ESA_Lab@UCL

Space at UCL

UCL has a very wide range of interests and engagements in Space-related activities and has contributed to numerous ESA space mission, through the provision of hardware/software; satellite operations; data analysis; science research and publications.

UCL's main interests are summarised in the following list. This is however, not complete and a future ESA_Lab@UCL would not be confined solely to these areas, nor would the development or inclusion of new areas be excluded. We have not explicitly included an Outreach theme although it is very active within UCL especially within the area of Space Science and Exploration.

Subject Areas:

- Artificial Intelligence and Machine Learning
- CubeSats and Nanosats
- Earth Observation
- Economics, Innovation and Public Policy
- Exoplanet Research
- Interdisciplinary Space Studies
- Materials Science
- Off-world Living
- Orbital Dynamics and Space Safety
- Planetary Science
- Satellite Communications
- Space Law and Regulation
- Space Medicine
- Space Policy, Governance and Security
- Space Project Management and Systems Engineering
- Space Science Instrumentation
- Space Weather

Contents

Artificial Intelligence and Machine Learning

Updated 25 June 2021

Theme leader: Dr Ingo Waldmann, Department of Physics and Astronomy

The University College London is one of the leading institutes in Artificial Intelligence (AI) and Machine Learning and has a long history of applying AI in the astronomy and planetary science domains.

The departments of Physics & Astronomy and Space and Climate Physics are collaborating on a large number of current and future space and ground based astronomical surveys (e.g. Ariel, JWST, Euclid, Plato, Juno, Juice, LSST, SKA and the ELTs). The big-data nature of these surveys lends itself to machine learning and AI approaches, which has been an active focus of research at UCL. Here we benefit from the significant expertise in fundamental AI development at UCL.

Though AI is a new addition to the UCL ESA_lab initiative, we can already showcase two successful AI focused OSIP studentships shared between UCL and ESAC (ESA PI: Bruno Merin). The studentships focus on developing unsupervised learning and graphical network approaches to catalogue and characterise the ESA mission archival data.

UCL puts great emphasis on the training of the next generation of interdisciplinary researchers well versed in astrophysics and AI, who can apply themselves to the big-data challenges of modern astrophysics. To this effect, the UCL Centre for Doctoral Training in Data-Intensive Sciences (CDT-DIS) was established in 2017. Being the countries first CDT-DIS, it has now grown to be the largest with four PhD cohorts and 49 PhD students in total. Over 60 UCL academics from 6 Departments are associated with the CDT, and each student is supervised by two academics from different groups or departments. The CDT-DIS PhD programme includes a formal training component in which PhD students attend lectures on deep learning, high-performance computing, and statistical methods.

CubeSats and Nanosats

Updated 25/6/21

Theme leader: Professor Dhiren Kataria, Department of Space and Climate Physics

The scope of activity at UCL related to CubeSat/NanoSat development includes:

- Develop CubeSat-based mission concepts across a range of strategically important scientific areas;
- Develop technologies and sub-systems enabling CubeSat-based science and commercial missions;
- Teaching and training;
- Provision of engineering expertise.

UCL (mainly through MSSL) has flown instruments on more than 200 sounding rocket flights and over 40 space missions and have developed extensive in-house facilities and engineering capabilities underpinned by a large pool of expert and experienced engineering staff. MSSL in particular has benefited from the co-location of science and engineering expertise and includes four internationally competitive technology and innovative R&D groups developing bespoke technologies for space missions.

UCL has a strong interest in exploitation of CubeSats/NanoSats for science research and for incorporating into hands-on teaching and training. UCL (through MSSL) is the only university in the UK to have built and launched a CubeSat with a scientific payload on board as part of a constellation of CubeSats for upper atmosphere science and continues to be involved in proposals and missions studies for exploitation of CubeSats for cutting edge science. A particular area of interest is in future CubeSat constellation mission for astronomical and near-Earth missions. Along with technology development interests in other theme areas discussed here, UCL also plan to include CubeSat technology development across a large number of the proposed ESA_Lab@UCL interest areas and to develop roadmaps, identify key technologies and provide a framework to facilitate their development and exploitation.

In all the above, UCL plans a significant contribution from Masters and PhD students, as part of their education. UCL would welcome ESA support and advice in such projects, ensuring relevance and access to state-of-the-art context.

Earth Observation

Updated 21 June 2021

Theme leader: Professor Julienne Stroeve, department of Earth Sciences

Earth Observations from satellites are the only way to monitor changes happening in remote and inhospitable areas of our planet, such as the polar regions. It wasn't until the start of the multichannel passive microwave data record in October 1978 that routine monitoring of pan-Arctic and Antarctic sea ice and ice sheets was possible. In the last 40 years, there has been an explosion of satellite missions around the world, with the European Space Agency (ESA) playing a key role in helping to monitor polar regions. In particular, ESA has launched satellites that help scientists monitor how sea ice thickness and ice sheet mass balance is changing.

