Institution: The Open University

Unit of Assessment: B9

1. Unit context and structure, research and impact strategy

1.1 Overview

The Open University's (OU) Unit of Assessment (UOA) B9 covers five disciplines: *Astronomy*, *Physics*, *Physics Education Research*, *Planetary & Space Sciences*, and *Space Instrumentation*.

During the REF 2014-2020 period, the Unit has been at the forefront of Space Science and Exploration. UOA B9 researchers have designed and/or built instruments that have returned ground-breaking measurements from the surface of a comet (European Space Agency (ESA), Rosetta) and from orbit around Mars (ESA Trace Gas Orbiter). Unit staff have determined the physical structure of the Near Earth asteroid Bennu (NASA OSIRIS-REx), revealed the 'wet' nature of the previously considered 'dry' interior of the Moon, and through the Dispersed Matter Planet Project, pioneered new techniques to discover hot rocky exoplanets. The unit hosts the *Centre for Electronic Imaging* (CEI), a long-term commercial partnership with Teledyne e2v, and developed and built detectors for space missions including the ESA flagship mission JUICE. The Unit's space instrumentation expertise has led to innovative solutions for problems beyond space-research, in areas as diverse as monitoring air quality on submarines and ensuring the provenance of Scotch Whisky.

The UOA B9 research and impact strategy aims are:

- to undertake excellent science and enhance the Unit's international research leadership (Section 1.3.1)
- to ensure the Unit's research is sustainable (Section 1.3.2)
- to inform and influence relevant research communities and wider society (Section 1.3.3)
- to have a positive impact on society (Section 1.3.4)

The UOA comprises 42 (41.8 FTE) Category-A staff (CAS; CAS names underlined throughout), 25 grant- or project-supported Post-Doctoral Research Associates or Research Fellows (RAs), 21 research-related staff (Project Officers; PO), 64 Postgraduate Research Students (PGRS) and 11 technical-support staff.

1.2. Context and Structure

In REF2014, research in Space and Physical Sciences was a central element of the OU's submission to UOA B7 (Earth and Environmental Sciences) that included the majority of the OU's Centre for Earth, Planetary, Space and Astronomical Research (CEPSAR) research. Since then, University-level restructuring established the *School of Physical Sciences* (SPS, led by Jordan) and the *School of Environment, Earth and Ecosystems Sciences* (EEES) as two of six Schools in the *Faculty of Science, Technology, Engineering and Mathematics* (STEM).

This restructuring consolidated Space and Physical Sciences research into SPS, enabling a submission to UOA B9. SPS is home to 40 of the 42 CAS submitted in this return; the two others work in EEES and the *School of Life Health and Chemical Sciences* (LHCS), also within the STEM Faculty. The Unit's research is often interdisciplinary, e.g., six UOA B9 CAS are affiliated to the cross-disciplinary Astrobiology Research Centre (*AstrobiologyOU*), formally based in EEES (UOA B7).

Alongside the restructuring, in 2015 the OU invested GBP 7M to form key Strategic Research Areas (SRA) to selectively promote and develop internationally leading research areas. The

Space SRA is closely aligned to UOA B9 research and included an enhanced focus on impact and knowledge exchange activities (see Section 1.3.1).

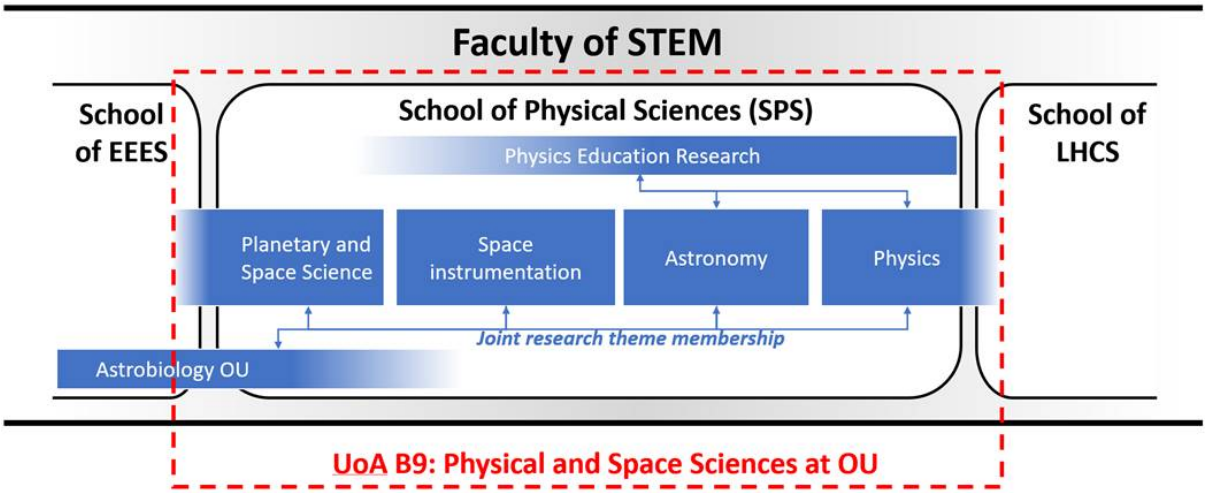

Figure 1. Organisation of research within the UOA B9 and relationship to STEM Faculty structures.

The Research Disciplines within the Unit are described below, with their organisation within SPS and relationship with STEM shown in Figure 1. The interdisciplinary nature of UOA B9 research means that many staff are members of more than one discipline:

- Astronomy (11 CAS led by Haswell). Research areas include exoplanets, stellar astrophysics, extragalactic astronomy, astrochemistry and astromaterials.
- Physics (11 CAS led by Gorfinkiel). Research areas include molecular, plasma, surface and condensed matter physics, quantum technologies and biophysics.
- Physics Education Research (PER; 5 CAS led by Hedgeland). Research areas include e-learning and e-assessment, physics education in an open and distance learning environment and equality, diversity and inclusion in physics education.
- Planetary and Space Science (PSS; 14 CAS led by Rothery. Research areas include cosmochemistry, the structure and origin of planets and small bodies, and planetary geology, geomorphology and atmospheres.
- Space Instrumentation (SI; 10 CAS led by Patel). Research areas include developing instruments for planetary, astronomical and terrestrial applications, spectroscopic and imaging techniques. Includes the Applied Science and Technology Group (ASTG) and CEI.

1.3 Research and Impact Strategy Since REF2014

The Unit's research vision and strategy, formally updated biannually, builds on the OU *Research and Enterprise Plan 2018-2023* that seeks to "inform, inspire and influence". The overarching strategy is to support and build upon areas of internationally excellent, world-leading research, creating capability and capacity to exploit new opportunities whilst engaging with industry and policy makers to address real world challenges. Part of this has been through the Space SRA, created to increase space research capacity around its original core themes of Electronic Imaging and Analytical Instrumentation, augmented in 2017 by In Situ Resource Utilisation (ISRU) for lunar missions and beyond. How the Unit has met specific strategic aims during this REF period is described here; section 1.4 details the Unit strategy for future success.

1.3.1 Enhancing the Unit's international recognition for research leadership

The Unit's REF 2014 strategy included building on research excellence and leadership. Successes during the REF period include:

Space mission and technology development
The Unit's recognised strength in laboratory and spaceflight instrumentation enabled staff to take on leadership roles on missions and instruments such as Rosetta (Green, Snodgrass, Wright), including the first measurements of organics on a comet's surface (https://doi.org/10.1093/mnras/stx2741, https://doi.org/10.1126/science.aab0673, https://doi.org/10.1098/rsta.2015.0385); OSIRIS-Rex, including Rozitis's role in ground-breaking close-up studies of the rubble-pile asteroid Bennu (e.g. https://doi.org/10.1038/nature13632, https://doi.org/10.1126/science.aay3544); and GAIA, Holland and Hall having key roles in the development of the detectors for the telescope. Unit leadership in upcoming missions include BepiColombo (Rothery), Hera (Green), and Euclid (Holland, Hall). Work on lunar ISRU and sample return missions (Anand, Sheridan, Barber), builds on new discoveries about water on the Moon led from within the Unit (https://doi.org/10.1038/ncomms11684).

