Institution: Aberystwyth University

Unit of Assessment: 9: Physics

Section 1: Unit Context and Structure, Research and Impact Strategy

Context

The Department of Physics provides a supportive research environment aligned with University and National strategies based on the principles of vitality, sustainability and inclusivity. The **vitality** of our research culture is reflected by our growth within the new organisational structure provided by the re-establishment in 2014 of the Physics Department (initially within the Institute of Maths, Physics and Computer Science, and since 2018 in the Faculty of Business and Physical Sciences). This co-operative environment has enabled staff to engage in leading research. Our structures and policies foster local and international collaboration across disciplines, securing competitive funding and leading to high quality publication. A structure of research groups and wider networks provides peer support, postgraduate training, seminar programmes and funding for engagement in conferences and networks that has led to publication of 228 papers during the REF 2021 period, with 2,595 citations and a field-weighted citation impact of 1.3 (SciVal). 72% of papers are published with international collaborators, 14% of papers are in the top 10% most cited worldwide (field-weighted), and over a third are in the top 10% international journals (CiteScore Percentile). Our research income has increased over the REF 2021 period from a yearly average of £490k in 2013-2016 to £712k in 2017-2020, an increase of 45% (section 3).

Central to our **sustainability** strategy is co-operation. Early and-mid career researchers are supported through training, professional development and mentoring within our groups and wider research networks and the next generation of researchers are additionally supported through the University Graduate School and training networks. Facilities and support staff are shared across the Faculty, ensuring investment in state-of-the-art experimental and computational equipment, and the technical infrastructure to enable the development and upgrade of bespoke instrumentation. Space instrumentation is a particular area of investment that forms the core of one of our impact case studies. Our knowledge, expertise and outward-facing ethos has enabled collaborations with national and international academic and industrial partners across all our research areas, detailed in section 4. Outreach and public engagement are key activities in all research areas that have grown in recent years due to a co-operative strategy. These activities are enabled by major programmes bridging the science and arts (as detailed in one of our impact case studies) and providing research-inspired intervention that targets schools in Wales (see section 4). Engagement in wider national networks has also provided the framework for more effective and numerous interactions with businesses.

The Department has an **inclusive** structure and culture where all staff, including those on fixed-term external contracts, are encouraged to participate in all aspects of the Department's activities, in all its groups and committees. Changing circumstances and career stages are recognised through varying workload distributions, for example through targeted support for early career researchers and individuals returning from interruptions to research. This process has enabled the promotion of three early career researchers and one mid-career researcher, the latter progressing to a research group leader and Director of Research. Building on our leading role in Welsh medium Physics, our structure has facilitated a bilingual research culture where interaction is natural in both languages within an environment that encourages an awareness of local and global, societal and economic responsibilities.

Research and Impact Strategy

Our vision is to build an environment that encourages innovative research of international scope and standard that inspires the next generation of researchers, that informs and educates the public and policy makers, and that enables its relevance to be effectively exploited across disciplines and sectors. In REF 2014 we set out strategic aims in support of our vision, including *promoting high quality research and growing income streams; supporting and training junior*

researchers; exploiting the interdisciplinary environment; expanding international collaboration, and to *enhance and focus our public engagement.* Our progress through co-operation and leadership in key partnerships is summarised as follows:

- In REF 2014 we stated that we would *lead projects in solar and planetary observation, modelling and exploration and broaden and deepen the physical understanding and application of materials through new instruments and computational methods and new collaborative projects***.** We have achieved this goal, evidenced by increased research income through UK and European funding schemes aligned with the strategic areas of Space and Photonics. Through our support for collaborative partnerships we have gained funding for major projects in each of these areas and in new areas (sections 3 and 4).

- Our research strategy has enabled the recruitment and training of early career researchers in key areas, and we reward researchers for *using their research beyond academia* as stated in our REF 2014 impact statement. We have made six new appointments to strengthen all research areas, bringing in new expertise in solar physics, modelling, exoplanets, energy materials, instrumentation and radio spectrum (Section 2).

- We have exceeded the proposed expansion strategy stated in REF 2014, for example to *expand the mathematics – condensed matter physics interface; working closely with mathematicians and computer scientists*. This has been achieved through investment in quantum control and a new soft matter laboratory, and, at the computer science – space interface, we have united robotics and photonics instrumentation in a new shared laboratory and workshop infrastructure (section 3). Interdisciplinary research with researchers in the Earth and Life sciences has been enabled through joint grants (STFC, UKSA), publications and shared student supervision as part of the institutional strategy to build research capacity (REF5a).

- We have formalised our outreach and engagement through interdisciplinary projects with other universities, government, national organisations and companies (section 4), having set out in REF 2014 to *co-ordinate, enhance and focus our public engagement activities*. Based on our research, we have attracted funding and have led projects that bridge the science and arts and bring our research to schools and businesses.

Moving forward, the Department is working to a research strategy that is aligned with the University's new Research and Innovation Strategy, adopted in 2019 and outlined in REF5a, and builds on the core principles of encouraging ambitious, entrepreneurial research that challenges existing approaches and knowledge; creating a coherent research-led academic environment; enhancing inclusivity in research; and collaborating with external partners, in Wales and globally, both in generating research and in passing on the benefits of research through impact and innovation. The key points of the Departmental strategy are to:

- Seek roles within larger national or international collaborations, where our expertise can provide key functions, for example through building on recent participation in space missions.

- Seek lead roles on focused projects within our areas of strength, and where we can maximize impact, for example in space-based imaging, photonics instrumentation and surface characterisation.

- Identify and foster new areas of growth where the Department can excel (for example space weather, photonics and radio spectrum).

- Maintain access, and build closer links, to central facilities such as synchrotron radiation sources and ground-based solar telescopes.

- Expand Welsh-medium research and engagement activities and build on communication networks to inform the public and influence policy makers.