The Earth Science Department at UCL has a long history of supporting ESA satellite missions, from helping to develop satellite mission requirements and algorithms for cryospheric studies, to processing of raw satellite imagery from ESA satellites (e.g. CryoSat-2, Sentinel) and finally, making available level 3 data products to the broader science community (e.g. sea ice thickness). UCL scientists first demonstrated how radar altimeters can be used to map sea ice thickness, leading to the design of CryoSat-2 for polar monitoring and launch of the satellite in 2010. A data portal developed at UCL in conjunction with CPOM and ESA provides updated data and images of sea ice thickness from CryoSat-2 (http://www.cpom.ucl.ac.uk/csopr/seaice.html). UCL ES scientists are currently funded under ESA grants to improve these sea ice thickness retrievals as well as derive snow depths over Arctic sea ice, a key data gap for polar studies.

In addition, Sentinel-3B was launched in April 2018, joining Sentinel-3A (launched in February 2016) in a constellation aimed at providing optimal coverage and revisit times of the global oceans and the cryosphere. These satellites continue a 26 year heritage of ESA altimetry missions. As an Expert Support Laboratory (ESL) for ice surfaces to the ESA Sentinel-3 STM Mission Performance Centre (MPC), UCL's Mullard Space Science Laboratory (MSSL) is currently leading an in-depth study in to the performance of Sentinel-3B, cross-calibration of Sentinel-3B with Sentinel-3A over sea ice and land ice surfaces and comparison with contemporaneous Cryosat-2 LRM, SAR and SARin measurements.

Finally, while UCL has a long history of using ESA satellites to monitor how fast the Arctic and Antarctic regions are changing, ESA satellites are also used to monitor earthquakes and volcanic eruptions, ground water pollution and other hazards. For instance, the Institute of Risk and Disaster Reduction and others at UCL use satellite data and statistical models to anticipate the effects of major natural disasters.

Economics, Innovation and Public Policy

Theme Lead: Professor Mariana Mazzucato, UCL Institute of Innovation and Public Purpose (IIPP)

The IIPP aims to inform space policy by directing space innovation activities towards maximum socio-economic benefit. This includes: public private partnerships (PPPs) in space; mission oriented policies (space as a contributor to missions on Earth also); and rethinking public value and public purpose in space. The IIPP's approach builds upon its work on market creating 'mission-oriented' policies, as opposed to traditional 'market-fixing' frameworks steering public agencies worldwide.

Public activities in space are changing significantly, with >60 space faring nations and a growing number of private sector organizations interested in the space. The space sector is rapidly evolving in its 'ecosystem', and is under pressure to deliver socio-economic impacts at a reasonable cost.

In the era of Space 4.0, or 'new Space' creating a strong European space innovation system is a key mission for ESA. ESA is exploring new ways of partnering with the increasing number of space faring nations, private space firms and other non-space entities. It seeks socio-economic impacts, including jobs/growth and addressing societal grand challenges. What is needed to create demand for new space services and products to enable a commercial lunar ecosystem in Europe?

The IIPP collaborates with NASA commissioned analysis on the emerging 'economy' in low-earth orbit (LEO) and on ESA commissioned research on innovation policy challenges and market creation opportunities. The IIPP explores how to create markets based on sustainable and symbiotic PPPs.

The IIPP could help ESA:

- define visionary goals and objectives for each activity and programme to anticipate future public, private institutional needs, in particular where there is not yet a market;
- assess and reinforce the 'added value of ESA' in terms of overall impact on European society;
- design a mutualistic space innovation ecosystem in Europe;
- enhance entrepreneurial activity within their Member States;
- become more agile and responsive, able to foster innovation, new partnerships and cooperation models, building on achievements, e.g. ESA's Business Incubation Centres;
- encouraging cross fertilisation between the space domain and other domains;
- rethink how to engage with the public and private actors to make exploration exciting again and enable new markets;
- foster ESA's activities/programmes through the development of remodelled programme-related instruments and the promotion of new types of partnership/funding schemes;
- better inform decision making processes and internal decision making structure;
- strengthen the Member States SME policy by increasing the benefits of innovation and focusing on SME financial viability, integrated supply chains and customization;
- Co-design can help mature conversations about socio-political implications & opportunities of sustained human lunar activities. This involves developing HRE's strategic position from a posture of learning, while aiming to support other stakeholders in doing the same;
- Explore open, participatory, web-like organizations and how they can inspire the way we approach future lunar exploration.

Exoplanet Research

Theme lead: Professor Giovanna Tinetti, Department of Physics and Astronomy

The Centre for Space Exochemistry Data (CSED) is an interdisciplinary hub that will take exoplanet science and astrochemical research to a new level by facilitating connections between observational data from space missions, deep learning techniques and quantum physics modelling of complex molecules.

CSED has grown out of the Exoplanet and Extragalactic Astrophysics Groups at UCL. The Centre is based within the Harwell Space Cluster, a strategic location that facilitates intersections with public organisations, including European Space Agency (ESA), STFC's RAL-Space, Satellite Applications Catapult and leading private companies from the space sector and start-ups.

CSED is an accelerator of the connection between the academic environment and other sectors that will attract private investments. It serves as an incubator for disruptive ideas to create spin-offs and develop partnerships in the industrial domain. To date, two successful start-ups have been created for the commercial exploitation of UCL exoplanet-related activities.

