Best Practice Examples in Citizen's Science

Implemented at UNIVERSEH'S Partner Universities

CONTENT

ESA F-Class Comet Interceptor Mission Study

Lead:	ISAE-SUPAERO, Toulouse, France
Keywords:	Science/Robotic Exploration Planetary Science Missions Minor Satellites and bodies of the Solar System
Project Summary:	The European Space Agency Directorate of Science selects its future missions through highly competitive mission calls where scientists across Europe present their missions proposals. In 2018, ESA announced its first Fast-Track (F-Class) mission call, requesting proposals for a small, cheap and quick scientific mission to be launched in 2029. Comet Interceptor mission study took thus place between 2018-2019. It analyzed the propulsive costs for a small spacecraft stationed at the Sun-Earth Lagrange L2 Equilibrium point to reach a dynamically new comet. This is a comet that reaches the inner solar system for the first time and, therefore, is still unknown to astronomers. Given this unannounced arrival, there is a need for the spacecraft to be waiting in space and ready to go, as soon as the comet is detected by astronomy surveys. The study computed intercept trajectories to thousands of hypothetic comets. The study demonstrated through statistical analysis that, despite the low propulsion capabilities expected for an F-Class spacecraft, the stored energy at the Sun-Earth L2 point could be wisely used to reach a meaningful population of these comets.
Impact:	The study convinced ESA engineering panel that the mission was feasible. The ambitious scientific objective to visit a yet-to-be-discovered comet convinced also the scientific panel. Comet Interceptor is today being developed by ESA and, once successfully completed, the mission will broaden our understanding of the formation, evolution and emergence of life in our Solar System. Read further in
Link:	https://www.cosmos.esa.int/web/comet-interceptor.

InSight

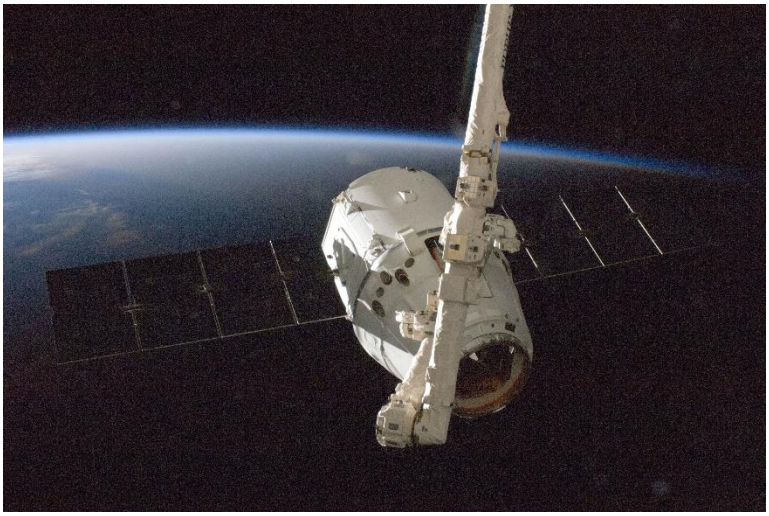
Lead:	DEOS/SSPA, ISAE-SUPAERO, Toulouse, France
Keywords:	Planetary Science missions Remote Sensing Instruments / Sensors
Project Summary:	The InSight mission was selected by NASA in August 2012 as part of the DISCOVERY programme. It deployed the first geophysical observatory on Mars on 26 November 2018, to provide scientific knowledge essential to understanding the fundamental processes of the formation of telluric planets and their evolution. To achieve this goal, it is carrying two scientific instruments: the SEIS seismometer and HP3, an instrument for measuring heat flows from the planet's core. SEIS is the most sensitive seismometer in the Solar System. It is currently measuring seismic activity, meteorite impact flux and Phobos tides, as well as helping to characterise the interior structure of Mars, by providing information on the thickness and structure of the crust, the composition and structure of the mantle and the size of the core. It was developed during more than 10 years by the Institut de Physique du Globe de Paris (IPGP) with the support of CNES and CNRS, and a wide range of international partners: IPGP, Swiss Federal Institute of Technology Zurich (ETHZ), Max-Planck Institute Lindau, Imperial College London and Oxford, Jet Propulsion Laboratory and ISAE-SUPAERO. ISAE-SUPAERO has contributed to the InSight mission through the SEIS instrument performance model, the mission performance model, the specification of the scientific software and the design of the concept of operations for the instrument on Mars. ISAE also contribute significantly to the exploitation of scientific data on the structure of the crust, the internal structure of the planet or the study of dust devils.
Impact:	First of all, understanding the sources of noise on the Mars surface (wind, atmospheric pressure, magnetic field and temperature variations) and their impact on the seismometer SEIS contributed to

	the exploitation of the data it provided. The analysis of the data allowed to better understand the internal structure of Mars, its formation as well as the proprieties of the Martian regolith and the whirlwind of dust on its surface
Link:	https://www.isae-supaero.fr/en/research/departments/department-of-electronics-optronics-and-signal-processing-deos/sspa-research-team/insight/

CREME: Cubesat radiation environment monitoring experiment

Lead:	DEOS/SSPA, ISAE-SUPAERO, Toulouse, France
Keywords:	Satellites and Probes Space weather Education and public outreach
Project Summary:	The aim of the project is to develop a nanosatellite to measure radiation around the Earth – a constraint for flying satellites. The CREME project will be dedicated to both space weather and the measurement of the radiative environment constraining EOR missions, while guaranteeing high-quality measurements. Its small footprint will enable validation via a flight on a 3U CubeSat. The proposed detector is based on the principle of silicon diodes combined with optimized shielding to discriminate charged particles encountered in the space environment. It must have a low cost and footprint, and its design must enable it to be easily carried on any type of platform (industrial or scientific). This 3U platform draws on the expertise and feedback acquired during the EyeSat (CNES), Entrysat (ISAE-SUPAERO - ONERA) and NIMPH (ISAE-SUPAERO, TAS, CNRS/LAAS) projects. It will be derived from the platform currently under development (MONITA) for the NIMPH project. The design/realization differential will remain limited, especially as the radiation monitor does not require precise attitude control
Impact:	The ambition of this project is to offer space industry a low-cost, small-footprint, low-mass and highly versatile radiation monitor, so that it can be easily integrated on commercial satellites. The in-flight measurements collected will be used at the CSUT (Universitary spatial center of Toulouse) to promote the space sector among students. They will also be used to validate the concept of the in-orbit sensor, and to obtain new measurements that can be used to enrich space weather monitoring services.
Link:	https://www.csut.cnrs.fr/en/project/cubesat-radiation-environment-monitoring-experiment/