Mars Exploration
Unit staff have leadership roles in Mars missions, including Co-PI of the ExoMars Trace Gas Orbiter (TGO) NOMAD spectrometer (Patel) that resulted in outputs quantifying Methane abundance and describing the first observation of martian Oxygen dayglow emission. Leadership in forthcoming missions includes Co-PI of the ExoMars 2022 Lander 'HABIT' instrument (Lewis), Deputy PI of the ExoMars Rover PanCam (Balme) and ExoMars Rover instrument Co-I roles (Patel, Schwenzer). UOA members also have leadership roles in preparations for Mars (Grady) and Phobos (Patel, Franchi, Eden) sample return.

Astrophysics
UOA B9 staff hold leadership roles in international astrophysics projects. The Dispersed Matter Planet Project (led by Haswell) has developed new ways to study ExoPlanets and reveals the incredible diversity of Planetary systems (https://doi.org/10.1038/s41586-018-0677-y, https://doi.org/10.1038/s41550-019-0973-y). This evidence of the Unit's strength has facilitated new leadership roles in preparation for the ESA Ariel mission (Haswell, Barstow). Other forthcoming astrophysics missions with prominent UOA B9 roles include Athena (Croston), Plato2.0 (Kolb; Haswell), James Webb Space Telescope (JWST; Fraser), and Euclid (Serjeant). Closer to home, Unit staff (Fraser) reported the first detection and quantification of phosphene on Venus, with implications for the presence of life there.

Unit researchers authored over 1300 outputs in this REF period, with highlights from across the UOA including the demonstration that simple models of quantum matter can break expected notions of how matter relaxes to equilibrium, and how gender-bias in Physics attainment is strongly related to how assessments are written.

1.3.2. Ensuring the Unit's research is sustainable

The Unit ensures its research is sustainable in two main ways:

Fostering a dynamic research environment by strengthening the PGRS cohort
The number of funded PhD positions starting per year in the UOA increased from typically around 13 at the start of this REF period to 16 in the current academic year. The UK Research and Innovation (UKRI) Science and Technology Facilities Council (STFC) quota award to the Unit funded approximately five students each year, complemented by 1 or 2 STFC Cooperative Awards in Science & Technology (CASE) annually. The STEM Faculty and Space SRA offer match-funding to support staff bidding for new PhD funding, which can be particularly helpful for smaller partners and/or funding schemes that do not cover all expenses. During this REF period additional funding sources have included ESA, STFC ISIS, Engineering and Physical Sciences Research Council (EPSRC; from 2021), STFC DISCNet (Centre for Doctoral Training in Data-Intensive Science, with Sussex, Queen Mary, Southampton and Portsmouth) and the Ogden Trust.

Diversifying and strengthening external income

Since 2014, internal investment through the Space SRA has played a significant role in enabling the Unit to diversify its income and enhance its research sustainability. The Space SRA has provided direct or indirect support for new projects led or co-led almost exclusively by UOA B9 staff totalling more than GBP 40M. This investment has increased UOA B9 research capability and enhanced its international standing, helping the Unit to bid successfully for large international space project funds. Examples of this success include:

(1) ESA funding (Figure 2) increased from approximately GBP 400k in 2013/14 to over GBP 900k in 2019/20. Barber led the evolution from the Ptolemy instrument, designed to measure cometary volatiles on the ESA Rosetta mission, to the more capable 'PROSPA' instrument at the heart of the ESA 'PROSPECT' lunar mission payload (launch in 2025). ESA have provided GBP 11M in funding for the project, plus a further GBP 1M to provide an Exosphere Mass Spectrometer (EMS) to the NASA 'PITMS' instrument to launch in 2021.Technology developments from the Ptolemy instrument continue, with Sheridan leading work for the GBP 770k EU Horizon 2020-funded 'LUVMI' rover study to explore permanently shadowed regions of the Moon.

(2) UK Space Agency (UKSA) funding (Figure 2) has increased dramatically from approximately GBP 200k in 2014/15 to GBP 1.6M in 2019/20. CEI has secured approximately GBP 5.1M for the provision and characterisation of detectors for space missions from UKSA alone. Patel's success in the leadership of the UV-visible spectrometer of the NOMAD instrument onboard TGO has secured over GBP 3M of funding from UKSA for delivery, operation and data exploitation.

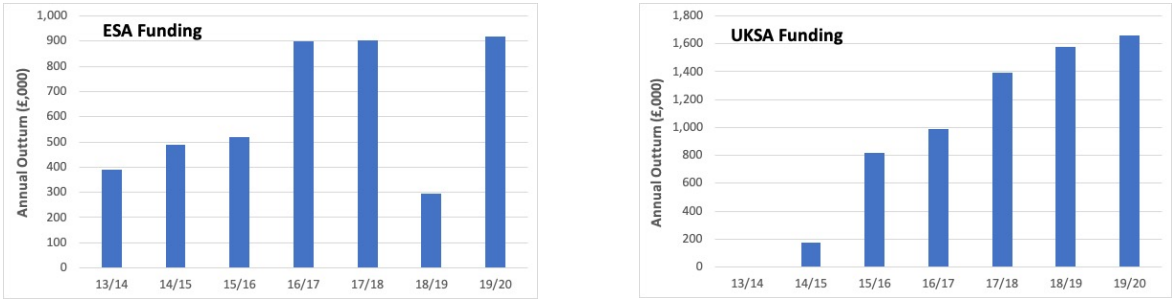

Figure 2. Research external income outturn/FY from European (left) and UK (right) Space Agencies

As in the OU's REF2014 B7 submission, developing interdisciplinarity remains a core element of the research strategy and provides funding opportunities from both new and existing funders. The largest success to date is the pan-Faculty AstrobiologyOU Centre, set up with an GBP 6.8M Research England Expanding Excellence in England (E3) award (UOA B9 Co-Is Morgan, Patel, Pearson, Schwenzer plus affiliated members Balme and Sheridan). Meanwhile, Patel and Pearson's GBP 300k ESA contract fuses social and legal expertise from OU's Faculties of *Arts and Social Sciences* and *Law and Business* with Unit-based space research to understand space exploration's socioeconomic benefits. ISRU science and technology combines engineering expertise from the *School of Engineering and Innovation* and UOA B9 analytical science (recently awarded GBP 230k in ESA/UKSA contracts; Anand, Barber).

1.3.3. Influencing research communities and wider society

Staff in the Unit provide extensive leadership within and beyond their immediate research communities through work on panels, committees and other bodies (see Section 4.5 for highlights). The Unit's Outreach and Public Engagement (OPE) strategy seeks to maximise research impact by promoting physics to schools and the general public. It includes professional development for teachers and encouraging more young people to pursue Physics at university level, particularly those from underrepresented groups and disadvantaged backgrounds. These goals align with the OU's core mission of social justice and widening participation. Several

external funding awards to the unit, and two part-time OPE officers, support this activity, which focuses on two areas:

Developing the unit's engagement capacity and skills
Internal funding supports one OPE officer (Starkey) who works with staff and PGRS to organise events and capture impact evidence, and to deliver training to Unit members. The Unit mentors Early Career Researchers (ECRs) to strengthen their skills to exploit OPE opportunities. Its leadership staff are also regularly selected and funded for engagement and communications activities. For example, the EUR 2M Horizon 2020 EuroCARES project to develop a roadmap for a European Sample Curation Facility selected Grady to lead its communications work package (WP), awarding funding of GBP 137k to UOA B9. Similarly, Serjeant is communications and citizen science WP lead on the EUR 16M (OU funding GBP 583k) Horizon2020 ESCAPE project to build the European Open Science Cloud for astronomy- and accelerator-based particle physics. Serjeant also led the citizen science WP of the EUR 15M ASTERICS H2020 project (GBP 275k to OU). Among other successful elements of this project, the Muon Hunter experiment engaged approximately 8000 volunteers worldwide. Throughout the REF period Unit researchers received a further GBP 184k for smaller OPE activities.

Engaging schools and the general public
The Ogden Trust (GBP 65k; PI Bergamini) funds OPE officer Dunford who supports Unit engagement with schools to enhance teachers' knowledge. These activities include delivering specialist teacher training and online resources for trainees across England and Continuing Professional Development for secondary school teachers in Wales. They also deliver events in schools such as School Physicist of the Year competition for pupils across the UK and workshops on 'shattering stereotypes' and increasing diversity in STEM subjects.