- Identify opportunities for industrial and governmental collaborations to exploit the potential commercial applications of our research, such as in our ongoing collaborations with large anchor companies and SMEs (for example, Qinetiq, Airbus, Varichem, Techion).

Our involvement in international partnerships, strategic allocation of research time and fostering of early career researcher talent will lead to publications in the top interdisciplinary, highest-impact journals over the next five years. Publications will be open access, building on the Department's engagement with the open science agenda in the current assessment period. In line with University policies described in REF5a, staff are required to deposit copies of author's final manuscripts on acceptance for publication to be made available post-embargo in the Aberystwyth Research Portal repository. 'Gold' open access publishing has been supported for journals covered by JISC agreements with publishers, and for UKRI-funded research, through funds administered by the University. We also conform to UKRI guidelines on data management and open-access data and software. For example, we have published three source-code software packages for solar data analysis and a large data repository of solar atmospheric maps within the international open access SolarSoft library.

Structure

Research in the Department covers two broad areas of Solar System Physics and Materials & Quantum Physics, with a common core of instrument development and high-performance computing through the University's access to SuperComputing Wales (SCW) facilities (see REF5a).

Researchers, outputs and income are equally distributed across the groups and there is extensive sharing of people, facilities and projects between the groups and with other groups within and beyond the University. Research is supported by a shared Faculty-level infrastructure of research laboratories, mechanical & electronic workshops and computational facilities. Researchers in both groups make extensive use of external central facilities in the UK and internationally.

Interaction and communication are facilitated by weekly research group meetings, Faculty Research Committee meetings, regular seminars and meetings of external networks. The structure and strategy are regularly reviewed with input provided at Faculty level by the Departmental Director of Research and Head of Department and at University level by the Faculty Associate Dean of Research, Knowledge Exchange and Innovation. Research and impact strategies are standing agenda items at weekly Staff Meetings, fortnightly Faculty and Departmental Executives, and termly Staff and Faculty Boards.

Research expertise in Space Physics lies in the solar atmosphere, the solar wind and space weather, the moon and planetary magnetospheres, and remote-sensing instrumentation including space instruments. Our computational modelling, data processing and instrument development expertise is recognised in international collaboration and missions, and we are committed to the effective communication and exploitation of our discoveries.

In Materials and Quantum Physics, our research expertise lies in measuring and predicting the properties of materials at the atomic level using unique combinations of experimental and theoretical methods including bespoke instrumentation developed within the Department, and linking to macroscopic applications in photonic, radio and quantum technology. This has enabled interdisciplinary projects in sectors such as photonics (polymer opals), health (dental cements), space (camera calibration), energy (transparent conductors) and digital technology (quantum control).

Research is primarily undertaken through externally funded collaborative projects and networks. Major projects and initiatives during the REF 2021 assessment period have included participation in the ERDF-supported Centre for Photonics Expertise (CPE) (2019-2022) and the Solar Photovoltaic Academic Research Consortium (SPARC II) (2016-2023); contributions to the ExoMars, BepiColombo, JUICE and PUNCH space and planetary missions; a competitive EU (Sêr Cymru) Fellowship on advanced computational analysis and modelling for solar physics; grants for research on space weather (Leverhulme) on the development of perfect glasses by solid state synthesis (industry) (2013-2016); and partnership in the EPSRC Centre for Doctoral Training (CDT) in Diamond Science and Technology (2014-23). Through these projects we have made significant advances in the state of the art of scientific knowledge in our specialist fields, for example the melting of metal-organic frameworks to network topology, large-area nanoparticle ordering in polymer opals; new protocols for processing diamond surfaces; quantum feedback models for circuit quantum electrodynamic systems; a novel method of Multiscale Gaussian Normalization for image processing; the Solar Iterative Temperature Emission Solver (SITES) method for temperature analysis of the solar atmosphere; and the development of coronal rotational tomography. An important part of this work has been instrument design and build, with notable contributions including calibration targets and fiducial markers for visible and infrared cameras on the ExoMars mission; optimisation of radiation shielding for PEP package instruments on the JUICE mission; a high-resolution spectrometer for visible emissions lines of the solar corona; a high-temperature levitator for extreme materials and a combined optical and electron spectrometer for rapid surface analysis.

Priorities for the Next REF Period

Our approach in the next REF assessment period will be shaped by the continuing research strategy outlined above, and especially by objectives for expanding research collaborations, strengthening the impact of our research, and developing new areas of growth in space weather, photonics and radio spectrum research. Within this framework, our priority areas for research and innovation over the next five years include:

- Exploiting and expanding space instrumentation, building on the reputation gained through solar eclipse instrumentation and involvement in planetary exploration missions.
- Capitalising on our recent expansion in space weather through collaborative projects and exploitation of data from new missions such as PUNCH and Lagrange, with potential to deliver economic and societal impacts.
- Building interdisciplinary research in materials and nanomaterials with applications in energy, bio-medical, quantum, radio and photonic technologies, including continued engagement with business.
- Expanding the laboratory and workshop infrastructure to include dedicated facilities for space instrumentation, planetary environments, radio spectrum, soft matter and environmental surface analysis, with potential for commercialisation.
- Building on our leadership in research and societal impact through the medium of Welsh.

Three recent developments will help to deliver these objectives over the next REF assessment period: our participation in the Centre for Photonics Expertise (CPE), the establishment of a National Spectrum Centre at Aberystwyth, and new space weather consortia. These initiatives will strengthen our industrial collaboration and enhance research impact.

Section 2: People

Strategy and development

Our staffing strategy is integral to our research strategy and aims to enhance the vitality of the research environment. We enable staff members to undertake high-quality and impactful research, and ensure the sustainability of the research environment by recruiting, training and

developing excellent early career researchers, post-doctoral researchers and postgraduate students. These aims are delivered through three focused objectives:

- Recruit and retain a diverse, gender-balanced team of excellent physicists;
- Prioritise the research needs of early career researchers;
- Respect research time allocation in the workloads of all staff members, and reward success in research.