Mars microphone on Perseverance (SuperCam)



Lead:	DEOS/SSPA, ISAE-SUPAERO, Toulouse, France
Keywords:	Science / Robotic exploration Planetary Science missions Remote Sensing Instruments / Sensors
Project Summary:	Perseverance is a rover sent by NASA to Mars to select Mars samples for collection and return to Earth, in order to determine whether or not life ever existed on the 4th planet of the solar system. It landed on Mars on February, 18th 2021. ISAE-SUPAERO SSPA group is present on the rover through its contribution to the SuperCam instrument, which analyzes rocks remotely using LIBS technology (Laser-Induced Breakdown Spectroscopy). The team developed and supplied the first Martian microphone, which complements the LIBS measurements by providing calibrated information on the hardness of the rocks. ISAE-SUPAERO SSPA group has been involved since 2016 in the design, manufacture and testing of the SuperCam microphone, as well as in the scientific preparation of the mission. Perseverance recorded the sounds of the Red Planet for the first time on February 19, 2021, the day after its arrival. These sounds fall within the human audible spectrum, between 20 Hz and 20 kHz. First and foremost, they reveal that Mars is quiet.
Impact:	By studying the propagation of these sounds on Mars, whose behavior is perfectly well known on Earth, we can finely characterize the acoustic properties of the Martian atmosphere. This analysis enables us to learn more about the physical characteristics of the Red Planet's atmosphere, in particular the speed of sound and its attenuation. Scientists have shown that the speed of sound is lower on Mars than on Earth: 240 m/s, compared with 340 m/s on our planet. They also discovered that there are actually two sound speeds on Mars, one for high frequencies and one for low frequencies. The attenuation of sound is greater on Mars than on Earth, particularly for high frequencies which, unlike low frequencies, are lost very quickly, even at close range. These factors are due to the composition of Mars' atmosphere, which is 96% CO2, compared with 0.04% on Earth, and

	the very low pressure at its surface, which is 170 times lower than on Earth.
Link:	https://www.isae-supaero.fr/en/research/departments/department-of-electronics-optronics-and-signal-processing-deos/sspa-research-team/mars-microphone-on-perseverance/

TELEOP

Lead:	DCAS/SacLab, ISAE-SUPAERO, Toulouse, France
Keywords:	Human Exploration Spaceflight Automation & Robotics Systems
Project Summary:	TELEOP measures the impact of confinement on crew performance during teleoperations, such as piloting a rover on the Moon's surface. This experiment is used on space simulation missions to the Moon or Mars. The operator is locked in and isolated from the rest of the world for a period of 3 weeks to 4 months. Each piloting mission on a defined circuit lasts 15 minutes, but the operator is mobilized for a total of 30 minutes. He must equip himself with eye-tracker sensors and an electrocardiogram and fill in a questionnaire. The pilot cannot see the rover or its physical environment. All maneuvers are performed by the computer. The rover has a camera and is controlled by keyboard, software and a specific connection program created by an ISAE-SUPAERO student. It is the influence of confinement on performance, motivation and involvement in the task that is being studied. The experiment is not concerned with learning, but with the evolution of an operator's skills over the course of a mission. TELEOP collects physiological, psychological and technical data. The results are statistically processed by a team of researchers assisted by students from ISAE-SUPAERO. The TELEOP device has been tested on several occasions over the past years. Firstly, during two MDRS (Mars Desert Research Station) missions to simulate life on Mars in Utah (USA) in 2018 and 2019 by crews of ISAE-SUPAERO engineering students, and secondly during the ARES-III mission in Lunares, Poland, a base for preparing astronauts for space missions.
Impact:	TELEOP provided valuable insights which drive advancements in human space exploration. By addressing the psychological and

	operational aspects of confinement, researchers can improve mission planning, enhance human-robot collaboration, and optimize astronaut training, ultimately leading to safer and more successful space missions.
Link:	https://www.isae-supaero.fr/fr/actualites/teleop-une-experience-de-confinement-de-l-isae-supaero-selectionnee-pour-sirius/

EntrySat

Lead:	DEOS/SSPA, ISAE-SUPAERO, Toulouse, France
Keywords:	Orbital debris / Space debris Aerothermodynamics & Atmospheric entry
Project Summary:	EntrySat was the very first French 3U cubesat produced for an academic project. It was deployed from the International Space Station on July 3rd 2019. The main objectives of the EntrySat mission were to study of the atmospheric reentry of space debris based on information from position, pressure, temperature, and heat flow sensors. The reduced dimensions of the satellite as well as the absence of special protective systems make it very similar to debris produced during the breakup of a spacecraft. EntrySat was part of the CNES JANUS project (Young Apprentices for the realization of Nanosatellites in Universities and Higher Education Schools). The development was led by the SSPA team and many researchers, engineers and students from ISAE-SUPAERO have participated in the conception of the nanosatellite, helped by the ONERA (French National Aerospace Research Center) and the University of Toulouse.
Impact:	Understanding the behavior of small debris during reentry is critical for ensuring the safety of the population and property, mitigating space debris, promoting sustainable space operations, establishing legal frameworks, and maintaining public confidence in the space industry-
Link:	https://websites.isae-supaero.fr/entrysat/

NEO-MAPP (Near Earth Object Modelling And Payload for Protection)