The Unit's research has been presented at The Royal Society Summer Science Exhibition in five of the past seven years, covering topics such as comets, asteroids, Mars and the Moon. UOA B9 staff exhibit at major events such as the UK Space Conference, the Farnborough Air Show and Edinburgh and Northern Ireland Science Festivals with audiences of up to tens of thousands. The Unit's lunar research showcase marking the 50th anniversary of the Apollo 11 mission achieved audience exposure of approximately 20M (approximately 11M through TV and radio interviews and 9M from online news feeds, events and articles) and more than 35,000 people have experienced the UOA B9 annual Moon Night Events since 2015. Grady and Rothery wrote more than 100 articles for The Conversation during the REF period that have attracted more than 5 million reads.

1.3.4. Having a positive impact on society

Training and supporting of researchers
In recognition of the growing importance of impact during this REF period, the Unit appointed an 0.2 FTE Enterprise and Knowledge Exchange (EKE) Lead (Morgan) in SPS. Working with the Faculty Research, Enterprise and Scholarship (RES) Office, they support and mentor UOA members on topics including consultancy, contract research, sponsored PhD Studentships, strategic partnerships and intellectual property licensing. The EKE lead has been instrumental in establishing a new community to help support and share best practice throughout the university. This community approach was pivotal in securing funding (Sheridan; GBP 307k) from STFC for a Knowledge Exchange Fellow to exploit the OU's miniaturised valve patent.

Building external partnerships
The Unit actively encourages staff to build relationships with external partners for impact activities. Recognising that this process takes time, sometimes several years, it also offers staff support with workload allocation where required.

CEI researchers have held a strategic collaboration agreement with US technology conglomerate Teledyne e2v (Te2v) for the past 15 years to work in the field of imaging detectors. Reviewed every five years, most recently in 2018, the unique partnership enabled

staff to develop new projects and funding opportunities and is a robust pathway to impact. It has allowed the CEI to undertake leading detector research, leveraging the company's involvement in many high-profile space missions and in turn contributing to the company's growth. The collaboration helped Te2v recently secure approximately GBP 20M in contracts for CCD manufacture, supporting a significant proportion of the jobs at their plant in Chelmsford. The manufacture and export of CCDs was worth over GBP 10M from ESA and NASA. CEI have trained 100 employees from Te2v, ESA ESTEC and Airbus.

Holland and Morgan are Co-Is on the highly successful GBP 4.7M CCF (Connecting Capability Fund) SPRINT (SPace Research & Innovation Network for Technology) programme. Since 2018, the programme has supported 12 projects with 11 different companies including nine led by Unit staff (creating research activity worth GBP 861k; GBP 503k awarded to OU). Applications include Earth Observation, optimisation of gas tank manufacture processes, stress analysis for aerospace propulsion systems, valves for satellite propulsion, and new food and drink technology development. Serjeant and Morgan are Co-Is on the GBP 1.2M STFC Food Network2.0. They have facilitated or received funding for 13 pilot-projects ranging from chicken welfare to food quality monitoring.

Evidencing impact
The Unit's four Impact Case Studies (ICS) highlight outcomes generated through close relationships between researchers and industrial or policy-making partners:

ICS 1 and 2 illustrate the impact of our research on the miniaturisation of analytical instrumentation. This work developed an award-winning air monitoring system for use on all future UK submarines to break a US company's 30-year monopoly to supply the NATO fleet, generated 13 new jobs and a GBP 13.7M orders for a UK SME. An offshoot of the research led to partnership with the Scotch Whisky Research Institute (SWRI) and IBM Research UK to develop a method to automatically detect fake and adulterated Scotch Whisky, protecting brands that contribute significantly to the UK economy.

ICS 3 describes how the CEI/Te2v research on radiation damage effects in image sensors has enabled several ESA missions (Juice, Euclid, SMILE). It also demonstrates how this work helped the company secure contracts to manufacture Charge Coupled Devices (CCDs) and Complimentary Metal-Oxide-Semiconductor (CMOS) image sensors.

ICS 4 describes the Unit's research leadership in lunar science, how it has built a new realisation that there is extensive water on the moon, and its role in developing ESA's multi-billion Euro European Exploration Envelope Programme. The ICS explores the significant economic impact that the Unit's development of novel technologies for in situ analysis and processing of lunar samples has had.

Research Open Access:
The UOA is committed to OU's Open Access (OA) policy (see Institutional Environment statement, IES). Since 2014 approximately 85% of the Unit's approximately 1,300 published books, chapters and journal articles meet gold or green OA standards. All staff and PGRS receive regular training and reminders about data publication requirements, using Open Research Online (ORO), the corresponding Data repository (ORDO), and the UKRI OA block grant. Where the block grant cannot be used, the Unit has funded gold standard OA costs.

1.4 Future strategic aims and goals for research and impact from REF 2021 onwards

Through the current REF period, the unit has continued to develop successfully across multiple fronts, so much of the strategy through the next REF and beyond extends the existing strategy, although with several new areas and opportunities identified. The key aspects are:

1.4.1 Build recognised excellence in research

Building on existing expertise and leadership (see Section 4.5 for examples) Unit staff will:

- Propose, lead and deliver forthcoming and new international ground- and space-based science and exploration projects. UOA staff will take leadership in key contributions to the science that drives the projects, in decision-making, data exploitation and high-quality outputs.
- Capitalise on the Unit's excellent analytical facilities to gain access to unique material returned by recent and forthcoming missions to asteroids (Hayabusa2, OSIRIS-Rex) and the Moon (Cheng'e 5) and prepare for future sample return missions to Phobos (Martian Moon eXploration, MMX) and Mars (MSR) through continued development of analytical and simulation facilities.
- Use the expanded UKSA National Space Innovation Programme to bid for involvement in payload development and science definition for space missions, including India's Shukrayaan-1 Venus mission and Mangalayaan-2 Mars mission. Staff will exploit current ESA- and UKSA-funded activity in lunar ISRU to make significant future contributions to this emerging field.
- Exploit new developments in telescope instrumentation to develop data science and AI or machine learning technologies for data exploitation, in readiness for analysis of the much larger and more complex datasets to come from the next generation of instruments (including WFIRST/Roman, LSST, SKA, Euclid).
- Use the Unit's capabilities in quantum mechanics experimentation, modelling and analysis to exploit the effects and techniques of quantum mechanics for applications with societal and economic impact. This includes Quantum machine learning, new methods to probe and control molecules for use in radiotherapy, and to investigate the molecular origins of life.
- Expand Physics Education Research, focussing on remote and virtual experimentation, interactive online assessment and equality, diversity and inclusion in physics education.

1.4.2 Enhance and expand research impact with commercial partners

Utilise the Unit's strong cohort of industry-facing expertise to develop existing partnerships and forge new industrial collaborations, and through this develop stronger synergy between our research activities and commercial impact. The extension of the OU-Te2v funding and collaboration agreement and the OU's commitment to continue Space SRA investment to at least July 2022 ensures a major pillar of the Unit's engagement programme is secure and provides a springboard for these activities. Fresh OU investment in a dedicated business development officer will support exploration of potential commercial opportunities in the microgravity environment emerging through new UK launch facilities.

1.4.3 Expand the reach and significance of public engagement

The Unit will work with local and national communities and networks such as the South East Physics Network (SEPNet) to identify OPE areas to focus resources and then deliver actions and pilot programmes. It will also expand engagement by exploiting existing links with BBC and other leading media outlets.

1.4.4 Staff recruitment and career development

Recruiting the next generation of research leaders and developing existing staff are the most important tools to meet our overarching research goals (see section 2.1.2). Attracting more externally funded Research Fellows is a cornerstone of this approach and has already seen success (e.g. two new UKSA-funded Research Fellows starting April 2021, and STFC Ernest Rutherford Fellow (ERF) Barstow). Maintaining demonstrable leadership in key research and

enhancing lab-based facilities will facilitate further recruitment, and in turn increase income and ensure sustainability in staff and infrastructure.

A key goal for existing staff is improving quality of research time. For example, to reduce academic workload fragmentation the Unit has focused staff teaching effort to create larger blocks of time on fewer modules (30% fewer modules per staff member since 2017) and will continue to improve the quality of research time available. More targeted training and mentoring is planned to better meet the needs of research-active staff and ECRs.

