipment allowing astronauts:

1. First, to cook healthy and balanced meals, manage food stocks (using either food shipped from Earth or food produced on site) and adapt recipes according to the nutritional needs of astronauts during long-duration space flight (e.g. lunar base, mission to Mars)
2. Second, to give the astronauts the pleasure to prepare recipes during missions and enjoying eating them.

- Using the ISS capability, the intent is to perform a technological demonstration: the first prototype of the Food Processor will be able to cook the first in-flight recipe with the validation of two basic cooking functions: beating and mixing food basic components..

SCIENTIFIC **OBJECTIVES**

- The objective of the ASSF is multiple: scientific and medical (maintaining nutritional values, pleasure and good health of the crewmembers), educational (eating well, good and healthy), technological (technological evolution), communication (a robot can cook in space?) but also psychological (involving astronauts in the conception of meals for long duration flights).
- The present technological demonstration experiment is to test the equipment (prototype) with one specific recipe using three primary cooking functions: rehydration (using water from the ISS water dispenser), beating egg whites and mixing products; then the fully functional equipment (weigh, mix, knead, heat, dry, cook, colour, rehydratation) will be developed and available for exploration flights. Furthermore, the objective is also to demonstrate that the expected results (see section below) will be obtained and that the physico-chemical processes will perfor adequately under microgravity conditions (see below).

NEED OF SPACE

- This equipment is developed to help astronauts to cook meals adapted to their nutritional needs and give them some pleasure with eating time.
- This equipment will cook for them in a secure way respecting space/microgravity related restrictions.

CNES Lumina – Stand-alone

SCIENTIFIC **BACKGROUND**

- Optical Fiber Dosimenter 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.

CNES MatISS-3 – Stand-alone

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 reducing the contact area of water droplets with surfaces.
- Matiss-3 aims to test new surface treatments using new technologies and analytical tools, as the current sample holder only allows morphological analysis of the contamination using light microscopy techniques.
- At this stage, modifications of the sample holder used until now are proposed to allow more in-depth analyzes of the contamination of the exposed surfaces and, in particular, the identification of the particles by the use of Raman spectroscopy techniques, in a first phase, and then by the use of X fluorescence in a second phase.

SCIENTIFIC **OBJECTIVES**

- Strategy on Matiss-3 is to focus on microorganisms over different contamination sources by testing new antimicrobial coatings in the ISS. Using hydrophobic coatings will help to target microorganisms via their water droplets.
- Selected new coatings will precisely target microorganisms rather than bigger particles, in order to define and design new control systems of biological contamination for the exploration.
- Matiss-3 will use a modified sample holder from the versions used for the previous parts of the project. The new sample holders constitute a notable evolution by allowing identification of contamination via Raman spectroscopy and X-ray fluorescence methods. Flight sample holders will integrate innovative surfaces supplied by CEA-Leti.
- Post-flight analysis of the sample holder will be conducted by Raman and X spectroscopy in order to validate the instrumental concept and the associated analysis.

NEED OF SPACE

- Antimicrobial surfaces are currently used on Earth in a number of sectors, such as healthcare, food industry, water industry, textiles. Consequently, numerous tests and standards exist for evaluating antimicrobial surfaces for terrestrial applications. However, they are not being adequate for closed habitats environment, and do not take into account parameters specific to manned spaceflights such as environmental conditions including radiation effects and impact of microgravity on the attachment mechanisms of contaminants on modified surfaces.
- Studies are currently being conducted to derive standard requirements for the evaluation of antimicrobial surfaces in the very specific context of manned spacecraft, but the complexity of the environment need to be derived in precise test parameters. In particular, the concentration and content of test inoculum lead to complex and hardly reproducible tests conditions, calling for in-situ data collection to support theoretical studies.

DLR Concrete Hardening

SCIENTIFIC **BACKGROUND**

- Concrete is a widely used material for construction purposes. It is based on cement that acts as a binder in which an aggregate such as sand is embedded, thus forming a rigid material. The cement itself results from the chemical reaction (hydration) of the initially dry cement powder with added water (H). The commonly used Portland cement contains mainly calciumoxide (C) which reacts to calciumhydroxide Further reactions occur which involve the sand (S), resulting in silicates and silicate hydrates. Various crystalline phases are formed from the mineral and silicate hydrate constituents, where the C-S-H phase gives the main contribution to the material's rigidity.
- Currently, not only various chemical compositions, potentially with alternative binders or aggregates, are investigated in contemporary research, but also the rheology, the effects of packing density and polydispersity that all determine the material properties of the slurry and the final hardened concrete.