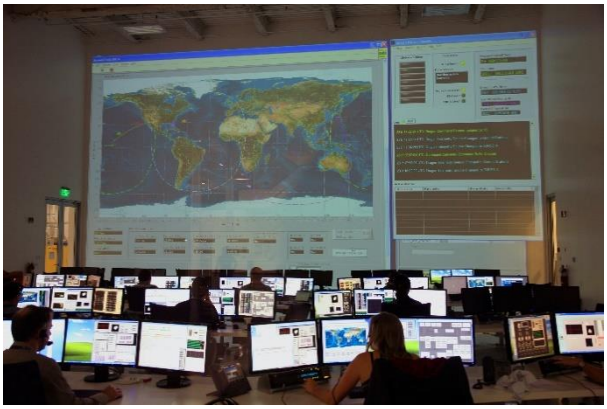
Lead:	DEOS/SSPA, ISAE-SUPAERO, Toulouse, France
Keywords:	Planetary protection Space data exploitation
Project Summary:	This project is funded by the H2020 program of the European Commission and addresses the topic "Advanced research in Near Earth Objects (NEOs) and new payload technologies for planetary defense" (SUSPACE-23-SEC-2019). In recent years, demand has increased for planetary defense, science and resource missions to asteroids. This demand requires major advancements in numerical modelling of asteroid responses to an impact, asteroid dynamics and physical properties as well as space mission payload development, data processing and operational capabilities. It could also provide, due to its public roots, a high social and environmental impact mainly due to the benefits of impact mitigation, science understanding of asteroids and asteroid mining. Involving scientific and industrial experts, the EU-funded NEO-MAPP project aims to provide significant advances in these areas, while at the same time sustainably increase expertise of European scientists and engineers in both planetary defence efforts and asteroid exploration. The main goal of NEO-MAPP is to support the development and data analysis of NEO missions and provide significant advances in both our understanding of the response of NEOs to external forces (in particular a kinetic impact or a close planetary approach), and in the associated measurements by a spacecraft (including those necessary for the physical and dynamical characterization in general). In a multi-disciplinary and synergetic approach, NEO-MAPP incorporates two activities: numerical modelling, and technology and data processing developments. NEO-MAPP will bring modelling capabilities well beyond the state-of-the-art, producing major advancements in our understanding of the response of NEOs to a kinetic impact or an Earth encounter, and of their physical and dynamical properties. NEO-MAPP will also increase the maturity of five innovative payloads specifically optimized for NEO space missions and devoted to the surface,sub-surface and internal

	properties of a NEO; parameters that are currently poorly constrained yet of high importance to planetary defense. In parallel, the NEO-MAPP team will define innovative measurement and data processing strategies, combining multiple payloads, in order to maximize the exploitation of scientific and technical data. These objectives will be addressed by adopting a framework of two "Reference Missions". The team will ensure that the mission scenarios are both highly relevant to the current international and European programmatic context while remaining generic enough to be transposable to any alternative scenarios.
Impact:	NEO-MAPP will thus provide significant advances in our understanding of NEOs while ensuring the future leadership of European scientists and engineers in both planetary defense and small-body exploration. The project outcome, especially regarding impact mitigation (but also asteroid mining), responds to a public demand and, therefore, will have a high social and environmental impact.
Link:	https://neomapp.eu/

PIONEERS

Lead:	DEOS/SSPA, ISAE-SUPAERO, Toulouse, France
Keywords:	Remote Sensing Instruments / Sensors Planetary protection Planetary Science missions Space data exploitation
Project Summary:	The EU-funded PIONEERS project is developing two advanced seismometers with innovative data analysis capabilities, one for planets and one for small bodies such as asteroids. The PIONEERS project will develop two 6 DoF instruments for measuring ground deformations of planetary objects. The first instrument is a very low noise 6-DoF engineering model dedicated to imaging the internal structure of terrestrial planets. The second one is a high TRL, reduced scale version of the same instrument dedicated to the exploration of small bodies, in order to support planetary defense and asteroid resources applications. We will build the instruments with the expertise in planetary seismology and high performance optical technologies provided by the PIONEERS partners. Innovative data analysis methods, as well as Earth analogue field testing will validate the expected increase of performance level by two orders of magnitude. Cost optimization, ITAR-free strategy and adaptation to CubeSat standards will drive other technological developments opening new markets for high precision scientific instrumentation. Instruments developed by our consortium members are demonstrating their predominance this year (SEIS on board InSight, blueSeis commercial rotational seismometer release, ROMY laser interferometer)
Impact:	The technology developed will support understanding of planet formation, the search for habitable planets and planetary defense.
Link:	https://h2020-pioneers.eu/about.php

Developing Organizational Ambidexterity in a Space Organization



Lead:	TBS Education and a Space organization (confidential)
Keywords:	Space economy Start-up companies
Project Summary:	TBS Education is working alongside a space organization to develop disruptive projects and innovations by anchoring organizational ambidexterity. At the organization level, developing ambidexterity will promote innovation culture in the space organization and will contribute the organization to cope with the many changes occurring the space industry, referred to as New Space (including new entrants, new policies, new technologies). At individual level developing organizational ambidexterity is perceived as a strategic development axis able to foster the working force well-being, enhance competencies development and finally act as a career accelerator. For 4 years, 42 interviews has been leaded by TBS Education within the collaboration of several actors of the space organization (projects leaders, business units directors and even punctual participants) with diverse profiles and competencies (electronic, software, satellites construction, etc.) working on various thematic such as Earth observation, Telecoms and Navigation.
Impact:	So far, the data collection phase has been done and TBS Education is working very closely with the Space organization project leaders. The analysis phase is ongoing and 3 teachers-researchers from TBS Education are collaborating. The working analysis will be published and shared to develop good practices on this topic. Long-term reflection and survey upon ambidexterity aims to adapt employees working environment to New Space disruptions and enable them to develop their efficiency and competencies.
Link:	https://chaire-sirius.eu/documents/67a3d4-chng-le-huy-2019-organizational-ambidexterity-how-space-companies-can.pdf

Ageing modelling of Li-Ion batteries for satellites

Lead:	Toulouse INP, LAPLACE, Toulouse, France
Keywords:	Energy storage technologies
Project Summary:	It is well known that several factors such as electrical (current amplitude, depth of discharge, frequency), environmental (temperature, humidity) and functional (vibrations, thermomechanical stresses) constraints influence the life of satellite batteries significantly. On the other hand, the implementation of lifetime models giving robust degradation indicators including these constraints remains difficult. This project is part of the methodological context of the modeling of the lifespan and more broadly the prognosis, as well as the modeling of the degradation of Li-Ion batteries in accelerated stresses and operational stresses for aerospace applications.
Impact:	In parallel with lifespan modeling, this work will also focus on Li-Ion battery lifespan indicators. These indicators can intervene at 2 levels: either so as to warn of a critical level of the battery and its inability to continue the mission, or so as to enrich and update the service life model over time. This work may also help to reduce the oversizing of the battery with a better knowledge of its degradation under space constraints.