The objective of recruiting and retaining a diverse, gender-balanced team of excellent Physicists has been advanced during the assessment period. We are submitting six new academic appointments to REF, all early career researchers within 7 years of their PhD, and of an equal gender balance. Cross, Gunn and Jiliani have been appointed to the Materials and Quantum Group, with Cross and Gunn contributing to research in space instrument design and calibration, and Jiliani's appointment marking a strategic investment in growing our capacity in radio spectrum science and technology. Knight, Gorman and Kuridze have been appointed to the Solar System Physics group, with Gorman working primarily on research on molecular lines, Kuridze on the coronal magnetic field, and Knight on radiation shielding of spacecraft instruments. Kuridze was appointed to a Sêr Cymru COFUND Fellowship, as part of a Welsh Government and Horizon 2020 funded programme to attract world-leading talent to Wales. The recruitment of highly promising early career researchers has been especially poignant as the assessment period has been marked by the tragic loss of two long-serving stalwarts of the Faculty, David Barnes in 2014 and Neville Greaves in 2019, whose legacies are sustained by the ongoing research led by a new emerging generation.

With the changing profile of the Department's staff, the second objective of prioritising the research needs of early career researchers has been especially important during the assessment period. Policies and procedures that have been adopted to facilitate this goal include the provision of teaching assistant support to ease teaching loads for early career researchers; Departmental financial support for conference travel and publication costs; and access to the University Research Fund and to other ring-fenced funding from the University to support small-scale pilot research studies. Early career researchers in the Department have participated in training and professional development courses provided by the University on topics including proposal writing and grant management, as well as in the prestigious Welsh Crucible programme, a 6-day intensive forum developing the research leadership of rising early and mid-career researchers in Wales (Finlayson, Morgan).

Research in the Department involves seven research assistants funded externally (RAs), with a total of 21 RAs and fellows during the REF period. Support for RAs follows the Concordat to Support the Career Development of Researchers, to which Aberystwyth University is a signatory. All RAs have an annual meeting with a senior member of staff to discuss progress and career planning, and targets for the coming year. In the past two years, all RAs have presented their work in conferences, including internationally. RAs are encouraged to contribute broadly, for example in teaching and public engagement. Three RAs have been appointed to lectureships during the assessment period. The supportive research environment created in the Department has enabled our early career researchers to make significant contributions in their fields, gaining external recognition; for example, Gunn is PI on UKRI grants for space instrumentation and Co-I and calibration lead for the PanCam instrument.

To further the third objective of respecting research time allocation in the workloads of all staff members and rewarding success in research, a minimum of 550 hours is ring-fenced for research activity in a Workload Allocation Model for research-active staff and we prioritise the research time of early career researchers. Flexibility in workload allocation has enabled teaching-focused staff to engage with research and has enabled two changes from teaching to research-focused roles. We encourage applications for research leave through the new University policy target of one in eight semesters research leave.

All staff engage in the Effective Contribution Scheme (ECS) with the Head of Department annually. The ECS's mechanism is a set of SMART targets which include research targets and supports the promotion process and access to contributory salary points. All new staff are assigned a senior staff member as mentor for their probation. In addition, the Faculty Associate Dean for Research meets individually with all academic staff every two years to appraise their research and provide constructive feedback on plans. Five promotions (three female) were made during the REF cycle, despite a lengthy period of promotion freezes (see REF5a), including Pryse to Professor and Morgan to Reader.

Our faculty-wide team of technicians play a key role in research, teaching and outreach. They are involved in Departmental staff meetings, and share the same ECS process as other staff. They are represented by the Faculty Director of Infrastructure who is a member of the Faculty Executive along with the Heads of Department and Associate Deans. This empowering framework has enabled, for example, a former technician to advance to research fellow, then a lecturer during the assessment period. Technicians are encouraged to participate in, and lead, research and engagement projects such as industry contracts and outreach. For example, one of our technicians has received a top STEM ambassador award by STEMNET and another is studying part-time for a PhD in nanomaterials.

Research students

Over the REF period, 25 PhD students have graduated, 3 jointly with Computer Science, Mathematics, and Biological Sciences. This is a 20% increase on PhD awards per year compared with the REF 2014 cycle. We currently have 23 active PhD students (20 full time, 3 part time), evenly distributed across our research areas. Postgraduate students are funded from STFC quota studentships, an EPSRC-funded Centre for Doctoral Training (CDT) in Diamond Science and Technology, and internal and international scholarships including the Iraqi Cultural Attache, Coleg Cymraeg Cenedlaethol, the European Union, and industrial collaborations that include Foremost Advanced Materials Ltd. (China), Element Six Ltd. and three Knowledge Economy Skills Scholarships (KESS) funded in collaboration with small and medium-sized enterprises (SMEs).

A key strategy in the assessment period has been an effort to improve the quality and diversity of our PhD intake. Our improvement in staff diversity will provide additional positive role models for future research students; of the 15 current year 1-3 students, five are female (33%) in comparison with the seven females among the 25 graduates over the assessment period (28%). The University's AberDoc scholarship application system ensures a fair and transparent, university-wide mechanism that we use as a vehicle for all funded PhD position applications. This approach has led to an increase in the number of external PhD students: 6 of our 15 current year 1-3 students have joined us from external institutions, including 4 overseas students. Our strategy for improving quality is further reflected by four of our current students who were authors on refereed journal publications prior to starting their PhD.

Our students are successful in finding postgraduate-level employment. Of the 25 PhD students graduating during the REF period, four have become lecturers in UK or overseas institutions, nine are RAs at UK and overseas institutions including NASA, ESA, and the National Physics Laboratory, and seven work in scientific or corporate computing including leading roles in these fields. Others are outside Physics and IT, for example a senior fund manager in an international corporation.