The inspirational nature of exoplanet and extragalactic science attracts the best students and young minds from all over the world. The intersectorial environment of CSED prepares a new generation of highly-qualified leaders and managers in scientific, technical and business areas.

CSED fosters educational initiatives connected to exoplanet science and STEM, including plans for a national and international roll-out of the successful EduTwinkle and ORBYTS programmes currently run in the London area.

Interdisciplinary Space Studies and Research

Updated 25 June 2021

Theme lead: Professor Victor Buchli, Department of Anthropology

This theme promotes interdisciplinary research between the hard and social sciences and arts and humanities. It develops teaching, publication, outreach and research initiatives across the various disciplines at UCL contributing to the study of outer space as a new and emerging field of area studies.

Activities:

- COSS, the Center for Outer Space at UCL, The Institute of Advanced Studies, Director Dr. David Jeevendrampillai, offers a rich and varied programme of interdisciplinary seminars, talks and events across the arts and sciences.
- The development of a new UCL wide MSc in Interdisciplinary Studies of Outer Space highlighting UCL expertise across the hard and social sciences and the arts and humanities.
- Anth 0185: Extra-terrestrial Anthropology, a graduate level introductory course to the study of outer space from an anthropological perspective.
- Off Earth Atlas, UCL lead Dr. David Jeevendrampillai, the project in conjunction with Paris Science et Lettres considers life in outer space in many different and exciting ways- from what biological definitions of life are to the new social relations that come about in outer space.
- ETHNO-ISS, a five-year ERC funded project on the anthropological study of the International Space Station. This is a multi-sited and interdisciplinary project that focuses on the various space agencies and mission controls and their attendant communities that contribute to the modular architecture of the ISS.

Materials Science

Updated 30 June 2021

Theme lead: Professor Kwang Leong Choy, Institute for Materials Discovery

The Institute for Materials Discovery's interests in advanced materials for space include:

- in-space propulsion technologies;
- nanotechnology;
- modelling, simulation, information technology and processing; and
- materials, structures, mechanical systems and manufacture.

We have also demonstrated CIGS solar cells with superior radiation tolerance that are light weight and can be deposited on a flexible substrate.

A cutting edge Electrostatic Assisted Vapour Deposition (ESAVD) method has been developed that can deposit high efficiency CIGS/CZTS thin films using non-vacuum conditions, that have high uniformity, with no secondary phase. Fully non-vacuum processed CIGS solar cells absorber and Ag nanowires based transparent TCO has reached efficency above 14%.

We are also keen to implement our newly developed perovskite solar cell technology with outstanding power conversion efficiency (i.e. >25.2%), high specific power (i.e., power to weight ratio), compatibility with flexible substrates, and excellent radiation resistance for space application.

We are interested in the application of nanomaterials/nanotubes/nanocomposites in satellite applications in the areas of light-weight structures, electrically conductive polymer composites, sensor technology and wear resistance as well as multifunctional nanocomposites integrating structural capabilities, robustness, radiation shielding, and electrical conductivity for used in extreme hostile space environments

Off-world Living

Updated 25 June 2021

Theme Lead – Professor Andrew Edkins, UCL's Bartlett Real Estate Institute

UCL has commenced an initiative in the area of Off-world Living through the creation of the UCL Off World Living institute (OWLI).

With considerable activity and investment now focussed on returning humans to the Moon and then considering the challenges of the far further journey to Mars, consideration of human presence for longer durations on extra-terrestrial bodies is now gaining increasing attention and consideration. UCL, through its Space Domain and the creation of OWLI is in an excellent position to draw upon its many world-class areas of academic expertise to consider the multitude of issues that such off world environments pose for human presence and ultimately human habitation.

The creation of a new substantial campus on the Queen Elizabeth Olympic Park, together with UCL's existing facilities, offers the potential to embed off world living into many areas of UCL's activities, ranging from new and novel research, through teaching to create the future experts that will be needed in the growing space sector to the various forms of engagement that will aid the channelling of knowledge derived from considering off world living to be applied here on Earth and at a time when we face many forms of challenge.

UCL is now growing the community of interest and it is clear that this is both a topic of significant interest and great potential. OWLI, along with the UCL Space Domain, is seeking to secure additional resources to further encourage and expand the wide range of opportunities that off world living presents to a university as large and diverse as UCL. Along with other parts of UCL that are involved with the ESA_Lab@UCL, there is both excitement and expectation that new discoveries, new knowledge, new technologies and indeed new science will result from focussing on the challenge of achieving off world living.

UCL areas of expertise/potential application in this area include:

- Robotics, for exploration, building, maintenance and service provision;
- Building materials development and manipulation;
- Off-world architecture
- Communications;
- Residence design including 'village' level design;
- Psychological issues related to remoteness and self-reliance;
- Space policy issues related to the creation of an Off-world living environment including new approaches to organisational networking and international collaboration;
- On-site education and training, particularly where real-time contact with Earth is impossible (i.e. Mars and beyond);
- Cultural impact (both on Earth and Off-world).