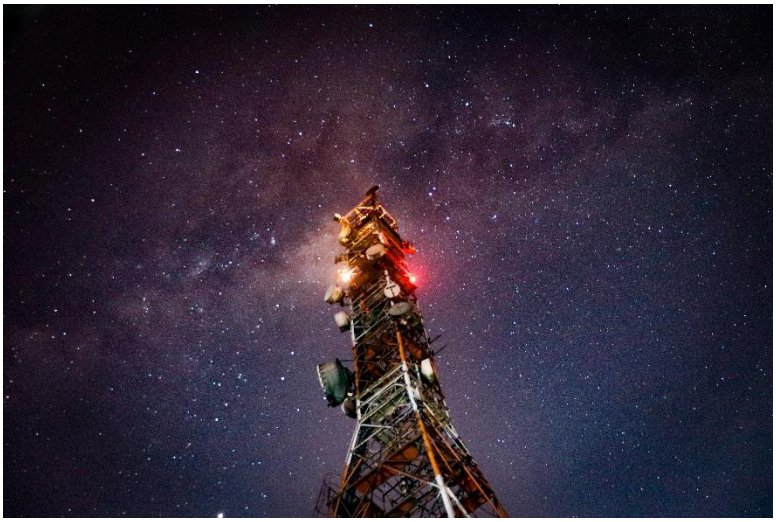
Surface functionalization with Spaceship-FR

Lead:	Laplace-CNRS, Toulouse, France.
Keywords:	Energy storage technologies
Project Summary:	Environmental Control & Life Support Systems (ECLSS) + Habitation Systems Human health, life support, habitation systems Materials & Processes.
Impact:	Spaceship initiatives, bringing together engineers, astronauts, and researchers, have been set up to develop and study new operational concepts and technologies for space exploration. In particular, Environmental Control and Life Support System (ECLSS) for habitats such as the autonomous inflatable lunar module require technological innovations, for example, to purify air or water, inhibit the proliferation of bacteria or viruses, prevent surface ageing with very high resistant and wear or self-repair the habitat envelope. The main objectives are to (i) translate requirements into coating properties and compositions, (ii) develop and optimize technological solutions, and (iii) assess these processes from the point of view of sustainable development, and in particular, the life cycle of processes and materials, their impact on people and the environment, and cost-benefit analysis.

Definition of a controlled natural language for satellite specifications writing at CNES

Lead:	CNRS et U. Toulouse
Keywords:	Space services and products
Project Summary:	As part of a thesis and then a post-doc, the CNES-funded project enabled the creation of an ergonomic controlled natural language (CNL) to assist in the writing of satellite requirements. A controlled natural language gives writing recommendations to limit the comprehension difficulties inherent in the use of spontaneous language. To guarantee usability, the CNL defined was based on existing requirements, and its effectiveness was evaluated by means of surveys.
Impact:	The project has led to the definition of an ergonomic controlled natural language for requirement writing. This CNL is now taught to CNES engineers in charge of writing requirements.

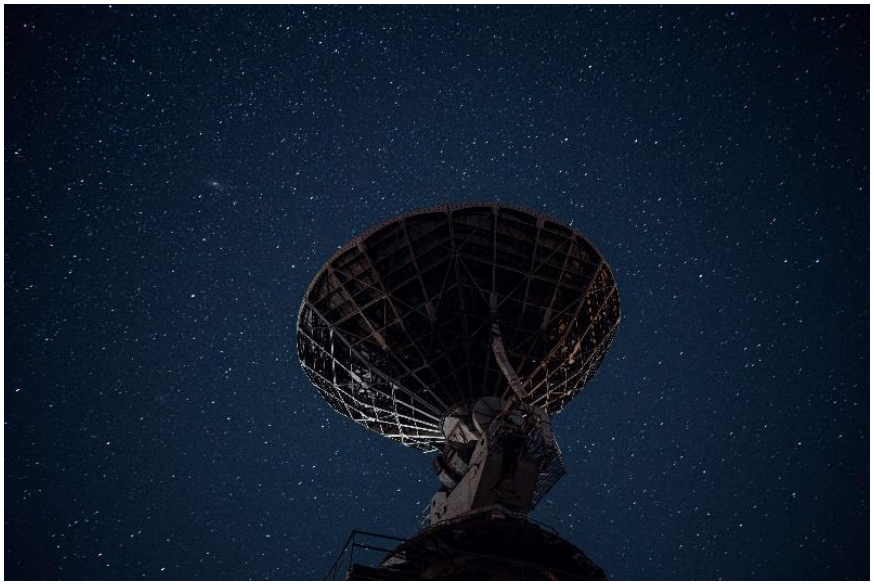
RIT 2021: NRFP-4: Visual Navigation around a Small Celestial Body



Lead:	Luleå University of Technology, Luleå, Sweden
Keywords:	Automation & Robotic Systems | Science/Robotic Exploration | Autonomy | Automation, | Telepresence & Robotics | Minor satellites and bodies of the solar system
Project Summary:	NRFP-4 project is a collaborative initiative with OHB Sweden, under RIT 2021, as a co-financed EU project. NRFP-4 established an autonomous visual navigation framework around small celestial objects. Exploring small celestial objects like asteroids and comets is of great importance to the space community, as they contain evidence about the evolution of the solar system and the origins of life. The scientific interest in bringing back samples from near-earth objects and a global interest in protecting Planet Earth from future collisions with celestial objects, drives the high demand for asteroid exploration missions. In such ambitious missions, precise and autonomous space navigation is critical. The NRFP-4 project proposed a robust navigation architecture that enables precise onboard autonomous visual navigation around a small celestial body (illustrated in Figure 1), using a Vision-LiDAR fusion-based Simultaneous Localization and Mapping (SLAM) algorithm. Figure 1. A Vision-LiDAR fusion-based SLAM algorithm for autonomous navigation around an Asteroid. The state-of-art ORB-SLAM algorithm is used for processing consecutive image frames for deriving the spacecraft's pose. To overcome the deviations in the pose from ORB-SLAM algorithm (which