The Department and University are committed to the provision of an appropriate level of training for all its postgraduate students. Within the Department, all PhD students are expected to attend monthly research seminars from internal or external speakers and to attend weekly research talks or a journal club. Many of our PhD students attend a weekly 'Hacky hour' run by SuperComputing Wales (SCW) and participate in other SCW workshops.

Within the University Graduate School, Physics staff coordinate research-focused modules, and are proactive in schemes such as the UKCGE good supervisory practice framework. The University Researcher Development Programme provides modules, workshops, and training courses. The Department provides Welsh-medium postgraduate training and events through the Coleg Cymraeg Cenedlaethol. All postgraduate students can gain teaching experience, formalised through teaching contracts and the Teaching for Postgraduates at Aberystwyth University training framework.

The Department monitors student diversity in staff meetings and has equality, diversity and inclusion as a standing item for discussion at its regular staff meetings. Our Equality, Diversity & Inclusion Committee (with members from the academic, administrative and technical staff, the student body and the University Diversity and Inclusion Manager) provides a forum for raising ED&I issues of concern to students following a regularly revised plan defined by the Juno principles.

Our postgraduate training and research environment is accredited by STFC and reviewed biannually. It covers training, ED&I, research environment, and annual monitoring. On admission, students attend an induction meeting with the postgraduate co-ordinator, and participate in University induction events and training.

EPSRC CDT students undertake an MSc in Warwick prior to commencing their PhDs that includes two 10-week mini projects that ensures cohort cohesion. During their PhD training, students from all of the eight partner universities attend a residential training and research course and participate in the annual Diamond Conference that attracts leading international attendees from academia and industry. Aberystwyth students have won prizes for their contributions and have led the cohort's outreach activities, for example at the Royal Society Summer Exhibition. In 2018 our students were awarded a Royal Society of Chemistry outreach grant for an exhibition at the Science and Industry museum in Manchester which had 879 visitors in 5 hours. They were also awarded an Institute of Physics Wales public engagement grant for a Diamonds in Space event at the Green Man festival, attracting 900 visitors.

We have several internal financial awards for outstanding research work, including the annual R.M. Davies prize, with a cash reward of £1,200. Postgraduate students are provided with training to present their research work that includes an annual Faculty Conference for second and third year students with awards for best written, oral and poster presentations. Students also participate in the University postgraduate research conference, which includes a 3-minute talk competition with winners entered to a national competition. Students are supported to attend and present at national and international meetings and this has led to the award of prizes for presentations such as the Diamond Conference, the Interdisciplinary Surface Science Conference and the Materials Research Society (MRS) Fall meeting.

Equality, diversity and inclusion

The Department is improving the diversity and gender balance of its research community. Three of six new staff members appointed during the assessment period are female and two of the seven current RAs are female, as were eight of the 21 RAs working in the Department over the assessment period. The Department conforms to University policy regarding equality in recruitment and follows a code of practice that removes discrimination from the process. The Department has formalised equal opportunity through the Institute of Physics Juno program. We train staff on policies and procedures for recruitment, including a training session on equality and diversity. Unconscious bias training is mandatory for all staff. Staff are trained in ethics requirements for research and comply with University ethics policy and procedures (REF5a).

The commitment of the Department and Aberystwyth University to Equality, Diversity and Inclusion (ED&I) is recognised by a Disability Confident Employer accreditation, and participation in Stonewall's Top 100 UK Employers for a LGBT+ friendly workplace. All staff are required to have completed ED&I Training and several networks promote equality issues and provide support for researchers, including the Women in Research Network, BAME Network, LGBT

Network and Disability and Wellbeing Network. Staff, RAs and students are represented on our Departmental ED&I committee, which reports directly to the Departmental Executive Group and whose Chair is a member of the University ED&I Committee. Arrangements for flexible working include researchers returning from maternity leave, and those with medical conditions and caring responsibilities. We ensure that researchers who take family leave are not disadvantaged in their career progress and staff are consulted on meeting schedules, for example. Senior staff members participate in the University female researcher mentoring scheme. Pryse was one of the Royal Astronomical Society's (RAS) *21 Women* in 2016, a project that profiled leading females in astronomy with the aim of improving gender balance. We funded early career researcher Cross to take part in the Aurora leadership course, an external course for female leaders in HE, in 2015.

ED&I principles have been incorporated into the REF 2021 selection process, as outlined in the University's Code of Practice, with all members of the REF Reading Committee and supplementary reviewers required to have completed unconscious bias training. The Departmental REF Reading Committee included independent members from a cognate Department in the Faculty to monitor fair practice. Applications for output reductions for Individual Staff Circumstances are assessed through an anonymous process, with decisions made outside the Department.

The Department supports a bilingual research environment in which English and Welsh languages have equal status. All research in Wales follows the University's Welsh Language Policy, with opportunities for research subjects to participate in Welsh and bilingual communication with research participants and the public. Research through the medium of Welsh is further supported by the Coleg Cymraeg Cenedlaethol, and the Department currently has two PhD students partly funded by the Coleg Cymraeg Cenedlaethol who are active in Welsh-medium workshops, conferences and public engagement, and who will present their theses in both Welsh and English. Staff members, many of whom have learnt Welsh during the last REF period, are leading in developing a Welsh research forum. Staff-driven research activities such as these have played a major part in growing our provision of Welsh-medium undergraduate modules, and several of these undergraduates have become PhD students in the Department.

Section 3: Income, infrastructure and facilities

Research funding

Figure 1 shows the total research income per year through the REF period (including research income in-kind). The total research income is £4.5m, and the average income is approximately £640k per annum, with a general upward trend through the assessment period. Figure 2 (left) shows an increase in the number of active grants each year. The larger number of grants in recent years includes increased applications from early and mid-career researchers, and a broader diversity of funding sources. As shown in Figure 2, our grant income is dominated by UKRI (£2.3m) and European funds (£930k). There is £2.7m in current active grants that provide a platform for research over the next three years.