Orbital Dynamics and Space Safety

Theme lead: Professor Marek Ziebart, Space Geodesy and Navigation Laboratory at UCL

This group works on a range of topics in astrodynamics, space geodesy and navigation. Primarily a modelling and algorithm development group we also have some experience in hardware development. This ranges from orbital dynamics and the modelling of the behaviour of atomic clocks in the space environment, through to satellite signal modelling and exploitation, and onto planet scale reference frames and surface modelling. This has expanded over the last eight years to include the analysis and modelling of space debris and topics in space situational awareness

Related projects conducted in this area include:

- Modelling of surface forces of the Galileo FOC and IOV space vehicles – ESA;
- Feasibility Study for a Reduced Planetary Navigation and Communications System – ESA;
- Use of EGNOS in Urban Environments – ESA;
- Galileo Integrity Chain – real-time modelling of sensor station atomic clocks – ESA;
- Improving Force Models for the Real-time Prediction of GNSS Satellite Positions – EPSRC (with NASA Jet Propulsion Laboratory) (resulting in UCL orbit models adopted as operational standards by NASA for several missions);
- Long Term Prediction of GNSS Spacecraft Orbits for Integration with Chipset Location Devices – EPSRC;
- Exploitation of geometric city models for the modelling of satellite availability and signal degradation – EPSRC (resulting in IP run on all Uber apps globally);
- Stabilising the Orbital Reference Frame for Ice Cap and Sea Level Observation and Modelling – NERC (Cryosat II, Jason 2) (with NASA Goddard Space Flight Centre);
- Reducing the Impact of Orbit Error on the Measurement of Polar Ice Thickness and Sea Level Variations – NERC (Cryosat II, Jason 2)(with NASA Goddard Space Flight Centre);
- Looking inside the Continents from Space: Insights into Earthquake Hazard and Crustal Deformation – NERC (Sentinel-1 orbit modelling);
- Track Custody at GEO – US Air Force of Scientific Research.

The group has worked for several years on the Galileo spacecraft surface force models, which are an intrinsic component of the system. It has actively supported ESA in the endeavour to make Galileo the most accurate and robust satellite navigation system for scientific applications. This effort is currently funded by ESA and has recently been extended. The group has applied its long-term understanding of the impact of the space environment on the trajectories of space vehicles to the space debris problem. This is an evolving challenge relating to space situational awareness, space traffic management and ultimately secured access to space.

Planetary Science

Updated 25 June 2021

Theme leader: Dr. Dominic Papineau, Centre for Planetary Sciences, Department of Earth Sciences, and London Centre for Nanotechnology, UCL

The Centre for Planetary Sciences at UCL/Birkbeck (CPS) is one of the UK's leading centres for planetary science. It houses expertise in understanding planets from their deep interiors, through their surfaces and atmospheres, to their space environment. This expertise is complemented by world leaders in astronomy, terrestrial and solar science, life and chemical sciences.

The CPS is a centre of excellence for research in planetary sciences, based on a collaboration between three UCL departments – Physics and Astronomy, Earth Sciences and Space and Climate Physics – and with the Department of Earth and Planetary Sciences at Birkbeck. The CPS is primarily a "virtual" research centre, and comprises researchers within the following groups:

- Planetary Physics & Exoplanets Group, Dept of Physics and Astronomy, UCL;
- Imaging Group, Dept of Space & Climate Physics, UCL;
- Planetary Science Group, Dept of Space and Climate Physics, UCL;
- Planetary Dynamics, Crystallography and Mineral Physics Groups, Dept of Earth Sciences, UCL;
- Precambrian Research, London Geochemistry and Isotope Centre (LOGIC), and Micropaleontology Groups, Dept of Earth Sciences, UCL;
- Comets and meteorites groups in the Department of Earth & Planetary Sciences, Birkbeck.

CPS members are playing or have played key roles in planetary and exoplanetary space missions led by ESA or with ESA's involvement such as Giotto, Mars Express, Venus Express, Cassini-Huygens, and Rosetta. These involvements have included scientific and hardware activities.

Members of the CPS community have led technology developments related to both in-situ measurement and data production including sensors, planetary penetrators, imagers and image processing algorithms. They have led and contributed to a number of successful ESA contracts.

CPS members represent diverse scientific backgrounds from mineralogy and space physics to biogeochemistry and exoplanets. The deep involvement of the CPS community in ESA activities continues to be underlain by actively researched basic scientific questions about the origin of life (and synergies with Centre for Life's Origin and Evolution (CLOE)), the biosignatures of life, life's co-evolution with redox and climate change, and the cycling of carbon and volatile in the deep interior, on the primitive Earth, and in interplanetary space. Questions about extraterrestrial life are in everyone's mind and ultimately link many of these efforts, which also notably include the search for habitable exoplanets and biosignatures on other planets.

Many CPS members are leading or are involved in scientific and hardware provision for planetary and exoplanetary missions such as ExoMars, JUICE, PLATO, and ARIEL. The CPS are also leading proposals for future missions including potential lunar projects and leadership of the Comet Interceptor proposal submitted for ESA F-class mission. The Centre is also one of three UK universities to play a leading role in the European Union-funded *Europlanet* project that brings together Europe's major planetary science centres.