We remain committed to training the next generation of researchers through continued expansion of our externally funded PGRS programme.

1.5. Research and impact strategy challenges and opportunities from 31st July 2020 onwards

COVID-19 and Brexit could impact funding from UKRI and other providers, although confirmation of UK association to Horizon Europe ensures Unit B9 researchers can maintain significant roles in pan-European projects. Most of the Unit's research is linked to major programmes, primarily space exploration or large astronomy facilities which, as indicators of 'National Esteem', should be well-supported to completion in the next REF period. Underwritten by multiple projects with diverse funders, the Unit is therefore well-positioned to retain core expertise and continue varied research, even in unfavourable national funding environments.

As a post-Brexit and post-COVID 19 world continues to adjust to a reliance on virtual presences, the OU's expertise in distance learning places it in a strong position. The Unit's decision to formalise PER research as a standalone research discipline appears prescient: the future holds rich scope for research into how best to engage, retain and challenge new demographics in online learning, and provide "hands-on" teaching online.

2. People

2.1 Staffing strategy and staff development

2.1.1 Staffing Strategy

The UOA B9 staffing strategy is built upon a welcoming and collegial working environment and research culture that has Equality, Diversity and Inclusion (EDI) at its heart. The Unit aims to ensure sustainability through succession planning, while exploiting opportunities to expand into new avenues, starting from strong established research themes.

Of the 42 Unit CAS, 37 held permanent contracts at census date and five were fixed-term (FT); three of the FT academics have since become permanent. CAS include 12 professors, 16 senior lecturers/research fellows and 14 lecturers/research fellows. The CAS mean age is about 45 years, with more than 60% under 50, giving a healthy balance between early-, mid- and senior researchers. Nearly 30% of Unit staff identify as female (compared to <13% in the OU Physics and Space contribution to the B7 UOA in REF2014) and ~ 19% meet the ECR definition. More than 10% are non-UK nationals. Two staff tutors (teaching-focused academic roles) and five FT researchers meet the Code of Practice (CoP) thresholds for research independence and are part of our submission. The diversity of the Unit's staff is a strength that reflects its commitment to EDI.

The positive research environment is demonstrated by the low academic staff turnover during this REF period: since 2014, three senior research-active academic staff have retired and two have moved to other institutions. The Unit appointed one FT and eight permanent academic staff and converted six research or research-related posts to permanent research contracts within this REF period. Of these 15 appointments, five are ECR and six (40%) female.

Academic staff:
Croston was appointed as a Lecturer (now Senior Lecturer) in extragalactic astronomy. Dawes' Daphne Jackson Fellowship allowed her to return to astromaterials research following a career break; she won a Leverhulme Trust Research Fellowship and was then appointed to a Lectureship. Hall moved from a five-year industry/OU fellowship sponsored by Te2v to a permanent Lectureship in solid-state sensor research. Hedgeland was appointed as a Senior Lecturer staff tutor; she leads the Physics Education Research discipline and maintains a high research profile in surface science. James was appointed as Lecturer in theoretical condensed matter physics, King as a Lecturer in Cosmochemistry and Nixon as a molecular physics Lecturer in LHCS, strengthening research links between SPS and LHCS. McDonald was appointed to an 0.8 FTE FT Lectureship in galactic stellar astronomy, and Research Investment Fellow Schwenzer became a Lecturer (now Senior Lecturer) in Mars geology, cosmochemistry and astrobiology.

Research Staff:
Barstow was appointed as an STFC ERF researching Exoplanets; she will transition to a permanent Lectureship in 2024. Research-related Project Officers Barber, Morgan and Sheridan and FT researchers Dryer and Stefanov became permanent Research or Senior Research Fellows in this REF period. This investment has created roles with greater independence and flexibility and fostered new enterprise activity: the impact cases arising from the Unit's research are testament to the success of that strategy. The confirmation of three further permanent research positions (Morse, Soman, Skottfelt) was delayed by the Covid-19 pandemic and confirmed just after the census date.

The recruitment and support of externally funded, prestigious Research Fellowships was identified as a mechanism to enhance research capacity within the UOA and supporting Fellowship applications in a Unit priority. All new Fellowship applications are mentored by senior academic staff during development and undergo internal peer review before submission. The success of this approach is shown by the cohort of successful Fellows during this REF period: a Daphne Jackson Fellowship (Dawes), a Royal Astronomical Society Fellowship (Rozitis), a Royal Society University Research Fellowship (Ioppolo), two STFC Ernest Rutherford Fellows (Barstow, Snodgrass), two Marie Skłodowska-Curie Fellows (Cernok and Raack) and five Te2v (industry-sponsored) fellowships (Hall, Bush, Skottfelt, Murray, Greig).

Of the three internally-funded FT Research Investment Fellows from REF2014, Schwenzer is now a Senior Lecturer whilst Bernard-Salas has a research position in ACRI-ST, France, and Wake a lectureship at University of North Carolina Asheville, USA. In addition, Space SRA investment created four full-time fixed-term fellowships to enhance space-research capacity (Skottfelt, Lim, Barrett and Morse). Morse transitioned from a PO position, to which he returned before the census date, but both he and Skottfelt were appointed as permanent researchers in August 2020.

2.1.2 Staff Development

Recruitment and induction
In addition to formal OU-level induction processes, all new Unit staff and students meet the Head of School during induction and receive information about support routes, School values, EDI and training. New staff are assigned a mentor; current staff are offered mentoring opportunities annually, and mentors can be sought from outside the research area if desired.

ECR development
The development of ECRs is a vital part of the Unit's research strategy. The OU is a signatory to the Concordat to Support the Career Development of Researchers and the Unit actively works to implement its seven principles. One example is reduced teaching allocation given for lecturers in their first year, with a gradual ramp-up over five years. ECRs are mentored by senior academics/researchers as appropriate and provided with workshops covering topics identified by ECRs themselves as relevant to their needs: fellowship applications, careers outside academia

(with external experts) and mentoring and teaching opportunities. Positive feedback has led to these workshops being delivered Faculty wide. To develop teaching expertise, an annual call allows research-focussed ECRs to participate in OU teaching. Their needs and availability are matched to modules through discussion with the Director of Teaching (Kolb). Fixed term ECRs are also encouraged to take on co-supervisory roles for PGRS where contracts permit, providing important leadership training.

Workload management and appraisal
Workload is managed transparently using the OU Academic Workload Management system (AWM). Externally funded research time is protected in workload planning, and staff with significant external research income are allocated reduced teaching or administrative workload. Staff participate in individual annual Career Development and Staff Appraisal (CDSA) meetings with their line manager (or alternative, if requested). CDSA allows staff to discuss their administrative, teaching and research duties as well as opportunities for development, training, mentoring, and engagement with enterprise or scholarship. Workload allocations as a function of protected characteristics are monitored by the EDI team to ensure fairness. Academic staff have an annual allocation of 25 research days plus 44 days study leave (22 for regional academics) to dedicate to research. A policy of "no School meetings and no timetabled teaching duties" on Fridays protects blocks of research time.

Professional development and training
Staff have allocated AWM time (usually at least 5 days per year) for professional development and are encouraged to attend the Faculty-led Academic Professional Development sessions, which complement the central provisions by People Services and the Institute of Educational Technology. Staff can apply for funding for externally provided training and take OU modules free of charge.

Promotion and merit awards
Since 2018, all Unit staff are reviewed annually by a School panel to identify, and then contact, those close to promotion boundaries. There is also an annual call where staff can put themselves forward for promotion. Those developing promotion cases are assigned a mentor with Promotions Panel experience. ECRs are actively championed in university-wide reward schemes, including the annual Research Excellence Awards, merit awards, discretionary salary-scale points and Going the Extra Mile awards.

2.2 Research students

The Unit's PGRS community is the largest in the University, currently with 55 full-time and 9 part-time PhD students working across all Research Disciplines. The effectiveness of the Unit's supervisory, monitoring and support arrangements is demonstrated by the successful completion of 85% of PhDs within 4 years during the REF period.