	render it unreliable), the project combined the image features with a projected LiDAR point cloud to determine the spacecraft's pose. To eliminate vision component's excessive reliance on good illumination, the solution incorporated a model-based propagator (using IMU, LiDAR, and model predictions) to provide pseudo-sensor measurements. This approach ensures that the algorithm's performance is resilient to varying illumination conditions and measurement noise. A representative result of the project can be viewed at https://youtu.be/GJcTFMqzpzI.
Impact:	The outcome of the NRFP-4 project, which is a framework for robust vision-based autonomous navigation, has immense utility in the future asteroid missions, due to its novel multi-sensor fusion approach, which enables operation irrespective of the illumination conditions around an asteroid. For the overall implementation, a virtual reality (VR) testbed was created in the physics-based Gazebo simulation software. This demonstrated the usefulness of Gazebo software, which is predominantly used in Robotics, for simulations in Space research. The designed VR testbed can be further used to develop and evaluate any other Guidance, Navigation and Control algorithm, for the development and validation of missions such as planetary landings, autonomous rendezvous and docking, and in-orbit robotic servicing. More information can be found at: https://ritspace.se/ai-to-navigate-space-exploration-in-new-innovation-partnership/
Link:	https://ritspace.se/ai-to-navigate-space-exploration-in-new-innovation-partnership/

Slider: A floating platform. A space technology-oriented pilot project



Lead:	Luleå University of Technology, Luleå, Sweden
Keywords:	Space R&D | Automation & Robotic Systems | Artificial intelligence, intelligent systems, multi agent systems | Robotics, Telerobotics & Autonomous Systems
Project Summary:	The development and validation of satellite guidance, navigation, and control (GNC) algorithms is performed on earth on hardware-in-the-loop spacecraft test-bed facilities, in environments that emulate space-like conditions. Various government organizations and university laboratories across the globe have such indigenously built testbed facilities. As no such testbeds are commercially available, there is a growing need for low-cost and 3D printable designs for: 1) integration into academic GNC courses to provide hand-on student experience and 2) for emerging startups to test their payloads and algorithms. The Slider (shown in Fig. 1) is a floating platform integrated with actuator units and sensors for visual navigation, that is fully designed and manufactured by the Robotics and Artificial Intelligence (RAI) group at Luleå University of Technology (LTU). The research activities at RAI in space robotics and autonomy are supported by multiple Sliders, which are used to emulate the orbital motion of spacecrafts. Fig. 1: The Slider platform, a hardware-in-loop spacecraft test-bed facility. The Slider platform is supported by three air bearings, which release compressed air to form an air cushion, thus allowing Slider to levitate over a smooth surface. A detailed design along with the mathematical model describing the platform's dynamic motion has been published and the entire design, including 3D printable CAD models have been open-sourced. Several experimental demonstrations have been performed to showcase the Slider's capabilities and illustrate its operation, some of which can be seen in the following videos. 1) https://www.youtube.com/watch?v=nJjMiHpQhhA

	2) https://www.youtube.com/watch?v=x2VSadbrBvk 3) https://www.youtube.com/watch?v=v5b94ca NKAs 4) https://www.youtube.com/watch?v=vvGkSl2ArP4
Impact:	Research Impact: Floating platforms, like the Slider, allow for testing of spacecraft GNC algorithms on ground. So far, Slider has been used to develop and validate algorithms for safe autonomous docking, trajectory tracking with variable payloads etc. For emerging startups, which are aiming t ovalidate their technologies on testbeds emulating operations in space, platforms like the Slider are extremely beneficial. The Robotics and AI group at LTU has been approached by several emerging startups, to host their sensors and algorithms onboard the Slider Platform, for testing and performance evaluation. Pedagogical impact: The Slider platform has been integrated into the Spacecraft Guidance and Navigation course at LTU. The platform is providing hands-on experimental experience to the students. The detailed CAD designs of the Slider platform have been open sourced and most of the parts can be easily 3D printed and assembled.

Creaternity Space: Circular Economy for Reuse and Recycle of Spacecraft Materials

Lead:	Luleå University of Technology, Luleå, Sweden
Keywords:	On-Orbit satellite servicing Manufacturingg of space products Orbital Debris, Space Debris Space Economy
Project Summary:	The need for material circularity and sustainability is not limited to human activities on Earth and in fact, has broad implications for the utilization of outer space. With the increased digitalization, global location and observation needs, and connectivity demands for Earth applications, an ever-growing number of spacecrafts being launched into an already “crowded” orbital space at the fast-growing risk of collisions. Sustainability, stewardship, and circularity have been identified as key concepts and enablers for the save and long-term utilization of outer space. However, as research projects related to space sustainability, recycling of spacecraft materials, and space debris mitigation gain traction, a mutual understanding of definitions and concepts is missing and the prospects and viability of circularity in space are unclear. This research attempts to fill this gap with an investigation into the possibilities to re-use spacecraft materials as an alternative to its complete disposal. A review of circularity and sustainability definitions is conducted, and to make an initial effort to examine and map requirements for re-manufacturing, refurbishment, and the re-use of spacecraft materials. A literature review is conducted to identify fundamental concepts to enable circularity. This research reviews best practices and approaches in areas like aviation, electronics, and car manufacturing to thoroughly examine similarities and to create a mapping for the space sector. Following this cross-industry approach, the research surveys academic and industrial topics like spacecraft and satellite mission design, business models and product innovation, and entrepreneurship and space ecosystems to find common patterns within sectors and activities. Consideration of a long-term view and the sustainable use of resources are among the major challenges for society, industry, and