Satellite Communication

Updated 1 July 2021

Theme leader: – Dr Kasia Balakier, Department of Electronic and Electrical Engineering (EEE)

Communications is a fundamental functionality present in every satellite mission. Satellite communication links can be based at RF frequency range (1-300 GHz) or optical wavelengths (1.5um). The satcom topics investigated at UCL are related to microwave, optical and quantum communication, including optical and microwave photonic equipment concepts demonstration using free-space path optical and THz test benches.

UCL academic and research staff has the expertise which supports future developments in data transmission links, including intra-satellites, direct to Earth and inter-satellite connectivity. We have developed technology which can be used for data processing and signal routing within the communication payload, such as antennas, phase arrays, microelectronics, RF over fibre links, transceivers, coherent detectors, frequency convertors, amplifiers and others. Some of the ongoing projects include:

- "Milimeter-Wave Power Photodetector for LO Generation and Distribution", (ESA AO 1-8571/16/NL/GLC)
- "Photonic Systems for next generation satellites", supported by EPSRC UKRI
- "Design and development of power efficient satellite optical links", supported by EPSRC UKRI

The researchers at UCL EEE, in addition to working on physical layer and hardware development, have been investigating higher layers of communication theory, signal design and data processing algorithms.

Satellite constellation networks are being explored within the Computer Science department, which work is relevant in the context of recent developments in the architectures of LEO constellations.

UCL is exceling in the development of cutting-edge terrestrial telecommunication systems operating both in RF and optical domains. We will aim to leverage on our ongoing work and know-how on communication and connected technologies to pursue an effective partnership with ESA and increase our collaboration with industrial partners operating in the space sector, to implement equivalent systems for satellite communication.

By means of knowledge exchange between UCL and ESA, we have offered bespoke courses on Photonics Devices and Sub-systems and jointly proposed student research projects.

Space Law and Regulation

Theme leader: – Dr Madeline Carr, Department of Science, Technology, Engineering and Public Policy (STEaPP)

STEaPP research focuses on the complex policy problems emerging in the 21st century that arise from continued innovation and application of science, technology and engineering. Work explores both the legal and regulatory problems themselves and also the future of policy making innovation and international policy cooperation.

Within UCL, the Space Domain and the Department of Science, Technology, Engineering and Public Policy are currently in discussions with the London Institute of Space Policy and Law (part of the University of London). STEaPP has established a collaborative programme of research and training and hope to integrate the ISPL within the proposed ESA.Lab@UCL. STEaPP would expect this aspect to be closely linked to its Security and Space Policy interests described above.

Legal and regulatory frameworks will help to shape future innovation and Space 4.0 developments. They pose numerous challenges and simply adopting frameworks developed for other regulatory contexts is highly problematic. Lessons learned from the difficulties of applying international law to cyberspace will have currency in this context as well. STEaPP and ISPL can assist the ESA by providing the following:

- Research into the future of space policy and law
- Identification of areas of growth and opportunity for the EU in terms of leading regulatory approaches
- Examination of the likely implications and outcomes of alternative policies and laws.
- Critical evaluation of security related regulation and legal frameworks with a focus on the promotion of international peace and stability.
- Critical evaluation of the potential links between international cooperation on the regulation of space and the promotion of the SDGs.
- Research into the development of international norms and customary law related to the responsible use of space.

We would expect Space Law and Regulation to be closely linked to our Security and Space Policy interests described above.

STEaPP is currently in discussions with the London Institute of Space Policy and Law (part of the University of London). The Space Domain has established a collaborative programme of research and training with ISPL and hope to integrate them within UCL and the proposed ESA.Lab@UCL.

Space Medicine

Updated 25 June 2021

Theme leader: Dr Iya Whiteley, Centre for Space Medicine (CSM), Department of Space and Climate Physics

CSM facilitates human space exploration through supporting and realising human potential, developing and extending our abilities and training methods; exploring our inner space to facilitate the exploration of outer space. The CSM has excellent links across the UK Space Biomedical community, within ESA's human space flight programme, the Russian Space programme, including IBMP and the Gagarin Cosmonaut Training Centre (GCTC), and NASA.

The CSM focus is on monitoring and continually improving cognitive performance and psychological well-being in isolated and self-sufficient environments; rapidly capturing and transferring rare expertise; bringing techniques and technology developed for Human Space Flight to improve the quality of life on Earth. The CSM is inherently innovative and interdisciplinary, seeks out novel techniques and applies knowledge across domains (see examples below). CSM investigates integrative health approach for isolated and extreme environments, bringing conventional and complementary approaches together for rapid learning and application in a coordinated way. The emphasis is on a holistic approach to health care and wellness, including physical, mental, emotional, functional, spiritual and social aspects.