2.2.1 PGRS Recruitment

Recruitment of research students is coordinated across all disciplines to ensure a consistent selection process. PhD opportunities are widely advertised online and directly to diverse University departments to meet the needs of our interdisciplinary research. Advert wording is monitored by the EDI team to ensure consistent communication with potential candidates across the protected characteristics spectrum. Since 2016, PGRS recruitment has been by trained and mixed-gender panels that includes one Post Graduate Tutor (PGT), one research discipline representative, and the School Director of Research or their deputy. Gender statistics are tracked throughout the recruitment process and monitored annually. The gender balance across PGRS cohorts has been stable over the past five years (35-40% female), significantly higher than the Institute of Physics benchmark for Physics (25%) and Astronomy (31%). PhD completion rates are also monitored by gender, with no significant differences found across the REF period.

2.2.2 PGRS support

Unit level PhD supervision and support arrangements are designed so that students have several sources from which to obtain help and support. Four PGTs support students and supervisors, with remits covering support, training, recruitment and funding. In addition to PGTs and the supervisory team, each student is allocated a Third-Party Monitor (TPM), an experienced researcher not directly part of the student's project or research group. The supervisory team plus TPM are arranged to ensure gender diversity. Two of the PGTs and many other members of academic staff have undertaken formal Mental Health First Aid training to support both staff and students. PGRS induction provides advice about student support routes, including additional support for neurodiverse students and those with disabilities, information about School values, the work of the EDI team and training options. PGRS have access to the OU Employee Assistance Programme, which provides free support and counselling.

2.2.3 PGRS training and career development

Skills and career development is provided by training programmes that benefit from the School's membership in SEPNet, in-house topical training, and the extensive OU Graduate School Network training portfolio. Workshops focus advanced physics topics and career development. Specialist training in data-intensive methods is available for DISCNet-funded students and a further five students working in related areas whom the OU funds as affiliate DISCNet members. Our membership of EU COST (Collaboration in Science and Technology) actions and ITNs (Innovation Training Networks) has enabled our students to receive specialist training and perform research in leading laboratories around Europe.

As part of the first-year probation process PGRS must complete a skills audit and maintain a training log. Project-specific training is identified by the PGRS' supervisory team and includes access to all OU modules. All first-year students attend a programme of weekly lectures, including topics such as Linux computing, error analysis and analytical techniques. Presentation skills form another key part of the programme, with all students preparing and delivering a short talk in the first year (pro-rata for part-time students), a 20 minute 'journal club' paper-review talk in the second year, and a 30-minute project seminar in their final year.

The success of our training and career development for PGRS is demonstrated by the first destinations of our PhD graduates: of the 89 PhD students who graduated in the REF period, 81% went on to employment either in academia or R&D/industry, with most of the remainder in other relevant employment (e.g., teaching and science communication) or self-employed.

2.3 Equality, Diversity and Inclusion (EDI)

2.3.1 EDI Overview

The Unit has a strong commitment to EDI and SPS have held Project Juno Champion and Athena Swan Silver since 2016, acknowledging the progress towards gender equality in UOA B9. Staff at all levels (including PGRS) sit on the SPS EDI team. Although the external awards focus on gender, many initiatives and implementations of good practice developed by the EDI team benefit other underrepresented groups (e.g., ensuring diverse representation of staff and students in promotional materials, diversity in scientists approached as seminar speakers, transparent appointment and promotion processes etc.).

UOA B9 has implemented Unconscious Bias, Gender Identity Awareness and Active Bystander training for all its staff and PGRS, demonstrating the Unit's desire to establish a work culture enabling people from all backgrounds to contribute and thrive. EDI-relevant policies (e.g. on professional conduct) are highlighted on the School's intranet pages. The EDI team has run an Annual School Survey since 2015. This allows staff and students to provide anonymous feedback to management about all aspects of Unit research culture and environment. The mental wellbeing of all staff and students' is paramount: to provide support and signpost specific

avenues for help with issues, SPS introduced 'School Listeners', a concept now being adopted in other schools within the faculty.

Building a more diverse research community (in what has traditionally been a field lacking diversity) has been a goal of the staffing strategy. This focused particularly on the recruitment process to widen the applicant pool. The EDI team reviews job advert templates and applications forms (incl. PGRS) and ensures language usage is suited to all protected characteristics. Appointment panels are mixed gender, using staff from outside the unit if needed, and all panel members complete the OU's 'Recruitment, Selection and Interviewing' training. In addition, the Unit actively supports Daphne Jackson Fellowships (for researchers returning from a career break) and provides support for staff with caring responsibility.

29% of our Cat-A staff identify as female, compared with the 2017/2018 Institute of Physics (IoP) 'Physics' benchmark of 18%, and annual School Survey responses about the work of the EDI team are very positive. The Unit is proud of the successes brought about by its EDI strategy but recognises that there is still more to do.

2.3.2 Working practices

Remote and flexible working is supported wherever possible. School meetings are held within core hours (10 am to 4 pm) and have been accessible through phone and/video conferencing for several years, enabling all to participate fully, including those that cannot be on campus (e.g., because of caring responsibilities and/or disabilities). Funding is available for external training dedicated to EDI related external matters, or to attend conferences and meetings with external stakeholders for their work. Returners from parental leave are prioritised for consideration of conference funds, including a budget to cover caring costs.

3. Income, infrastructure and facilities

3.1 Research income and internal investment

3.1.1 Research income

UOA B9 attracted GBP 30M direct research income during this REF period, with yearly income increasing from GBP 3.8M in 2013 to GBP 4.5M in 2020. Mean per FTE income in this REF period is GBP 103k/FTE, increasing from GBP 90k/FTE in 2013/2014 to GBP 107k/FTE in 2019/2020. The Unit maintained income diversification to reflect changing external landscapes with funds sought from a broad portfolio of sources. Income was divided approximately equally between UKRI and charities, the UK Space Agency (UKSA) and industries, and EU and international funders. UOA B9 also received competitively awarded UKRI-supported facilities usage with a value of GBP 12.12M during the REF period, including 6.12M for instrument leadership roles on ESA TGO.

Income highlights

UOA B9 researchers secured 17 large grants (awarded value > GBP 0.5M) during this REF period. Examples include (i) five STFC consolidated/rolling grants for Planetary and Space Science and Astronomy worth approximately GBP 9.9M in total; (ii) GBP 1.1M UKSA funding for Jupiter icy moon explorer (JUICE) detector development work; (iii) EUR 10M (GBP 1.0M direct to OU) European Commission award for Europe-wide collaborative 'Europlanet 2020' activities; and (iv) Grants totalling GBP 10.7M from ESA for the PROSPA lunar resource project. UOA B9 researchers also secured 54 medium-value grants (awarded GBP 100k to GBP 499k) during the REF period, including eight UKSA Aurora Programme grants totalling GBP 2.8M for mission science exploitation. In addition to the PROSPA work, the Unit received 25 ESA awards totalling GBP 5.9M for other space mission/science support and instrument development.

Income generation strategy

The five research disciplines produce five-year strategic plans that identify high-priority areas for support that feed into the Unit research strategy (sections 1.3, 1.4). SPS and the Space SRA provide pump-priming funding for future research and large collaborative and international bid development. Staff can also apply for internal funding to attend conferences and workshops to support the writing of high-quality funding proposals. This assistance particularly helps ECRs and those returning from caring or parental leave to get up to speed with current research in their field.

3.1.2 Organisational infrastructure and research support through significant investment

UOA B9 researchers benefit from access to centralised facilities within the STEM Faculty. Investments in centralised facilities with significance to the Unit during the period include:

- GBP 450k in 2016 for a computing cluster and data storage (780Tb). UOA B9 researchers employ an average 1 million CPU hours per year (approximately 15% of total use) to perform calculations not suited to Tier 1 or Tier 2 facilities. A Faculty IT team of nine staff support the cluster and other specialised computing needs.
- New scanning electron microscope (SEM), Research England funded (GBP 850k; installation March 2021), for which B9 researchers constitute the largest user group.
- Upgrade (GBP 100k) to a 24" mirror for the PIRATE robotic telescope on Tenerife.