SCIENTIFIC **OBJECTIVES**

- Mixing of Concrete

Dry mixtures of cement and sand or regolith simulant shall be uploaded within suitable containers. On orbit, water is added to the mixture. The water shall be obtained on-orbit from reverse osmosis. For samples with additives i.e. superplasticizer or air entraining agent, the water-additive mixture shall be uploaded in a syringe specific to each sample. The concrete slurry shall be mixed thoroughly. Trapped air shall be removed from each sample by crew adjusting the mixing container volume.

- Long-duration Hardening of Concrete

Each concrete sample shall be left to harden on orbit for multiple months. Selected samples shall be photographed just after mixing and at a later point in time. Finally, all samples shall be downloaded for analysis on ground.

NEED OF SPACE

- The samples prepared in microgravity shall extend the accessible parameter range to test theoretical models. In microgravity, buoyancy-driven processes are absent. Specifically, different sizes and spatial distributions of crystalline and amorphous phases and pores could result from the proposed experiments that cannot be realized on ground. This was shown already for the ettringite crystals which are formed during the early stage of the cement hydration, as investigated previously during parabolic flights. Experiments in microgravity of much longer duration on ISS showed increased porosity of cement samples as well as more bubbles of trapped air compared to samples from ground reference experiments.
- The project proposes the investigation of concrete mixtures containing aggregates of different chemical composition and size distribution, specifically sand and lunar regolith simulant. Samples of suitable size and geometry shall be produced in space for detailed analysis on ground to assess their mechanical strength and microstructure.

ICE Cubes – EPM

SCIENTIFIC **BACKGROUND**

- Experiment Cube #: 6.5
- Experiment name: Kirara #5
- Organization: Japan Manned Space Systems Corporation – JAMSS

- Features:
- Proteins are contained in dedicated capillaries that are inside plastic tubes where proteins are put in contacts with reagents in such a way to develop crystals during the period in microgravity (also see this paper for details about the technique). The technology was originally set up within the JAXA JCB-SGT experiments.
- Protein crystals were obtained during the Kirara #1, #2, #3 and #4 missions (Experiment Cube #6.1, #6.2, #6.3 and #6.4).
- The Cube is equipped with its own thermal control subsystem to automatically keep the temperature of the incubator at 20+/- 2° C. A Peltier module and a temperature sensor are used for temperature control.
- Cooling fins are placed on the outside of the Cube to more efficiently dissipate the heat generated by the Peltier module.
- The Cube is equipped with battery-powered temperature data loggers.
- The environmental temperature during the unpowered periods of ground transport and launch/retrieval must be kept in a range of 20+/- 5 ° C.

SCIENTIFIC **OBJECTIVES**

- Main objective: Protein crystals production
- The unit is a 1U-size incubator intended for the protein crystallization service called Kirara for pharma companies and researchers.
- The mission lasts ~4 weeks (upload and download with the same SpX vehicle)
- No crew interaction during incubation period is requested.

Immune Cell Activation

SCIENTIFIC **BACKGROUND**

- The project proposes to develop novel therapeutic (nano) tools for specific targeting of central nervous system (CNS) diseases and cutaneous cancers such as melanoma. This innovative approach will be based on nano-modified immune cells (NMCs), loaded with adhoc engineered nano-vectors carrying therapeutic agents/drugs (cargos) that will be delivered by NMCs specifically to their target cells. Basically, this approach combines the benefits of immunology (such as selectivity of the targets) and nanotechnologies.
- Recently proof-of-principle results supporting this strategy were achieved by demonstrating that carboxylated nanoparticles (NPs), feasible for future conjugation with drugs, can be successfully internalized by T lymphocytes that, subsequently, acting as a sort of “Trojan-horses” crossed undisturbed the blood brain barrier (BBB) and released these nearby their cellular targets into the Central Nervous System.