There are more explorers of outer Space on Earth than in orbit. We need to multiply these experts by several folds to extend human presence beyond Earth orbit and extend our senses to the farthest reaches of Space. Astronauts, cosmonauts and space scientists often report having a dream to work in the space domain at the primary school age. This requires exploration of how to foster abilities earlier in life for novel and creative thinking in future engineers, scientists and artists; of how to capture their imagination at a younger age; and of how to develop extra skills and abilities required in the next generation earlier to extend human presence and exploration reaches beyond imagined by our generation. Every current and future space mission beyond Earth orbit is prepared and supported by hundreds of innovators and experts stretching the boundaries of imaginable from all over the Earth; from space flight directors, space flight controllers, spacecraft engineers, rocket scientists, spacesuit designers, food and diet experts, chefs and even greater number of scientists that contribute to novel life support systems, practical material that can protect humans and equipment from the harsh reality of outer space. CSM sees the importance of supporting rapidly growing Space Tourism industry globally, which will require new type of professions and trainers. CSM recent activities include:

- **ESA iVOICE – Voice Analysis to detect and predict Crew Fatigue:** space, mining, aviation domains
- **ESA VULCAN – Voice and Content Analysis of Crew Performance:** space and general public domains
- **ESA iViewExpert – rapid transfer of expertise and rapid recollection of training:** space and medicine
- **ESA Study of Technologies/Techniques for Psychological Support Matrix for missions to the Moon and Mars:** space domain and applies to isolation environment of recent pandemic**.**

- **ESA Expert Tool to Support Crew Autonomous Operations in Complex Human Spacecraft:** space and applies to remote locations with limited resources.

Space Policy, Governance and Security

Updated 25 June 2021

Theme leader: Professor Serge Plattard, UCL Space Domain

The Department of Science, Technology, Engineering and Public Policy (STEaPP) has extensive experience in the areas of Policy, Regulation and Law (see Space Law and Regulation below). Professor Plattard who has a wealth of experience in the space sector will work closely with UCL departments including STEaPP and the Institute for Innovation and Public Purpose. We also anticipate greater engagement with the Institute of Space Policy and Law (see above).

UCL has focused areas of interest within the broad area of space policy, dealing with topics central for pursuing and expanding space activities at congested, contested and competitive environment. These areas include space exploration, exploitation of space resources, and space security including space surveillance and tracking (SST), space situational awareness (SSA), and space traffic management (STM).

Space exploration - The mechanisms for international scientific space exploration are well known and currently constitute the base framework for ESA cooperation. A shared vision is necessary, enabling a common human endeavour for space exploration. Although advisory instances already exist for the Moon and Mars, the optimisation of human resources and funds utilisation should be made more efficient. Raising the national flag is past policy, yet still very common, whereas a major paradigm shift is needed to address the changing 'New Space'. This is even truer when considering human space exploration. UCL expertise would help in elaborating scenarios/models along those lines.

Exploitation of space resources -Landing on comets and asteroids, including possibilities of returning samples to Earth, has made enormous progress recently; and plans to return on the Moon by the end of next decade may necessitate new space activities beyond sending back to Earth materials of strategic/scientific interest, e.g. mining celestial bodies for *in situ* use and fuelling exploration activities.

Although such challenging endeavours will need some time to mature and develop on a routine basis, there are a number of political and legal issues that remain to be solved with regard to space treaties, namely the 1967 outer space treaty and the Moon treaty: permission to exploit; under which regime?; ownership issues; celestial bodies protection; safety issues; etc. In short, a large set of issues that could involve both a space agency and a university to develop a set of in-depth analysis and proposals.

Space security – Without further intervention near Earth space is almost certain to become increasingly congested, especially with the advent of LEO constellations made of hundreds/thousands satellites. To ensure a long-term safe and sustainable space environment, a set of (incomplete) guidelines was endorsed by the COPUOS in June 2019. Yet, starting with the 2007 UN guidelines on space debris, transparency and confidence building measures in addition to those guidelines, there is still an enormous work to achieve effective space traffic management. Of critical concern is whether international agreements can be found on a timescale comparable with the rate of congestion.

Policy proposals are still in the making. UCL and ESA could advantageously explore some solution contributing to a robust STM.

At this stage regarding the three areas of possible collaboration, discussions are still ongoing with ESA, in particular with the Head of External Relations, to pick the right angle to address these topics, if not all of them, at least to start with one on a robust stance meeting both the interests of UCL and ESA.

Space Project Management and Systems Engineering

Updated 25 June 2021

Theme leader: Prof Michael Emes, Centre for Systems Engineering, Department of Space and Climate Physics, UCL.

Through the Centre for Systems Engineering (UCLse), UCL has been actively teaching project management and systems engineering drawing inspiration from the space sector for over 20 years, and has undertaken research projects in space project management and systems engineering.

Project Management Training

Most large and complex projects (in all sectors) face difficulties delivering the required technology performance within their budget and schedule constraints. In this context, the Director General of ESA was encouraged in 2008 by Council at Ministerial level to "*put in place methods, processes and tools, to reinforce the Agency's capabilities to control the cost and planning of ESA projects*". One of the recommendations of the Edwards report (2010), was therefore that ESA should develop a Project Manager Training Programme for major space projects (€50M+). ESA put out an invitation to tender to find an organisation suitable for delivering the training, and UCL-MSSL responded with a proposal to deliver a series of lectures and realistic 'simulations' based around a challenging recent ESA mission (Aeolus). UCL was successful in winning the contract to design and deliver the programme, with significant input from current and former ESA staff. Prof Smith and Prof Emes have now successfully run 4 cohorts of the 14-day programme, with a total of 54 trainees. A primary focus has been in establishing effective risk management as a unifying philosophy across ESA's projects. The course is on-going, and the contract has recently been extended to 2030.