In addition to staffing and PGRS (see section 1.3.2) the Space SRA has also invested in significant equipment purchases (GBP 70-100k per year). This investment, combined with approximately GBP 50k per year from SPS, has helped UOA staff win further external funding. Examples of SPS/SRA investment in equipment and infrastructure include:

- GBP 90k in Data Infrastructure (Unit-dedicated 60 core computing cluster) to analyse the effect of radiation on CMOS image sensors for ESA's JUICE mission.
- GBP 100k funding from the Space SRA, OU and STEM Faculty purchased an automated thermal desorption unit, a pyrolysis unit and GCxGC modulator for the Applied Technology and Science Group's laboratories. This enabled projects with new customers, including many initiated with SPRINT funding.
- GBP 28k purchase of a Parr pressure vessel, providing key science outcomes underpinning the successful bid for E3 funding that supports the AstrobiologyOU interdisciplinary research group, including six UOA B9 researchers.
- GBP 50k to develop a microwave heating vacuum vessel for developing construction processes for building lunar habitats. UKSA and ESA have awarded two UOA B9 proposals featuring this system summited during the REF period (total GBP 230k).
- GBP 29k for a Van der Graaf velocity unit, instrumental in the OU's contribution to the Athena ESA mission.
- GBP 15k for a new Cathode-luminescence detector for the SEM, enabling Anand's lunar volatiles project to secure STFC funding.

3.2 Unit Infrastructure, facilities and scholarship support

The STEM Research, Enterprise and Scholarship Team (STEM RES; >15 staff) provide professional services to Faculty researchers including UOA B9 staff. It supports the development of external bids for funding, and administration and management of funded research projects and PhD studentships. STEM RES also facilitates enterprise and partnership development, external engagement and scholarship activity. The STEM Impact Manager works with colleagues to develop and strengthen impact pathways during bid development. They also support the impact pathways progression, communication and implementation for awarded projects.

3.2.1 Unit research support: infrastructure

Two neighbouring buildings, with laboratory space of 850 m^2 and 535 m^2 house Unit-specific infrastructure. The two buildings include 35 separate areas of labs, clean rooms and technical support suites. Unit-dedicated facilities comprise five groupings:

A. Laboratory Analysis

Microscopy: (i) Cameca NanoSIMS 50L ion microprobe; (ii) FEI QUANTA focused ion beam-SEM, to be replaced 2021 (see 3.1.2); (iii) various petrographic microscopes including a high temperature heating stage. UOA B9 researchers also make extensive use of complementary shared facilities: (i) Zeiss field emission SEM; (ii) Cameca electron microprobe; (iii) JOEL 200 keV TEM; (iv) two desktop SEM with full remote access, vital for supporting activities during pandemic restrictions.

Spectroscopy: (i) Horiba LabRam HR Raman microscope; (ii) CRAIC UV-VIS microspectro-photometer; and (iii) THZ Desorption Emission Spectrometer.

Gas Source Mass Spectrometry: (i) Thermo MAT 253 with laser assisted fluorination system for high precision oxygen-three isotope measurements; (ii) Thermo MAT 253 with elemental analyser and GC-combustion system for organic molecule isotope analysis; (iii) Thermo Delta gas bench for carbonate analyses; (iv) FINESSE: a unique, in-house designed, fully automated system for simultaneous measurement of carbon, nitrogen and noble gas abundances and isotope ratios; (v) MAP 215-50 and Nu Instruments Noblesse with laser heating/ablation extraction for Ar-Ar dating and noble gas measurements.

B. Planetary and Astrophysical Environments Simulation

Environmental Chambers: (i) large (2m x 1m) chamber to simulate martian surface processes, including heating and cooling systems and monitoring apparatus; (ii) three static and two flow-through reactors to simulate the P, T, and anoxic/oxic sub-surface environments of Mars and icy moons to explore biotic and abiotic processes; (iii) chamber for generating and studying amorphous icy particles under astrophysical conditions, including a FTIR system, for use in external large-scale experimental facilities (e.g. synchrotron); and (iv) a chamber, deployable on parabolic flights, for studying low velocity dust and ice aggregation at low T and P.

Impact facility: (i) Hypervelocity 2-stage light gas gun, capable of delivering 4mm projectiles up to ~6 kms^{-1} at vertical to horizontal orientations, including high-speed video and monitoring apparatus, (ii) 2MV Van de Graaff accelerator delivering micrometeoroid analogue samples to targets at tens kms^{-1} to simulate weathering of atmosphereless bodies and impact damage to spacecraft.

Rover operations simulation facility: A 10m by 6m indoor terrain model to test rover operations protocols and operator training. The facility comprises a small instrumented 6-wheel rover, fully online controls and planning system software, and a 2m deep drilling pit.

C. Instrument Development and Operations

CEI: spans three laboratories and a new cleanroom, built late 2018 (GBP 40k investment from Space SRA and UKSA for SMILE). The clean room includes a calibration chamber and soft X-ray source. A dedicated area houses long-term "cryogenic irradiation" experiments (UKSA GBP 30k investment for the Euclid mission).

Instrument development: seven laboratories support the miniaturised mass spectrometer/gas chromatography (Mini-MS/GS) development programmes (e.g. PROSPA, LUVMI, EMS). Includes test and build facilities, large cryo-vacuum test chambers, clean room suite for space

flight hardware assembly, clean chemistry laboratory, mechanical and electronic workshop and support.

Applied Science and Technologies: State of the art gas chromatography-mass spectrometry (GC-MS) and comprehensive gas chromatography (GCxGC-MS), with various detectors and sample collection/introduction modules. Used to develop and validate bespoke solutions to a wide variety of societal and commercial challenges from food and drink screening to medical diagnostics.

Mission Operations: NoMAD/CaSSIS instruments (CaSSIS in partnership with Univ. Bern, Austria) onboard TGO are operated from a dedicated control area equipped with ten workstations and large format display facilities.

D. Experimental Physics

Cold atoms laboratory: includes optical systems and lasers for the trapping and excitation of atoms for quantum computing and machine learning applications.

Molecular clusters laboratory: includes (i) resonance-enhanced multi-photon ionization time-of-flight mass spectrometry experiment to study molecules and clusters in supersonic beams and laser-desorbed targets, (ii) Stark deflection apparatus to manipulate neutral molecules and clusters in rotationally-cold molecular beam and (iii) low-energy electron beam mass spectrometry experiment to study dissociative electron attachment to molecules and clusters

Plasma laboratory: Systems and diagnostics for low temperature plasma generation at low and atmospheric pressure to study surface engineering of novel photocatalytic materials for energy production and water purification. A customised Pre-vac X-ray Photon Spectrometer surface analysis tool is currently undergoing a GBP 160k upgrade.

E. Telescopes

The unit operates two robotic telescopes (17” and 24” mirrors) on Mount Teide, Tenerife. They support work on transients, exoplanets and asteroids, and commercial space situational awareness activities with Deimos Space UK.

3.2.2 Research and scholarly support

A team of 11 technicians and POs support Faculty facilities and laboratories. Nine additional grant-maintained POs provide support primarily for space mission projects. The Unit has a collection of >3000 different meteorite and returned samples (Apollo, Stardust, stratospheric dust particles) and a polished-sample preparation workshop to support research programmes.

A weekly research seminar series (mainly external speakers), a journal club for PGRS and ECRs, a monthly public lecture series (with the Institute of Physics) and library resources (on-site and significant online journal access) further support scholarly activity.

3.3 Collaborative use of research infrastructure, major facilities and in-kind benefits

3.3.1 Collaborative use of national and international facilities

During this REF period UOA B9 researchers have participated in international networks including four EU COST actions and five Horizon2020 European Innovation Training Networks (E/ITN) in areas of molecular and chemical processes in astrophysical or biological environments and nanofabrication.

Through the Horizon2020 EuroPlanet Network, the Unit has welcomed more than 25 groups of European researchers to use its highly specialised facilities, including the NanoSIMS, laser fluorination and large Mars simulation chamber. The total of 250 days’ access is equivalent to GBP 300k and has helped the Unit develop new analytical methodologies and spawned several

new collaborations. Its facilities continue to be a significant feature in EuroPlanet, which is now in its third five-year cycle.

UOA staff successfully competed for access to a wide variety of facilities, including UKRI funded (REF4c) and non-UKRI funded facilities (Table 1).

Internal investment has enabled access to other telescopes. The Unit is a shareholder in the UK Southern African Large Telescope (SALT) consortium, (GBP 7k/yr) which gives UOA B9 researchers access to the largest single optical telescope in the Southern Hemisphere. Membership of the James Clerk Maxwell Telescope (JCMT) UK consortium (average GBP 9k/yr) ensures access to the world's leading single-dish sub-mm telescope facility and next generation wide-field sub-mm camera, and opportunities to lead JCMT Large Programs. It also enables pump-priming for major Atacama Large Millimeter/submillimeter Array (ALMA) projects such as the recent Venus phosphine work.