SCIENTIFIC **OBJECTIVES**

The goal of the project is to understand if microgravity has an effect on magnetic NPs incorporation in immune and melanoma cells, therefore studying the genes affecting such response in a microgravity environment. If the hypothesis that space conditions will be ideal for the up-load of NPs by T cells comes to be true, then from a cellular point of view a modification of gene expression or a differential protein activity must be present.

For this project we aim:

1. To evaluate the ability of T cells or B cells to up-load NPs;
2. To unravel the cellular and molecular aspects of T-B cells interactions and activation in the presence or absence of NPs in the space environment.
3. To evaluate the ability of A375 melanoma cells to up-load NPs.

NEED OF SPACE

Our research proposal requires interaction between NPs and immune/cancer cells for more than 24 hours, therefore for this and other reasons the available ground-based facilities do not fulfil our needs for a prolonged microgravity needs:

1. Parabolic flights generate 20 seconds on weightless, and even if there are several rounds of weightless periods, the cellular system experiences not just weightless but also acceleration, vibrations and so on.
2. Zarm drop tower delivers 4.74 seconds of near-weightlessness up to three times a day. This microgravity time is too short for our experiment.
3. Sounding rockets deliver 13 minutes of microgravity. This weightless time is too short for our experiment.
4. Finally in Random Positioning Machines the samples in the center of the machine experience a state of low gravity as the gravity vector is averaged to zero over time. The random rotation of the device executes to obtain the average microgravity may affect the system due to inertial fluid movements and partial deposition of the cells and NPs.

DK Contributions

DK CONTRIBUTIONS
MOGENSEN MISSION
DK Aquamembrane-3
DK Circadian Light
DK Denmach
DK Earthshine from ISS
DK Sleep in Orbit
DK SpaceWear Monitor
DK Thor Davis
DK VR for Exercise
DK VR Mental Care

DK Aquamembrane-3

SCIENTIFIC **BACKGROUND**

- Aquaporins are water channel proteins with excellent water permeability and solute rejection, which makes them promising for preparing high-performance biomimetic membranes. Biological membranes have evolved the most effective way for water transport across an osmotic pressure gradient via aquaporin (AQP) proteins. The aquaporins are bound in phospholipid cellular membranes, so that water can pass through the biological membranes freely but ions cannot.
- With the growing scarcity of fresh water, more interest is being paid to the desalination of seawater. Among the various desalination technologies, reverse osmosis (RO) is the most common. Here, the aquaporin-based biomimetic membrane (ABM) can potentially achieve a water permeability two orders of magnitude higher compared to existing RO membranes. Recently an alternative technology (forward osmosis – FO) has stepped into the market of water treatment. The Aquaporin Inside membrane is especially developed for this FO technology.

SCIENTIFIC **OBJECTIVES**

1. To demonstrate the function of an Aquaporin Inside Membrane (AIM) test apparatus in Space.
2. To use the AIM to demonstrate treatment of actual ISS Waste Water in Space.
3. To use the AIM test apparatus to investigate concentration polarization effect.

NEED OF SPACE

- This flight experiment will investigate two factors that are critical to determining the applicability and design of a membrane based replacement to the ISS multifitration beds:

1. Water Flux Rate in Microgravity: Previous studies of FO membranes in space have shown reduced flux rates. This reduction in performance has been attributed to the effect of concentration polarization (CP). On the ground CP is reduced by nano-scale buoyancy driven mixing. In space there is no buoyancy driven mixing. In space all nano-scale mixing occurs due to Brownian motion which is about 100 times less effective than buoyance driven mixing.
2. Contaminate Rejection in Microgravity: Microgravity effects, such as CP, can impact contaminate rejection by increasing the level of contaminates at the membrane surface. Previous testing in microgravity with other FO membranes has shown that inorganic rejections are comparable to the ground but no organic testing has even been completed.

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 color 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.

DK Denmach

SCIENTIFIC **BACKGROUND**

- In this project, we will create an educational platform that allows school children of all ages to design and carry out experiments in microgravity. The platform will be based on the SPIKE Prime STEM learning tool by LEGO Education, which will be equipped with sensors and a satellite communication unit named denMACH ONE, to provide a flexible platform for experiments.
- The project will include pre-flight, in-flight, and post-flight activities where children will acquire hands on experience with programming, space technologies, satellite communications, and designing and implementing a space mission, along with data analysis and mission debrief – enabling them to be a part of a real space mission from concept to mission completed.