Systems Engineering Training

In 2015, ESA issued an ITT to refresh its Space Systems Engineering training programme. This had previously been run for a number of years by Southampton University and had a spacecraft subsystem technical focus. It was felt that a new course was needed to make ESA staff more knowledgeable about the Space System Engineering processes and on the interaction of the different sub-systems. UCLse proposed a programme of lectures and simulations based around the Sentinel-2 mission, and have now successfully delivered two cohorts of the 11-day programme to 30 trainees. This training draws upon a number of key principles, including the value of taking an integrated approach to systems engineering and project management.

Research

UCLse hopes that engagement with ESA will allow us to identify areas of mutual interest for research, and perhaps give us access to data and staff to improve the depth and quality of its research. Each year several MSc students declare an interest in space-related projects and UCLse welcomes ESA involvement in areas such as: Risk and reliability modelling; Requirements management; Technology selection and decision making; Working in technology development in international teams; Monitoring progress in complex projects.

Ongoing, completed and future PhD projects are briefly summarised in the sections below.

Ongoing and completed research projects

One of our PhD students (Juan Carlos Guerrero) is currently modelling the cost and schedule performance of projects, with a particular focus on the challenges of managing projects delivering scientific instrumentation for spacecraft. Part of this research has involved input from ESA project managers who have helped us to understand the prevalence in the space context of common system archetypes. This is helping us to understand the dynamic behaviour of projects, including modelling the sharing of resources between two projects running concurrently. A previous PhD student (Dr Zakari Tsiga) explored attitudes to risk in space projects and critical success factors for space projects, and other PhD students (Mohamed al Ali and Fahmi Ibrahim) are now exploring decision making models in a project context, including exploring how project decision is influenced by heuristics and biases.

New research project – MBSE

One of our new research initiatives in partnership with ESA is a 4-year PhD research project to explore the use and evolution of Model Based Systems Engineering (MBSE) models through the project lifecycle. In August 2021, Benoit Pigneur is due to start this project, which was developed in response to a call for research projects in MBSE under ESA's Open Space Innovation Platform. Recent advancements have been made in MBSE and use of other digital tools. The overall maturity of such tools has individually increased but we will take a holistic view of the problem and explore the need for an evolution across the lifecycle. In other words, the MBSE needs at an early stage will be different to a later stage. Can we anticipate and plan out a digital model strategy at the start of a project? In comparison, a physical model philosophy is established in project management and system engineering plans. We will explore the conditions and characteristics where we could do the same for a digital model philosophy. This will require us to identify specific needs for each project phase and work on the interoperability of the models. The aims would be to make recommendations on the optimal set of digital models and philosophy that will allow for interoperability, evolution of maturity, compatibility, traceability and continuity. Ideally, these recommendations would be applied on different real space projects to demonstrate and validate their effectiveness.

Future research – Information Systems research for space

More broadly, Dr Chekfoung Tan has recently started developing ideas to conduct information systems (IS) research in the space sector. IS research is multidisciplinary in nature, and includes studies of the design, application or adoption of information system artefacts (e.g. frameworks, models, methods), which aim to deliver benefits to individuals, businesses and society. IS research has been widely conducted and applied in various sectors such as healthcare, construction, retail, education, marketing and government sectors. However, limited research has been done on the role of information systems in the space sector. We there see an opportunity for us to define, position and expand the application of IS to explore how it can deliver value and sustainability in space systems and projects. This might begin with a systematic review of the literature to explore relevant themes in terms of the role of information systems in achieving sustainability in space operations, and could be followed by developing a conceptual sustainability framework and validating the framework with case studies. The research outcome could contribute to creating a sustainable ecosystem for ESA space operations by creating new opportunities or optimising existing capabilities of all agents involved (human and non-human), to eventually drive economic and technological innovation and environmental benefits.

Space Science Instrumentation

Updated 25 June 2021

Theme leader: Professor Dhiren Kataria, Department of Space and Climate Physics

The scope of activity at UCL related to space science instrumentation development includes:

- Design and develop novel instrumentation based on cutting edge technologies with applications across a range of strategically important scientific areas;
- Develop instruments and technologies for space-based science and commercial missions;
- Teaching and training;
- Provision of instrument engineering expertise.

UCL (mainly through MSSL) has flown instruments on more than 200 sounding rocket flights and over 40 space missions and have developed extensive in-house facilities and engineering capabilities underpinned by a large pool of expert and experienced engineering staff. MSSL in particular has benefited from the co-location of science and engineering expertise and includes four internationally competitive technology and innovative R&D groups developing bespoke technologies for space missions.