Table 1. Competitively awarded facilities usage not covered in REF4c. Usage in hours for the telescopes, days for the other facilities.

Facility	Hours	Facility	Hours
Ground-Based Telescopes		***Space-Based Telescopes***	
Janksy VLA	38.5	NASA Chandra X-ray Obs.	36
JCMT	600	NASA NuSTAR	33
Las Cumbras Obs. Global Telescope	28	NASA Swift	150
Observatoire de Haute Provence	209	Spitzer Space Telescope	50
SAAO 1.9m / SpUpNIC	133	ESA XMM-Newton	305
South African Large Telescope	19	***Other Facilities***	**Days**
Submillimetre Array	22	ISA/ASTRID2/UV1	71.5
Telescopio Nazionale Galileo	19	EuroPlanet Access	31

3.3.2 Unit research in-kind benefits

In-kind equipment loans have directly benefited research and impact activities. For example, in-kind contributions from the IBM IROR scheme (6 months staff effort), and equipment loans from several companies (equivalent value >GBP 0.5M) led to the development a fully automated screening method to detect fake and adulterated Scotch whisky. LECO Instruments (Europe) have offered a five-year strategic sponsorship of the ASTG miniaturised mass-spectrometer development laboratory (total GBP 120k) to build relationships developed during the SPRINT project.

The infrastructure described here has enabled much of the Unit's impact generation, including that of its four ICS. UOA B9 research on radiation damage effects in image sensors facilitating the selection of several space missions (Euclid, SMILE and WFIRST/Roman), and contributed to the growth of Te2v's space imaging business. Laboratory infrastructure and expertise developed for cosmochemistry research led to the design of the Ptolemy instrument for the Rosetta mission, which underpins ASTG's work across diverse applications, as well as influencing ESA's new lunar exploration strategy and the design of a novel water extraction technique for ISRU on the Moon.

4. Collaboration, impact, engagement, responsiveness to emerging priorities and influence

4.1 Support for networks, partnerships, and joint research projects

UOA B9 staff engaged with approximately 120 different partners through hundreds of collaborative research projects, joint PhD studentships, consultancy and strategic partnerships

during this REF period. The Unit's collaborations reflect its focus on space-related research and involve approximately 50 Higher Education Institutes and more than 20 national and international research institutes across the UK, Europe, Asia, Australasia and North America. These partners include RAL Space, Diamond, and the Natural History Museum in the UK, PSI Switzerland, PTB Germany and MBI Germany in Europe, and NIST, the Smithsonian, the American Museum of Natural History, and NASA's Goddard Space Flight Centre, Jet Propulsion Laboratory and Johnson Space Centre in the U.S. The Unit works with industrial partners and charities, and host visiting researchers for periods from a few days to use its facilities, to months for those taking longer sabbaticals.

Space research is multidisciplinary, involving astronomers, chemists, geologists, physicists, engineers, mathematicians and more. A recent example of successful internal interdisciplinary research projects internally includes AstrobiologyOU, which received GBP 6.8M in 2019 to expand its capability to address fundamental questions about life beyond the Earth. Staff also collaborate with the OU School of Engineering and Innovation for plasma physics research and its applications, and with the OU Knowledge Media Institute (KMI) in Physics Education Research.

4.1.1 Industrial collaborations

The Unit collaborates with more than 50 industrial partners including multinational companies (e.g. Airbus, Thales, BAE, Te2v), SMEs and start-ups (e.g. XCAM, Quantemol, Applied Science & Technology Solutions and Dynamic Imaging Analytics). The OU's Research and Enterprise Unit, and Unit EKE lead (Morgan) support the preparation and negotiation of legal agreements including Non-Disclosure, collaboration, consultancy, material transfer, and strategic partnership agreements. They also oversee IP management, including patenting, funded by the OU directly. Their expertise helps establish and cement industrial collaborations, while Space SRA funding pump-primes proof-of-concepts to make these collaborations possible.

4.1.2 Academic collaborations

Staff collaborate with academic colleagues across the OU, and at national and international institutions. Their research expertise is evidenced by their leadership as PIs and WP leads of international consortia, including collaborative H2020 projects such as EuroPlanet (EUR 10M), ASTERICS (EUR 15M), and ESCAPE (EUR 16M). Funding from Faculty, School and the Space SRA supported new collaborations through travel, conferences and workshops. The Unit offers pump-priming funding for large and international projects. It also provides protected dedicated workload allocations for research, study leave and external roles such as expert advisory committees, BBC consultancies, editorships, learned society and peer review roles. A generous matched-funding scheme for PhD studentships facilitates collaborative ventures such as DISCnet (see sections 1.3.2, 1.4, 2.2.3).

4.1.3 Collaborations to develop research impact

UOA B9 recognises that generating impact from research takes time and hence provides its staff with dedicated support (e.g. workload allocations and internal funding) to achieve it. The four submitted ICSs represent work selected from a portfolio of impactful research covering the past decade. This research has been facilitated by the OU's roles in the STFC Food Network+ (Technology Champion, Data Science Liaison) and as a partner in the GBP 4.8M SPRINT project for SME engagement with space research.

The current five-year GBP 2.5M CEI/Te2v agreement runs until 2023. Te2v's former Chief Design Engineer David Burt continues to work one day per week at the CEI, providing training and supervision to students and researchers. Other senior Te2v staff act as industrial supervisors for CEI students and researchers. Te2v staff visit CEI regularly to enhance

knowledge exchange and technical and business expertise transfer. The CEI and Te2v hold at least three workshops at the Te2v's factory in Chelmsford and at the OU each year.

4.2 Economic impact

Long-term engagement with industry partners provides UOA B9 researchers with opportunities to deploy their research technology to make an economic impact. The unit's research has positively impacted various sectors beyond the work described in the four submitted ICS. In Agriculture, Unit staff work with the Plant Health Agency to support enhanced bovine tuberculosis detection in badgers and projects with Public Health England improved Campylobacter detection in chickens. Work with fragrance and flavour manufacturer Givaudan impacted the consumer goods industry by decreasing chemicals levels in washing powders. Meanwhile, a collaboration with Innovate UK, TISICS Ltd, EAL Ltd and the University of Surrey produced innovation in spacecraft propulsion systems.

4.3. Engagement with diverse communities

The OU engages the public through its unique relationship with the BBC to commission and co-produce TV and radio programmes. During this REF period, Unit staff shared their research through several prime-time BBC series, watched by more than 14.1M people, nearly 40% of whom were C2DE demographic. These series included A Perfect Planet (BBC1, 2020, Lewis), The Planets (BBC2, 2019, Lewis, Rothery), 8 Days to the Moon and Back (BBC2, 2019, Anand), 21st Century Race for Space (BBC2, 2017, Morgan), Expedition New Earth (BBC2, 2017, Haswell), The Beginning and End of the Universe (BBC4, 2016, Serjeant), and Wild Weather with Richard Hammond (2014, BBC1, Lewis). The Unit also produces and distributes associated free educational materials to schools and the general public to accompany the programmes.

Informal learning provides another route for Unit staff to showcase their research and engage the public. More than 15,000 students registered for free online OU courses based on UOA B9 researcher's work during this REF period.

4.4. Responsiveness to national and international priorities and initiatives

4.4.1 Committee memberships

UOA B9 research informs and shapes the research policy landscape. Some 65% of the Unit's staff (a third of whom are female) held more than 60 roles on national and international research council, space agency or similar committees during this REF period. Examples include:

International

COSPAR: Member, Safety Assessment Protocol for Mars Sample Return WG (Grady)

ESA: Chair, ESA-NASA iMOST Mars Sample Return Committee (Grady).
Co-Chair, BepiColombo Mercury Surface & Composition Working Group (Rothery).
Science Assessment Review Panel for M4 (Haswell).
Astronomy Working Group of Space Science Advisory Committee (Haswell).
ExoMars Rover Landing Site Selection Working Group (Balme).
ExoMars Rover Science Operations Working Group (Balme).
Hera Mission Science Management Board (Green).
Voyage-2050 Topical Team (Green).

ESF: European Space Science Committee (Anand).