SCIENTIFIC **OBJECTIVES**

1. Some data is collected (and sent to earth) from the experiments the children create so they can analyse the data and see their mission come to life.
2. There is video/photos for the children to see so we can captivate them and society's excitement.

NEED OF SPACE

- With this mission we are raising the level and standards in schools in Denmark (also EU, and globally), where it will be possible for school children to learn about satcom IoT – a key tool for sustainability, and the space industry and the technologies that go along with it. Making satcom mundane knowledge at a young age helps to demystify not just the space industry and satcom, but also the sciences in general. It is crucial that Denmark retains its positioning as a true space nation by securing the interest of the generations to come in the educations that lead to such.
- The Danish delegation in the educational sector has put forth a subject that is mandated to be taught in grade school levels, meaning the need for such an educational activity is extremely high. Never before has such an educational platform existed – that allow teachers, children and youth to learn in such an exciting and comfortable setting how to tackle space engineering, satcom/telecom – and everything in between that society is dependent on.

DK Earthshine from the 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**

- To take pictures with a hand-held camera, at the right times, of the Moon from the Cupola on the ISS. The 'right times' are defined by lunar phase and lunar altitude above the horizon as seen from the ISS.
- Full success: Obtaining 2 x 100 correctly-exposed images of the Moon well above the horizon as seen from the ISS. On two different days obtain 100 images on each. 'Correctly exposed' implies that the images do not over-expose the bright side of the Moon, nor owers the exposure so much that the dark side is unnecessarily under-exposed.
- Partial success: Obtaining at least 50 correctly-exposed images of the Moon in that position.
- Minimal success: Obtaining at least one image of the Moon.

NEED OF SPACE

- The investigators have many years of experience using the earthshine method from the ground. They have realized the limitations (variability, mainly) contributed by even the thin and clean atmosphere available at Mauna Loa on Hawaii, and would now like to try from space to quantify the reduction in variability obtainable from outside the atmosphere.
- This study could help validate an ongoing PhD-student project with DTU Space, Denmark and the IRS in Stuttgart Germany, with whom an earthshine instrument is being studied, built and launched by 2025.

DK Sleep in Orbit

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.

DK SpaceWear Monitor

SCIENTIFIC **BACKGROUND**

- With the growing number of human spaceflight vehicles in development and planned for sub-orbital, orbital and cislunar spaceflight, a simple, flexible and reliable medical monitoring system is needed - one that can be worn by crew members and space flight participants under their suit or laboratory in orbit.
- Danish Aerospace Company (DAC) 's new wireless chest worn Wearable Health Monitoring System can monitor key medical parameters during crew training sessions as well as during short and longer duration human spaceflight activities. The system is autonomous, it just needs to be powered on and worn, and then it records the data autonomously. Continuous recording can be supported for up to 10 hours if started on a fully charged system. It measures medical data.
- The module is designed to be chest based and is attached to an adjustable fabric belt The belt includes 3 fabric electrodes for a single-lead ECG, Respiratory rate, Hear Rate (HR), Skin temperature, G-loads and other measurements.

SCIENTIFIC **OBJECTIVES**

The objective of the proposed activities is to acquire and evaluate data from the wearable device during launch, on-orbit stay and during landing. The main objective is not to perform medical evaluation of the subject, but to ensure data quality is adequate to perform such an evaluation.

The following session activities are proposed (in prioritized order):

1. Monitoring during on-orbit routine daily work, including CEVIS exercise. (3 sessions)
2. Monitoring during Launch (desired)
3. Monitoring during Landing (desired)

NEED OF SPACE

- For DAC to verify that the new chest worn Wearable Health Monitoring System works in microgravity it is of key importance to demonstrate this though a spaceflight. Ideally both worn during launch and landings (Desired), as well as during discrete sessions in orbit (Required). This will allow DAC to prove that they have a product for the commercial space companies which is space proven.
- As the commercial human spaceflight market covers both suborbital, as well as, orbital spaceflights, and might as well be part of future Human Moon flights, the proof of operation in space is essential.
- Testing under other extreme conditions will be performed in parallel on ground.