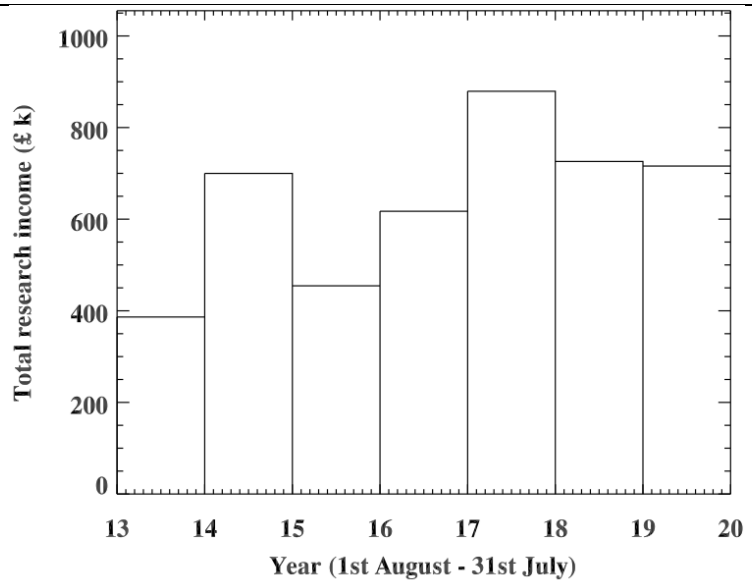

Figure 1. Total research income per year, including income in-kind. This is calculated from 1st August to 31st July annually (so '13' corresponds to 2013 to 2014).

Our faculty-based Research Development Officer assists in identifying funding streams and the application process. The University's Department of Research Business & Innovation provides training workshops for all aspects of research funding and grant management. All proposals are peer-reviewed prior to submission; this is usually done by a senior researcher within the relevant research group.

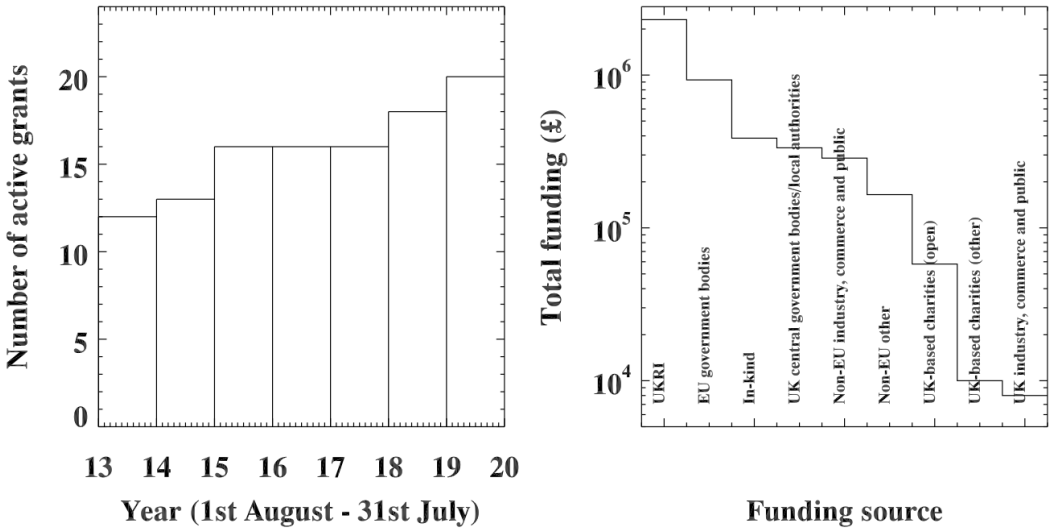

Figure 2. Left: Number of grants active within each year. Right: Funding distribution for different sources during the REF period.

In-house Facilities & Investment

Key to our research is a common infrastructure incorporating laboratories, computing, electronic and mechanical workshops and support staff, all located in the same building. Workshop capabilities include electronic and mechanical design and manufacture, enabling in-house development and production of bespoke research equipment and instrumentation. During this REF period the workshops have produced systems including flight hardware and ground support equipment for the ExoMars rover mission, hyperspectral camera systems for remote sensing and solar observations, a high-temperature levitating furnace and a combined optical and electron spectrometer for surface analysis.

This infrastructure investment of £1.4m during the assessment period has included new laboratories and workshops for optics, robotics and soft matter, for new equipment such as ellipsometry and reflectometry, and for upgrading facilities such as Computer Numerical Controlled (CNC) manufacturing, microscopy and spectroscopy. The most recent investment is a new Space Exploration Centre which will include testing capabilities for UKSA and STFC projects supporting current and future space missions.

We have a team of dedicated, Faculty-shared mechanical, electronic and computer technicians that facilitate our research. A Research Software Engineer for the European Regional Development Fund (ERDF) funded Super Computing Wales (SCW) network is based in the Faculty who has supported our increased use of this major facility in recent years. Researchers and PhD students are supported to engage in SCW activities including workshops, conferences, and training courses. Institutional investment in High Performance Computing hardware has complemented our research activities (see REF5a).

The research facilities were rapidly utilised in April 2020 to produce Personal Protective Equipment for local health services in the COVID-19 pandemic response, in a collaboration with a consortium of local companies, developed from a Centre for Photonics Expertise contract, with a production rate 20 times higher than that achieved by their previous manufacturing method.

Use of non-UKRI facilities

In addition to UKRI facilities, staff have been successful in gaining access to major non-UKRI facilities such as synchrotron radiation sources, ground- and space-based telescopes as summarised in Table 1 (below), totalling 245 days of allocated time plus over a million SCW core hours. Researchers also benefit from access to facilities awarded through our international collaborations, not listed here.