NASA: Chair, Origins Grants Review Panel and Laboratory Astrophysics Panel (Fraser).
Chair, Solar System Exploration Virtual Research Institute, UK node (Anand)
Programme Review Board, Laboratory astrophysics (Fraser).
New Frontiers Mission Selection Panel (Grady).
Solar System Workings Review Group Panel chair (Lewis).

National:

EPSRC: Cooperative Awards in Science & Technology Panel (Hall).
Strategic Advisory Panel - Engineering (Fraser).

STFC: Chair, Astronomy Advisory Panel (Serjeant).
Chair, Solar System Advisory Panel (Fraser).
Astronomy Grants Panel (Barber, Croston, Patel).
Education Training and Careers Committee (Hall).
Innovation Partnership Scheme Review Panel (Stefanov).
Public Engagement Advisory Panel (Pearson).
Spark Award Panel (Pearson).

UKSA: Academic representative (one of two), UKSA CEO briefing meetings (Holland).
Chair, Working Group for Mars Sample Return (Grady).
Chair, Space Environments Working Group (Fraser).
Chair UKSA/Economic and Social Research Council, Social Outcomes of Human Spaceflight Review Panel (Fraser).
Space Environments Advisory Board (Fraser).
Mars Robotic Exploration Oversight Committee (Balme).
Science Programme Advisory Committee (Haswell, Holland).
Space Exploration Advisory Committee (Balme, Patel).

4.4.2 UK Government advisory roles

Chair, Space Academic Network (SPAN; Holland). SPAN coordinates and unites the UK space research community and has four working groups (including Grady, Haswell, Patel and Soman). Hall represents SPAN on the national Space Skills Advisory Panel (SSAP). Former Chief Scientist for UKSA, Chris Lee, has acknowledged that SPAN influenced increases to the ESA Space Science and UK national space science budget.

Space Growth Partnership Board and Space Sector Council (Holland).
Expert Advisor, Dept. Health, Medicines and Healthcare Products Regulatory Agency, (Morgan) for development of Target Product Profile for a Rapid Detection Test using breath biomarkers found for SARS-CoV-2.

4.4.3 Roles that shape policy via learned societies

President, International Astronomical Union, B.5 Laboratory Astrophysics (Fraser)
President, Astrobiology Society of Britain (Patel).
President, International Meteoritical Society (Grady).
Vice President, Royal Astronomical Society (RAS; Norton, Anand).
Chair, European Assoc. Distance Teaching Univ. Pool of Expert Assessors (Jordan).
Chair, IoP Atomic and Molecular Interactions group (Gorfinkiel).
Secretary, Royal Society for Chemistry Spectroscopy and Dynamics Group (Eden).
RAS elected council members and RAS200 advisory board (Serjeant, Fraser)
Board Member, European Atomic and Molecular Physics Division, European Physical Society (Bergamini).
Member, RAS Policy Group (Haswell, Serjeant).
Member, International Union of Pure and Applied Physics C15 Commission (Gorfinkiel).

4.4.4 Unit leadership in Space- and Ground-Based Missions, Projects and Instruments

Table 2. CAS space mission involvement.

Past Missions (ended within REF period)		
Mission	*Instrument*	*Staff and Role*
ESA Rosetta	Ptolemy Grain Impact Analyser and Dust Accumulator (GIADA)	Wright (PI); Morse (Deputy PI) Barber, Sheridan, Morgan (Science Team) Green (CoI)
ESA/Roscomos ExoMars 2016 lander	Entry descent and landing science (AMELIA)	Lewis (Co-PI), Patel (CoI)
Ongoing Missions		
Mission	*Instrument*	*Staff and Role*
ESA TGO	NOMAD DREAMS Atmospheric Chemistry Suite CaSSIS camera	Patel (Co-PI), Lewis (CoI) Patel (CoI) Patel (CoI) Patel (CoI)
NASA Mars Reconnaissance Orbiter	Mars Climate Sounder	Lewis (CoI)
NASA Mars Science Laboratory Rover	Mission	Schwenzer (Science team)
NASA Mars InSight	Mission	Lewis, Patel (Atmospheres WG)
NASA OSIRIS-Rex	Mission	Franchi, Rozitis (Science team)
ESA BepiColombo	Mission MIXS	Rothery (Lead, surface and composition WG) Rothery (Geology lead CoI), Anand (Co-I)
Future Missions: 1. Solar System Missions		
Mission/Launch date	*Instrument*	*Staff and Role*
NASA Artemis Peregrine Mission One 2021	Exospheric Mass Spectrometer (EMS) within PITMS instrument	Barber (EMS lead/PI), Morse (EMS Co-I), Sheridan (EMS Co-I) Barber (PITMS Co-I)
ESA/Roscosmos ExoMars *Rosalind Franklin* Rover 2022	PanCam WISDOM	Balme (Deputy PI), Patel (Co-I) Schwenzer (Co-I)
ESA/Roscosmos ExoMars Kazachok Surface Platform 2022	Entry Descent and Landing Science HABIT MGAP	Lewis, (Co-PI) Lewis, (Co-I) Barber (Co-I)
ESA JUICE 2022	JANUS Camera	Holland (detector build lead) Patel (CoI)
ESA SMILE 2023	X-Ray Imager	Holland (CoI, CCD detector development)
ESA Hera 2024	Mission	Green (Science Management Board)
RosCosmos Luna-27 2025	ProSPA instrument PROSPECT	Barber (PI), Morse (CoI), Sheridan (Co-Is) Anand, Barber (Science team)
Future Missions: 2. Astronomy Missions		
Mission	*Launch/first light*	*Staff and Role*
NASA JWST	2021	Fraser (Lead, Early Release Science "Ice-Age" WG1)

ESA Euclid	2022	Serjeant (Co-Lead, Primeval Universe WG) Holland (CoI)
ESA PLATO	2025	Kolb (Lead, Contaminants WG) Haswell (Lead, Close-In Exoplanets WG)
ESA Ariel	2029	Haswell (Science Advisory Team) Barstow (Lead, Spectral Retrievals WG)
ESA Athena	2031	Croston (Science Advisory Team)

4.5 Indicators of wider influence, contributions to and recognition by the research base

4.5.1 Awards during this REF period

- Braithwaite: IoP Gold Bragg Medal in 2020 for outstanding, long-term contributions to the authentic teaching of practical science and leadership of OpenSTEM Labs (remote access to practical laboratory education). OpenSTEM Labs won the Guardian Universities Award for Academic Excellence, Times Higher Education Leadership and Management Award and Times Higher Education Award for Outstanding IT Initiative of the Year.
- Franchi, Grady, Lewis, Rozitis: NASA Group Achievement Awards
- Fraser, Grady and Haswell: three of twenty portraits commissioned of leading women in contemporary astronomy celebrating "Women and the Royal Astronomical Society: 100 years of Fellowship". No other institution had such representation.
- Grady: Coke Medal of the Geological Society of London for Science Communication and was appointed as Chancellor of Liverpool Hope University.
- Morgan: two BAE Systems Chairman's awards for Innovation and two LECO Instruments team awards (work forms the basis of two Unit ICS).
- Rozitis (ECR) had asteroid 11469 named for him to recognise his work on small bodies
- Sargeant (a PGRS at the time) was named one of Forbes' "30 under 30" in 2020.

4.5.2 Further indicators of influence and recognition

- Fourteen staff had leading editorial roles in research journals, including Space Science Reviews, Geochemica et Cosmochimica Acta and MDPI Sensors.
- All CAS have refereed scientific papers, covering almost 100 different journals and including the leading journals in the field.
- Unit B9 CAS have refereed research grants from over 30 different funding agencies and schemes, of which 30% are international. Examples include UKRI Future Leaders Fellowship, STFC and EPSRC Fellowships and Grants, Leverhulme Trust, Royal Society URF, UKSA Aurora Fellows and Grants, EU ERC Advanced Investigator and Horizon2020 awards.
- Unit researchers led and organised over 70 conferences and workshops in their research areas, including Royal Society Kavli Discussion meetings.
- Delivery of more than 300 invited talks at international conferences and workshops.
- UOA B9 ECRs held fellowships from prestigious schemes including Royal Society URF, STFC Ernest Rutherford and Innovation Fellowships, RAS Research Fellowship and Leverhulme Early Career Fellowship.