UCL plans to create an interdisciplinary platform for technology development across a large number of the proposed ESA_Lab@UCL interest areas and to develop technology roadmaps, identify key technologies and provide a framework to facilitate their development and exploitation. A particular focus will be to identify technologies that are generic in nature with applications in several of the areas of ESA_Lab@UCL research interests. Examples include mass spectrometry, detection, imaging, sensor and radiation technologies, bespoke electronics including ASICs and FPGAs, and novel materials for structures (see Material Science).

UCL also plans to facilitate the development of a technology resource pool. This will focus on enabling and/or enhancing research output, providing hands-on teaching and training capabilities and facilitate capacity building. From this pool we would support future space mission hardware provisions, facilitate spin-in and spin-out of technologies with other ESA_Lab@UCL research groups (both for supporting science as well as commercial exploitation) and industry.

In all the above, UCL plans a significant contribution from Masters and PhD students, as part of their education. UCL would welcome ESA support and advice in such projects, ensuring relevance and access to state-of-the-art context.

Space Weather

Updated 25 June 2021

Theme leader: – Professor Lucie Green, Department of Space and Climate Physics (MSSL)

MSSL has a demonstrated track record in space weather across the following areas:

- Instrumentation: A decades-long involvement in developing, flying and using instrumentation that is vital for space weather monitoring and the underpinning science through Cluster, Solar Orbiter, QB50, Sunjammer, SMM, SOHO, Yohkoh, Hinode and most recently after leading on the in situ instrumentation package for ESA's Lagrange mission MSSL is now the PI institute for the solar wind monitor (PLA);
- Space weather mission concepts: Involvement in an Alcatel study for ESA in ~2000. Current and recent activities have focused on the Lagrange mission mostly through the ESA P2-SWE-X Lagrange study and the IPSP study led by the UK Met Office;
- Data Analysis and modelling: Extensive data analysis through many missions that includes conditions in the radiation belts and modeling the solar magnetic field prior to eruption;
- Data access and metadata [HELIO]: Involvement in data archiving for several missions. HELIO, for example, has built our expertise in accessing data from many domains and managing the metadata needed. We have involvement in ESA Radiation Expert Service Centre;
- Policy: Through SOARS (Space Weather Pilot Project) we worked closely with the aviation industry to understand space weather effects. This work has been expanded through an IPSP funded study and a collaboration with Atkins. Close work with the Met Office Space Weather Operations Centre feeds into this area and connects us with UK policy makers;
- Teaching: Undergraduate, post-graduate and industry courses are currently available. In 2020 the group project for the MSc in Space Science and Engineering was run in collaboration with ESA through Dr. Melanie Heil (Space Weather Space Segment Coordinator) and focused on design of a D3S mission concept.

MSSL's strength is in the breadth of scientific research that spans the Sun through to the magnetosphere and the radiation belts (and indeed other planets) and in the development of new space-based instrumentation. UCL's space weather ambitions are to:

- Maintain leadership in the ESA Lagrange mission through the management of the in situ instrument package and provision of a solar wind analyser. Maintain momentum toward launch in the late 2020s;
- Provide hosted sensors on satellites;
- Become a centre of CME modelling and forecasting solar eruptions;
- Become a centre for radiation belt modelling;
- Become the "go-to" institution in the training of science and instrumentation for space weather;
- Develop concepts for the next generation, lightweight instrumentation through the use of novel techniques outside those currently used;
- Continue collaboration with industry on mission development, education and public policy.

Topics	UCL Lead	ESA Counterpart	ESA code
Overall Coordination	Prof. Alan Smith	Michelle Baker	OPS-OPC
Artificial Intelligence and Machine Learning	Dr Ingo Waldmann	Gabriele DeCanio	
Earth Observation	Prof. Julienne Stroeve	Mark Drinkwater	EOP-SM
Interdisciplinary Space Studies and Research	Prof. Victor Buchli	Jason Maroothynaden	TIA-AM
Space Project Management and Systems Engineering	Dr. Michael Emes	Heli Greus	TEC-QQM
Economics, Innovation and Public Policy	Prof. Mariana Mazzucato	Geraldine Naja	IPL-I
Materials Science	Prof. Kwang Choy	Thomas Rohr	TEC-MSP
Off-world Living	Prof. Andrew Edkins	Aidan Cowley	HRE-XE
Orbital Dynamics and Space Safety	Prof. Marek Ziebart	Klaus Merz	OPS-SD
Planetary Science	Dr. Dominic Papineau	Matt Taylor/Olivier Witasse	SCI-S
Satellite Communications	Dr Katarzyna Balakier	Mike Harverson	TIA
Space Science Instrumentation	Prof. Dhiren Kataria	Martin Linder	SCI-FI
Space Law and Regulation	Dr. Madeline Carr	Alexander Soucek	IPL-LT
Space Medicine	Dr. Iya Whiteley	Guillaume Weerts	HRE-OM
Space Policy, Governance and Security	Prof. Serge Plattard	Frederic Nordlund	DG-E
Space Weather	Prof. Lucie Green	Alexi Glover	OPS-SW
Exoplanets Research	Prof. Giovanna Tinetti	Kate Isaak	SCI-S
Cubesats/Nanosats	Prof. Dhiren Kataria	Roger Walker	TEC-SPC