Facility	Years	Location	Total time allocated
Swedish Solar Telescope	2017, 2018, 2019, 2020	La Palma	62 days
Gregor Solar Telescope	2016, 2019	Tenerife	20 days
DESY	2015	Hamburg	7 days
SWAP/PROBA 2	2015	Brussels	31 days
ASTRID2	2019, 2020	Denmark	39 days
Advanced Photon Source	2014	Chicago	7 days
Photon Science Institute	2017, 2018, 2020	Manchester	17 days
BESSY	2017, 2018, 2019, 2020	Berlin	56 days
SOLEIL	2020	Paris	6 days
SuperComputing Wales	2017-2020	Wales	1,029,826 core hours

Table 1: In-kind research benefit from time awarded on major non-UKRI external facilities.

4. Collaboration and contribution to the research base, economy and society

Research collaboration

Collaboration with external institutions is crucial to our research: 82% of papers are in collaboration with external institutions (SciVal data), and 72% of papers are published within international collaborations (increased from 62% in 2016) - the latter gain 86% of our citations.

Our research collaborations are enabled by funded consortia and programmes across space, materials and quantum physics and by collaboration with international partners funded in their home countries. Our researchers are attached to the following key funded partnerships:

- *ExoMars* (Gunn, Langstaff, Cross). As part of the PanCam team for the ExoMars (launch 2022) mission funded by UKSA and ESA, we have manufactured the calibration targets and fiducial markers for the visible and infrared cameras. This work is key to several interdisciplinary publications, encompassing applications in astronomy, geophysics, and archaeology.

- *JUICE and BepiColombo* (Grande, Knight, Pinter). We optimised the radiation shielding for the six instruments comprising the Particle Environment Package (PEP) on JUICE (launch 2023), following our role in the Solar Intensity X-Ray and Particles Spectrometer (SIXS) instrument on BepiColombo.

- *Space Weather* (Morgan, Grande, Kuridze). A new solar tomography method was developed during a Leverhulme fellowship in 2015-2016 and is key to our recent expansion in space weather research. We lead further projects that will deliver operational space weather forecasting tools for the Meteorological Office. We led the ten-year Committee on Space Research (COSPAR) space weather roadmap and collaborate internationally on alerting future manned space missions from damaging radiation.

- *Polarimeter to Unify the Corona and Heliosphere (PUNCH)* (Morgan). On the NASA PUNCH mission (launch 2023), we will apply our software analysis tools for interpreting and planning mission observations.

- *Advanced computational analysis and modelling for solar physics* (Kuridze, Taroyan, Morgan, Pinter, Gorman). Enabled by a Sêr Cymru Fellowship (2017-2020) and SCW facilities, our data analysis methods and advanced numerical models are used to study dynamic phenomena in the Sun's atmosphere. The new analysis methods have led to opportunities for cross-disciplinary applications including a collaboration with cancer researchers, funded by the Welsh Crucible.

- *Ground-based solar observations* (Kuridze, Morgan, Cook, Gunn). We are collaborating on observing, analysis, and modelling of ground-based solar observations with major international facilities - a timely field given the imminent observations of the Daniel K. Inouye Solar Telescope (DKIST) in 2021. Our work as members of the world-leading group of eclipse scientists has led to a new design and build of a high-resolution spectrometer for visible emission lines of the solar corona.

- *Development of Perfect Glasses by solid state synthesis* project (2012-2105) (Zhou, Greaves, Wilding, Langstaff). This industry-funded international collaboration has enabled the realisation and application of novel materials such as perfect glasses and bio-cements and has driven the development of new instrumentation, leading to further international funding for *Aerodynamic Levitation for materials at high temperatures.*

- *CDT in Diamond Science and Technology* (2014-2023) (Evans, Cross). This network is training our next generation of scientists and engineers who are finding new ways to exploit the unique optical and surface properties of diamond, and who are communicating their enthusiasm by leading major outreach events such as the Royal Society Summer Exhibition in 2016.

- *Solar Photovoltaic Academic Research Consortium (SPARC II)* (2016-2023) (Evans, Finlayson, Langstaff, Gunn, Cross, Winter). This is a £9.7m ERDF partnership of four universities to build research capacity in solar photovoltaic research in Wales. It is enabling us to extend research on new materials and the development of our bespoke cluster tools incorporating real-time X-ray and optical methods to give new insights to the physics of photovoltaic devices.

- *Centre for Photonics Expertise (CPE)* (2019-2022) (Cross, Gunn, Langstaff, Morgan, Evans). This is a recent £3.8m ERDF partnership of four universities that draws on leading academic capabilities offering light-based technological solutions to enable businesses across Wales to accelerate business growth.

- *Radio spectrum* (Pryse, Jilani, Langstaff, Gunn, Evans). Radio physics and technology is an area of investment that brings together new expertise in antenna design with established materials, instrumentation and ionospheric expertise and links to other disciplines and industry. This growth is part of a collaboration between the University, industry and Government to establish a National Spectrum Centre in Aberystwyth.

Beyond these partnerships, our UK and international collaborations, including corporate collaborations, extend across the Research Groups. We have very productive collaborations with Chinese institutions including Shanghai University, Wuhan University of Technology, and Hong Kong Polytechnic University. Across Europe, we have collaborated with institutions including the Austrian Academy of Sciences, Sorbonne Universite, Norwegian University of Science and Technology, KU Leuven (Belgium), and Observatoire de Paris. We have collaborated on multiple papers with several of the most prestigious US institutions including Harvard, Princeton, University of California at Berkeley, California Institute of Technology, Carnegie Institution of Washington, George Mason University, Johns Hopkins Applied Physics Laboratory, Southwest Research Institute, Rice University, University of Hawaii, Stanford University and Massachusetts Institute of Technology. We have multiple collaborations with other international institutions such as the University of New South Wales (Australia), the University of Canterbury (NZ), Czech Academy of Sciences, Swiss Federal Institute of Technology at Lausanne, and the University of Graz (Austria).