	academia. Transitioning from a linear to a circular economy is seen as a vital part and key enabler for sustainability. Nevertheless, the application of either concept depends on industry sector needs, technological feasibility, economic viability, and industry regulation. With humanity getting ready to explore and possibly settle in our solar system beyond Earth within the next century, we suggest a broader view and the need for new definitions of sustainability. The aim is to create a common understanding and with this, to advance the space economy by reusing spacecraft materials and recycle the non-reusable part
Impact:	Of course, the development of any technology doesn't make it beneficial by itself. If reuse of spacecraft materials is possible form a technology point of view, the space industry still must make it financially viable. Now, sustainability in space, regarding laws and regulations has three main topics under investigation: - Equality regarding the countries (or entities) entering space exploration and the country pioneer in space exploration: should they be allowed to do the same mistake than their predecessors? - Seeing space as a limited environment: the space used, around Earth, is a finite resource. - Extension of the idea of reuse/recycle/repurpose and manufacturing in space. This research attempts to contribute to all three but has its focus in the reuse and circularity topic. There are a few laws related to repurposing of space debris, with the most important one www.universeh.eu This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101035795 UNIVERSEH – European Space University for Earth and Humanity is an alliance of that space objects, including space debris, are legally under the jurisdiction and laws of the launching country. There is no salvage law in space as in the ocean. A suitable environment for the implementation of circularity in space and for reuse of spacecraft materials is closely related of the law issues of space debris. For more than sixty years, spacecrafts were left in space without any concern on the consequences due to the lack of more strict regulations. It can be compared to the carbon-dioxide emission on Earth before the application of stricter laws and taxes the industries have no direct interests to diminish their emissions. Therefore, one can imagine if the government implement a tax on the number of space debris "emitted" by a space actor or on the launch; it might force the space actors to rethink their spacecraft end-of-life and to investigate a circular mission model. Of course, the capability to reuse a spacecraft presents a geopolitical risk too, it could be militarized to attack a satellite and by extension its owner. Therefore, regulations might evolve within a circular space economy.

KvarkenSat: The First Finnish-Swedish Collaborative Nano Satellite

Lead:	Luleå University of Technology, Luleå, Sweden
Keywords:	Earth Observation Space data exploitation Remote Sensing Instruments/Sensors Space Qualification Entrepreneurship Space Economy
Project Summary:	Kvarken Space Centre is a project funded by the European Regional Development Fund to implement a long lasting regional economic develop- ment structure for space-based business and inno- vation. Kvarken is a region across the Baltic sea that shares common cultural and economical rela- tionships between Sweden and Finland. The primary objective of the planned centre is to support regional businesses to develop opportunities within the “new space economy” and commercialise existing space-based data. The centre will share knowledge and implement demonstration projects to bring the regional businesses to the level needed to independently manage their own space business activities. One of the aforementioned demonstration projects includes the development and operation of a satellite, called KvarkenSat. Ten partners comprise the space centre, of whom six are involved in the develop- ment of KvarkenSat: Luleå University of Technology, Aalto University, University of Vaasa, Swedish Institute of Space Physics, Swedish University of Agricultural Sciences and Novia UAS. a) Technical Objectives- - To provide hyperspectral images of the Kvarken Region and other areas of interest for monitoring, analysis and/or modelling of land and sea features. - To perform the in-orbit demonstration of a university-built AIS receiver for sea vessel tracking.

	- To provide unprocessed satellite navigation data on multiple frequencies for the later characterization of such signals. - To demonstrate and characterise the in-orbit performance of an array of water-based thrusters for spacecraft maneuvering. b) Educational Objectives - To advance the competence of the development team and involved parties to design and operate nanosatellites and ground stations. - To provide hands-on and project experience for university students. c) Outreach Objectives - To spread awareness and display the capabilities of the Kvarken Space Center and its actors, aiming to boost space-based business and innovation in the Kvarken region. - To provide local citizens the experience of ob- serving the design, implementation and operations of a CubeSat mission closely connected to the Kvarken region. KvarkenSat will comply with the CubeSat standard, a satellite in the nano-size class that consists of one or more 10 cm × 10 cm × 10 cm cubes. Its benefits are modularity, some degree of standardisation, agility and low cost. Through the development of KvarkenSat, the center plans to demonstrate the mission end-to-end processes while sharing progress systematically with industry and organization members.
Impact:	Kvarken Space Centre is a project conducted by a consortium of Finnish and Swedish academic institutions aiming to enhance the economic activities of the Kvarken region shared by the two countries, by improving the regional competence in space technology. In this framework, the consortium is developing KvarkenSat, a first 2U CubeSat with the goal of exhibiting the regional capabilities in satellite development via performing science and in-orbit demonstration of Finnish payloads. Since the main areas of interest are forestry and sea transportation, the 2U CubeSat will integrate a multispectral camera for forest health and seawater quality analysis and an automatic identification system (AIS) receiver for sea vessel tracking. In addition, the spacecraft will perform the in-orbit demonstration of a miniature water-based resistojet thruster system. KvarkenSat's last payload will comprise a GNSS receiver that will extract raw data in order to conduct precise point positioning (PPP) algorithm research. The development of KvarkenSat is currently in phase D. The launch process for the CubeSat is envisioned to be accomplished at the Esrange Space Center in Kiruna, Sweden through a flight opportunity awarded by German Aerospace Center (DLR) on one of the demonstration flights for new micro launcher space transportation vehicles and may be one of the first missions to gain access to space from northern Sweden
Link:	https://www.ltu.se/research/subjects/Rymdtekniska-system/Universitetet-bygger-svensk-finsk-satellit-1.215212?l=en

AlignSAR

Lead:	AGH, Krakow, Poland
Keywords:	Very large data bases: archiving, handling and analysis Geo-information and spatial data analysis
Project Summary:	The project aims to provide FAIR-guided open datasets and tools designed for SAR applications, ensuring interoperability and consistency with existing and upcoming initiatives and technologies. The project facilitates a wider exploitation of SAR data and its integration and combination with other datasets. The project is funded from the European Space Agency (ESA) in response to the ITT ESA AO/1-11394/22/I-DT. It kicked off in February 2023.
Impact:	The project aims to achieve the following objectives: · Define a procedure for creating SAR benchmark datasets for machine learning applications. · Develop a reference, quality-controlled, documented, open benchmark datasets of SAR spatial and temporal signatures of complex real-world targets with high diversity to serve a wide range of applications with societal relevance. The database will respect FAIR (Findable, Accessible, Interoperable, Reproducible) and Open Science principles. · Create the database considering both open and closed SAR missions (including at minimum Sentinel-1), maximizing the geographical and temporal coverage, and integrating and aligning multi-SAR images and other geodetic measurements in time and space. · Define a specification of the signatures and their associated descriptors so that they can be easily indexed, programmatically searched, and retrieved. · Develop an open-source software library with associated documentation to create, describe, test, validate, and publish SAR signatures, and expand the database. · Demonstrate, test, and validate the Open SAR Library (database and open-source software) on at least two use cases for machine learning applications.