DK Thor Davis

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.

DK VR for Exercise

SCIENTIFIC **BACKGROUND**

- During prolonged spaceflight mission, the crewmember only experiences the enclosed environment of the International Space Station, where there are limited variety in experiences. Also, during long duration missions in space, it is vital to exercise, in order to reduce the ill effects of prolonged exposure to microgravity environments.
- Virtual Reality during exercise can enhance the experience and possible help increase the motivation for the regular daily exercises.
- The proposed activity combines Virtual Reality with cycling exercise, to create variety in environment and provide motivation during exercise. By creating an immersive exercise experience, the crew member can experience the feeling of exercising in either familiar environment or at scenic locations.
- It is planned to use a VR headset during 3 of the regular exercise sessions on the CEVIS ergometer to test and demonstrate this capability. Cycling and/or mountain bike videos will be recorded and put on the VR device for use during the sessions.

SCIENTIFIC **OBJECTIVES**

1. Technical evaluation of the VR system performance and operation
2. Subject evaluation the use of Virtual Reality during exercise.
3. Subject evaluation of combining cycling intensity to match the virtual reality scene.
4. Subject evaluation if the use VR has an increased effect on the motivation of the crew member to perform the prescribed exercise.
5. Subject evaluation if the variety in scenery has a positive mental effect to the crew member.
6. Subject evaluation of the use of space to ground data communication to collaborate/compete with ground-based users has an effect of increased motivation.
7. Evaluate the use of accelerometers for position/orientation tracking in space, potentially combined with visual reference marks.

NEED OF SPACE

- Exercise is critical to all human spaceflight, and only by testing the use and concept is space is it possible to assess whether it can be employed further for government and commercial Human long during spaceflights.
- Furthermore, exercise in space can be monotone and dull as there is no change of scenery, where this can be achieved via VR.

DK VR for Mental Care

SCIENTIFIC **BACKGROUND**

- Astronauts' physical health is important, but so is their mental health. Given the upcoming long-term manned missions first to the Moon and later to Mars, there will be an increasing need to ensure that astronauts not only survive their missions, but that they also thrive while missions go on.
- Astronauts live in a non-stimulating stressful environment when they are in space. The idea with the current project is on a regular basis and for a few minutes to virtually (Using HQ film and HQ audio) take the individual astronaut out of this stressful environment and put them in a place, which in their mind is safe and implies complete relaxation and joy.
- The consortium is proposing a technology based on an extremely well proven and documented VR system and analysis tool, but further developed and tailored for the individual astronaut to ensure maximum benefit for the time invested. The enhanced system is called VAMB (Virtual Assistance helps Mental Balance).

SCIENTIFIC **OBJECTIVES**

- For measuring the effect before and after the use of VAMB a self-report questionnaire will be used. The questionnaire will be integrated in the VAMB VR-equipment or as part of the EveryWear App. Differences between the assessment before and after VRMH will be analyzed using paired t-test in SPSS ver.20.
- During the use of VAMB there will also be recorded biological measurements as Heart Rate and Heart Rate Variability etc. The use of biological measurement during the use of VAMB will strengthen the validity of the collected data.
- Before and After the mission the astronaut will participate in a qualitative interview that will be used to understand the personal experience of the astronaut in relation to the use of VAMB. The interview study was structured based on Kvale and Brinkmann's (2015) seven stages; thematization, design, interview, transcription, analysis, verification and reporting and were used to ensure the quality of the interview survey.

NEED OF SPACE

- Until now, space travel has usually been limited to a few weeks or a few months. In the future, man will be in space for several years at a time. That is another challenge. A challenge that requires us not only to train and take care of the astronauts' physical health, but also to ensure their mental well-being.
- Isolation and confinement during long-time space missions and the fact that crewmembers are forced to interact with each other in a small space will have significant influence on the mental health of the crewmembers.
- On earth the expeditions and exploration of Antarctica and cave environment have been a useful analog to space expeditions. Studies have shown, that living in such a hostile and confined environments have a significant effect on mental health. However, there is a need for addressing how psychological and interpersonal distress can be reduced in future long-distance and long-duration space expeditions