Within the UK, we have productive collaborations with institutions including the University of Cambridge, University College London, Queen Mary University of London, University of St Andrews, Warwick University, University of Oxford, Imperial College London, University of Bristol, University of Glasgow, University of Edinburgh, Cardiff University, Queen's University Belfast, and Newcastle University.

We collaborate with international government research institutes including CNRS (France), Chinese Academy of Sciences, German Aerospace Center, NASA Goddard & Ames, ESTEC (Netherlands), Joanneum Research (Austria), Max Planck Institute for Solar System Research (Germany), MacDiarmid Institute for Advanced Materials and Nanotechnology (NZ), International Atomic Energy Agency (Austria), and the Naval Research Laboratory (US). Our publications with corporate collaborators include Anglo American (UK), Schlumberger (US), Adnet Systems (US), Predictive Science (US), QinetiQ (UK), Aerospace Corportation (US), Materials Development Inc. (US), Lockheed Martin (US), and Element Six Ltd (UK).

Contribution to the research base

Researchers have held key or leading roles that contribute to the vitality and sustainability of scientific research, for example: Grande was on the COSPAR executive bureau and is the UK representative and Vice Chair of the COSPAR Space Weather Panel. He was President of Planetary Science for the European Geophysical Union, has served on the Royal Astronomical Society council, and on the Executive Committee of the French national Centre for Plasma Physics Data. Zhou is Deputy Director of the EU-China Urban Research & Innovation Laboratory, and Secretary General of the New Material Industry Promotion Committee (China-Europe Association for Technological and Economic Cooperation). Morgan was Chair of the Solar System Advisory Panel for STFC. Gunn is a member of the UKSA's Remote Exploration Oversite Committee. Evans chaired the working group for the B07 soft X-ray beamline at the Diamond Light Source and is a member of the advisory board for the EPSRC National X-ray Photoelectron Spectroscopy (XPS) facility at Harwell. Morgan was a member of the UK DKIST consortium. Cook is on the International Astronomical Union committee for the naming of features on Mercury. Jilani is on the Executive Committee of the Institute of Engineering and Technology's Antennas and Propagation Technical Network. Morgan was a member of a panel

reviewing solar facilities for STFC. Pryse is on the UK panel of Union Radio-Scientifique Internationale that co-ordinates radio science research. Grande is a member of the Welsh Horizon 2020 Experts and Evaluators Group.

Grant panel, journal editorial, and review roles

Researchers contribute to the UKRI research community through reviewing and membership and chairing of panels. This includes EPSRC panel membership for Physical Sciences, Platform Grants, Programme Grants, Supergen Solar, Mid-range Facilities and Chair of Fellowships Interview Panel (Evans). Morgan chaired the Priority Project panel for STFC in 2018. Grande has been a member of the European Research Council's Astronomy Consolidator grant panel and H2020 panels. Gunn is on the UKSA Aurora panel and Kuridze was a panel member for NASA's Research Opportunities in Space and Earth Science Heliophysics program. Staff members are regular reviewers for Horizon 2020, EPSRC, STFC, NASA Low-Cost Access to Space, NASA PDRA fellowships, Ernest Rutherford fellowships, Royal Astronomical Society fellowships, UKRI Future Leadership scheme, National Agency for Scientific and Technological Promotion (Argentina), National Science Foundation (USA), the National Geographic Society, and observing time proposals for major facilities. Staff members have given talks at UKRI and elsewhere on successful application techniques.

Journal editorial board membership include The Astronomy and Astrophysics Review, Frontiers in Physics, Scientific Reports, Rare Metals, Frontiers in Astronomy and Space Science, Diamond and Related Materials, Molecules, and the Russian Journal of Mathematical Physics. Pryse was Chair of the Editorial Board of the Welsh academic journal Gwerddon. Staff frequently review papers for high-impact journals.

Conference and workshop participation.

Early career researchers and PhD students are supported by the Department to attend national and international conferences and to present their work with students gaining prizes for best presentation at meetings such as the Diamond Conference and Interdisciplinary Surface Science Conference in the UK and the Materials Research Society (MRS) meetings in the US.

Researchers are active in conference and workshop organisation; for example, the European Planetary Science Congress (Grande was Chair of the Executive Committee and Organising Committee), Europlanet (Grande, Cook, Cross), Society of Photo-optical Instrumentation Engineers (SPIE) Photonex (Gunn), International Conference on UK-CHINA Emerging Technologies (Zhou) and the Isaac Newton Institute program (Gough). We are key in establishing, organising, and hosting the annual Welsh Scientific Conference. The Department hosted the 2019 STFC Summer School in solar system physics, an event for approximately 30 PhD students from UK and overseas. We help organise the UK Solar Online Seminar Series and have delivered invited seminars to the European Solar Physics Online Seminar series, to an international audience of over 100.

We have convened and chaired sessions for UK and international conferences including the National Astronomy Meeting (UK), MRS (USA), e-MRS (Europe), International Conference on Solid Films and Surfaces (Germany and Japan), Annual World Congress of Advanced Materials (China), International Symposium on Graphene Advanced Nanomaterials & Defects Engineering (China), and Solar Image Processing meetings (USA).

We frequently participate as lecturers in workshops including Solar Orbiter workshops, Quantum and Nano-Control workshops (Institute for Mathematics and Its Applications), STFC Summer Schools, Original Research by Young Twinkle Students Summer Schools, and several international workshops related to space missions, for example ExoMars instrumentation.