	· Ensure long-term availability of the database and open-source library, potentially through integration with other relevant open platforms and tools.
Link:	https://www.alignsar.nl/

LOOP - Landing Once on Phobos

Lead:	AGH, Krakow, Poland
Keywords:	Planetary Science missions Science / Robotic Exploration
Project Summary:	The goal of the project is to launch the first lander to a Mars satellite - Phobos. It is one of the two moons of the planet. Its area is over 6,000. km. The task is difficult due to the conditions prevailing on this Martian moon, which have not been studied in detail. Scientists assume that the gravitational acceleration on Phobos is over a thousand times smaller than on Earth, and the temperature ranges from minus 4 to minus 112 degrees Celsius. Another problem is limited knowledge about the soil of Phobos (called regolith). When landing, the moment of contact of the lander's feet with the surface of the moon will be crucial. According to the AGH UST release, determining various scenarios of the Phobos surface structure is one of the tasks of the research team from the Faculty of Mining and Geoengineering of the AGH UST in Kraków. In addition to finding a material with a similar composition to the soil on Phobos, the AGH UST research team will also develop a mathematical model of the contact of the lander's feet with the Phobos' surface. Due to the very low gravitational acceleration, it is important that the lander rests on the ground on the first attempt instead of bouncing off the surface. The subjects of experimental laboratory work, in addition to reconstructing the conditions on Phobos, will also include the study of the reaction of various soil types to the load of the lander's foot. The project was funded by the ESA Contract No. 4000122600/17/NL/CB
Impact:	Through this project, scientists and researchers hope to advance our knowledge of Phobos and enhance our capabilities for exploring and landing on the moons of Mars.
Link:	https://www.thefirstnews.com/tag/Landing%20Once%20on%20Phobos%20%28LOOP%29

Swarm4Anom – Investigation of the linkage between ionospheric plasma night-time density enhancements and magnetic field variability

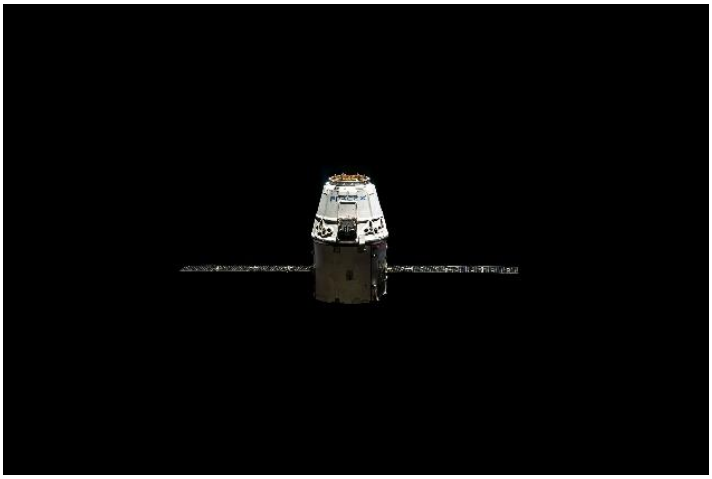
Lead:	AGH, Krakow, Poland
Keywords:	Earth observations from space/remote sensing Space weather
Project Summary:	The Swarm for Anomalies - Swarm4Anom is a project led by Space Research Centre PAS (Polish Academy of Sciences) in cooperation with a start-up OBSEE. The Swarm for Anomalies project, in brief named as Swarm4Anom, is focused on the linkages between ionosperic plasma night time density enhancements and magnetic field variability. Ionisation reversed diurnal cycle is one of distinctive features of the Earth's ionosphere, which is characterised by higher values of ionospheric plasma density registered in the night-time than in the daytime. Two well-known examples of this phenomenon are the Weddell Sea Anomaly (WSA) and the mid-latitude nighttime summer anomaly (MSNA). The WSA is a mid-latitude F region ionosphere phenomena taking place over the regions west of the Antarctic Peninsula. Though the WSA was discovered more than 60 years ago, still its generation mechanism is not fully understood and its modelling remains a challenge. Initial discovery of the WSA relied on measurements from the ground network of ionosondes. Satellite observations revealed that peculiar feature of the ionosphere is not limited to the southern hemisphere only. Similar behaviour is also present in the northern hemisphere. In situ registrations of electron density from the Langmuir probe on board three Swarm satellites are used to study spatial and temporal evolution of night-time plasma density enhancements (NPDEs). The study introduces the normalised density difference index I_NDD (Normalized Density Difference Index) in order to provide global estimates of the

	phenomenon. I_NDD is provided as a higher level product derived from Swarm data. The project was funded by the ESA, Contract No. 4000112769/14/NL/FF/gp
Impact:	By advancing our understanding of ionospheric plasma density enhancements and their relationship with magnetic field variability, the project contributes to the broader knowledge of the Earth's ionosphere and its complex behavior. This research has implications for various applications, including space weather forecasting, satellite communications, and navigation systems that rely on accurate ionospheric models.
Link:	https://cbkpan.pl/en/swarm4anom-investigation-of-the-linkage-between-ionospheric-plasma-night-time-density-enhancements-and-magnetic-field-variability/

5GLEO

Lead:	SIGCOM Uni.Lu
Keywords:	Fifth generation cellular network technology (5G) Global Satellite Navigation System (GNSS) / Services & Applications Positioning calculation / Techniques
Project Summary:	The main objective of the activity is to study, trade-off, and demonstrate the key technologies for enabling the use of 5G satellite networks for positioning in FR1 and FR2. Positioning shall be studied autonomously and in potential combination with the existing GNSS. In particular, the activity shall: 1. Perform system and technology trade-offs available within 5G satellite networks relevant for positioning in FR1 and FR2; 2. Study the performance and sensitivity of the different architectures and associated key technologies for enabling the use of 5G satellite networks for positioning in light of the consolidated use cases; 3. Demonstrate the key enabling technologies using experimental proof-of-concept; 4. Gather lessons learned, recommendations, and ways forward relevant in what concerns positioning with 5G satellite networks.
Impact:	The activity outputs shall aim at TRL 3: analytical and experimental critical function and/or characteristic proof-of-concept of this 5G NTN positioning system.
Link:	https://connectivity.esa.int/projects/5gleo