Staff members regularly give invited talks at specialist conferences in their respective fields, including several plenary talks including Graphene and Carbon Nanotechnology (Japan, 2019), Hinode 13/15th symposium of Interrelationship between Plasma Experiments in the Laboratory and in Space (Japan, 2019), Physics of Non-Crystalline Solids (France, 2018), High-resolution

Solar Physics: Past, Present, Future (USA, 2017), International Commission on Glass (Thailand, 2015), and Beijing Institute of Technology's 1st Emerging Industry Forum (China, 2014). Staff, RAs, and PhD students regularly present in conferences including UK National Astronomy Meetings, the European Geophysical Union meeting, American Astronomical Society meetings, American Geophysical Union meetings, and the Materials Research Society meetings.

Invited seminars and public lectures
We have given numerous invited seminars at other UK and overseas institutions including Catania Astrophysical Observatory, Czech Academy of Sciences, Max Planck Institute Gottingen, and Princeton University. Staff are also invited to present in specialist international workshops related to space missions, quantum control, materials science, and Solar Orbiter workshops for example.

Awards and recognition
The contribution of members of the Department to the research community has been recognised in awards and prizes, including the election of Pryse as a Fellow of the Learned Society of Wales in 2018, and the award of the Eilir Hedd Morgan prize for Contribution to Welsh Science to Morgan in 2014. Greaves received the Cooper Distinguished Lecturer Award from the American Ceramic Society in 2016 and held visiting academic positions at Cambridge University, University College London, and Wuhan University of Technology.

Contribution to economy & society
Engagement with the public, policy makers, schools and businesses is encouraged through financial support and workload allocation that values these activities alongside research and teaching.

To enhance interaction between academia, government and industry, our researchers have, for example, presented and led discussion at events such as the Science in the Senedd series (Morgan, Grande), and have engaged with policy makers, for example providing evidence to the Welsh Assembly's Enterprise and Business Committee (Evans) and advising media on science content (Morgan). Evans has chaired the Welsh Optoelectronics Forum steering committee and is a member of the Advanced Sustainable Manufacturing Technologies (ASTUTE) external advisory panel. Grande and Evans have chaired the Institute of Physics in Wales committee; Evans is Chair and Pryse member of the National Eisteddfod's Central Science and Technology Committee, Pryse has led on the RAS200 engagement project on which one of our impact case studies is based. Pryse's and Grande's links to the Royal Astronomical Society led to Aberystwyth being chosen for their strategy consultation meeting with the Welsh community in 2018.

Our collaborations with organisations, SMEs and anchor companies such as Airbus, Qinetiq and Qioptiq have been enabled by KESS PhD scholarships, Expertise Wales SMART partnerships, large consortia and consultancies. In recent years, three new initiatives in particular are establishing interactions that will lead to societal and economic impact in the next decade:

- A new STFC project that unites expertise at four UK universities delivering operational space weather forecasting tools for the Meteorological Office.
- Government and industry funding, including a SMART partnership, in radio science and technology that forms the basis of a National Spectrum Centre at Aberystwyth.
- The collaborative Centre for Photonics Expertise has established a framework for engagement of four universities with businesses to provide photonics solutions derived from our combined research expertise that enables a rapid process from initial contact, facilitated by shared business development officers, to project commencement. In its first year, the Centre has processed 20 contracts with companies based on Aberystwyth expertise in optical instrumentation, sensors, diamond science and solar energy.

We are contributing to the sustainability of the physics research base through initiatives to connect our research with school science teaching, inspiring the next generation of physicists. These include the £8.2m TrioSciCymru project, a collaboration between the Welsh Government and four universities that will reach 5,600 pupils in 30 schools with aims to encourage students from under-represented backgrounds to study science. We are leading the science activities in the University's Old College project, with support from the Wolfson Foundation (£250k, 2019), as part of a major transformation of this building as a centre for learning, culture, and enterprise.

More broadly, contributions to the public understanding of science include the RAS200 science-arts collaborative project 'Astronomy and Geophysics through the Traditional Culture of Wales' (2015-2022), led by the Department with other universities, the National Eisteddfod and the Urdd (Welsh youth organisation), and involving several artists, musicians, dancers, writers and composers. This project has enabled many cultural activities based on scientific themes to reach a wide audience, impacting on Welsh cultural life, and forms one of our impact case studies. We have organised public activities to coincide with major astronomical events (for example, the Mercury transits, the 2015 eclipse), as well as numerous smaller-scale stargazing or sungazing events at various venues throughout Wales. The 2015 eclipse event was attended by at least a thousand people. Other events include the launch of the ExoMars Rover full-size model (built in the Department for outreach purposes), which was attended by the UKSA Exploration Programme Manager, and televised live on a national Welsh TV broadcast. Our engagement with amateur astronomers has led to an asteroid being named after Tony Cook in 2016, in recognition of his outreach and planetary topographic mapping work.

The National Eisteddfod of Wales is a major annual cultural festival that has a wide reach with over 20,000 visitors per day to the science events over the week-long festival. Our research has featured prominently each year, and in particular in 2016 and 2017 when Aberystwyth led the exhibition with support from the Institute of Physics and the STFC through a grant in partnership with the Diamond Light Source.

In response to the cancelled Eisteddfod of 2020, Evans recorded a series of accessible home-based experiments in lieu of the usual science exhibits that linked our research to the school science curriculum, and Morgan recorded an astronomy-based presentation aimed at children as part of a Christmas 'Advent' series, as well as interviewing a popular author on her new novel which is based on astronomy themes.

Co-ordinating with the University's Communications team we promote science and our research through appearances on media outlets including TV and radio items on topics such as our participation in eclipse observations, the discovery of the strong magnetic field of coronal loops, our work on ExoMars instrumentation, and disproving moon landing conspiracy theories. Our researchers communicate across a range of media, with examples including Radio 4's Inside Science, the Guardian, New York Times, The Mirror, the "i", Discovery Channel and Channel 5. A high-resolution image of the solar corona processed using our methods, was chosen to adorn a wall in the new Oculus Rex (Facebook) headquarters in Oregon.