SnT AI4Space



Lead:	Uni.Lu
Keywords:	Artificial intelligence, intelligent systems, multi agent systems Thermal Control / Heat Storage and Rejection
Project Summary:	Failure and anomaly detection in space systems usually happens with conventional sensors and simple algorithms. However, researchers have started to investigate the capabilities of more advanced acquisition methods and algorithms, such as ones powered by Artificial Intelligence. The AI4Space project has developed a payload to experiment with one of these methods to detect temperature anomalies in satellite systems, and to investigate potential benefits in result accuracy, early prediction of anomalies, or even easier integration with a space system. AI4Space is the result of a joint collaboration between the the Space Systems Engineering (SpaSys) and the Computer Vision, Imaging and Machine Intelligence (CVI2) research groups in SnT, combining both teams' expertise to create a payload with an on-board AI algorithm. The AI4Space project is a 10 × 10 cm circuit board, hosting four infrared cameras, controllable heaters to emulate thermal anomalies, and an onboard computer to process the algorithms. It was launched in June 2023 as a payload hosted by a satellite from the Australian company SkyKraft.
Impact:	While AI4Space has not entered its operations phase yet, early development tests indicate that an Artificial Intelligence model can be easily trained to detect anomalies with a high accuracy, even on-board of a resource-constrained spacecraft. This mission also serves as one of the first missions of SnT; as a miniaturised autonomous payload, it paves the way for rapid low-cost technology demonstration missions, and provides a basic platform for SnT's future space endeavours.
Link:	https://www.uni.lu/fr/news/ai4space-snt-launches-in-space-machine-learning-experiment/

The Zero-G Lab: Testing in Micro-Gravity Environment

Lead:	Uni.Lu
Keywords:	Autonomous Rendezvous & Docking Automation & Robotics Systems
Project Summary:	This Laboratory emulates orbital dynamics and orbital scenarios to simulate on-orbit operations and on-orbit rendezvous in a dark and closed room. It consists of a perfectly flat floor where two identical pneumatic and robotic floating platforms designed and constructed by the SpaceR team emulate free-floating objects in space and orbital dynamics within 3-DoF. It uses air-compressed air-bearing under the base of the floating platform that generates an air cushion between the platform and the floor. In addition, the floating platform emulates the propulsion system of a satellite or spacecraft to navigate over the floor in a 2D environment. Furthermore, to simulate more orbital scenarios with higher degrees of freedom, the facility has two UR10e robotic arms mounted in one robotic rail each. One robotic rail is mounted on the ceiling, and another on the wall. The Zero-G Lab also has a sun simulator that could be mounted on the wall or in one of the robotic arms; it is painted in black and equipped with a motion capture system to verify & validate the different algorithms.
Impact:	On Earth, we take gravity for granted, but moving in its absence presents a number of challenges for in-orbit operations. For instance, a small push between two orbiting systems could make one or both to tumble and get out of control. Seeing how spacecraft and orbital robotics can be controlled or perform with decoupled systems in this environment provides students the unique chance of understanding and forecasting their behaviour in space.
Link:	https://ism.uni.lu/facility/zero-gravity-lab/

HELEN: High-fidELity tEsting enviroNment for Active Space Debris Remova

Lead:	Uni.Lu
Keywords:	Orbital Debris / Space Debris Automation, Telepresence & Robotics
Project Summary:	Space debris is a problem caused by millions of non-functional, human-made objects left in the space of varying geometry and weight, such as part of rockets or satellites, which are becoming a hazard for current operational and future space missions. SpaceR and Spacety target to explore, within the HELEN project, the potential of the 2D micro-gravity facility (Zero-G Lab) for validating FlexeS, a small Flexible Capture System for debris removal. Advanced computational methods will be developed, combining hardware and software to recreate high-fidelity in-orbit scenarios. Integrating virtual and physical systems will enable close-to-real testing, speeding up the transition between the development and deployment stages of ASDR systems.
Impact:	Within the HELEN project, SpaceR aims to explore the potential of 2D micro-gravity facility (Zero-G Lab) for the test, verification, and validation of FlexeS, a small Flexible Capture System for debris removal. Software-in-the-loop (SIL) and Hardware-in-the-loop (HIL) structures will be integrated to test ASDR systems in a ground-based advanced V&V framework. Eventually, the reduction of the gap between the simulation-to-reality will be realized.
Link:	https://www.spacer.lu/projects/HELEN

Secure and Safe Multi-Robot Systems (SESAME)

Lead:	Uni.Lu
Keywords:	Automation & Robotics components and Technologies
Project Summary:	European strategy and research roadmap documents emphasize the significant societal and economic benefits coming from robotic and autonomous systems. Multi-Robot Systems (MRS) comprise distributed and interconnected robotic teams that can carry out tasks beyond the competency of a single robot. Although MRS offer improved scalability and performance, increased robustness, and mission enablement, the lack of a systematic engineering methodology, covering the complete lifecycle of MRS, results in solutions that fail because of fragile design and unrealistic assumptions. SESAME addresses these problems through an open, modular, model-based approach for the systematic engineering of dependable MRS. SESAME is underpinned by public meta-models, components and configuration tools supporting the dependable MRS operation in uncertain settings characterized by emergent behaviours and possible cyber-attacks. To demonstrate this timely and ambitious goal, SESAME combines five enduser-led use-cases (in the domains of healthcare, agile manufacturing, agri-food, and inspection and maintenance) with R&D competences of partners that have a long track-record in conducting cutting-edge research on robotics, modelbased safety, security analysis, validation, and verification, towards the actual delivery of research results characterized by widely-used, sustainable and industrial- strength open-source software. An advisory board of world-class experts guides the development of SESAME.
Impact:	SESAME is very strongly aligned with addressing the challenges faced from increased use of Robotics targeted by call ICT-46-2020: Robotics in Application Areas and Coordination & Support, and in particular to address key issues in a modular and open way, that will substantially reduce the barriers that prevent more widespread adoption of robots. SESAME aims at delivering a disciplined approach addressing the engineering of dependable MRS.
Link:	https://cordis.europa.eu/project/id/101017258