

Institution: Aberystwyth University
Unit of Assessment: 10: Mathematical Sciences
<p>1. Unit context and structure, research and impact strategy</p> <p>Overview, and Aims and Structure</p> <p>The Department of Mathematics at Aberystwyth University is a long-established department which will be celebrating its 150th anniversary in 2022. Our aim is to develop and sustain a vibrant research environment by encouraging and supporting each member of staff to pursue a research agenda that emphasises their unique abilities and skills, working with their networks of internal and external collaborators to produce excellent research and impact. The research activity of the Department has a core of ten permanent full-time teaching and research staff, supported by research fellows, PDRAs, PhD students, honorary staff and visitors, as well as by technicians and professional services staff. We are a close-knit group of researchers: our research interests in operator algebras, quantum control, solid and fluid mechanics, and applied statistics show extensive overlap, and the size of the Department means that frequent and close interactions happen both organically and in a more planned way.</p> <p>The approach of the Department is aligned with the University's Research and Innovation Strategy as outlined in REF5a, and builds on its key 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. In this assessment period, research capacity in the Department has been strengthened by access to University and Faculty funding schemes (for example the University Research Fund, which is open to all researchers, and offers awards of up to £10k on a competitive basis, and AberDoc funding for PhD students); University policies and initiatives for researcher development and promoting equality and inclusivity; and the fostering of interdisciplinary research collaboration through strategic restructuring.</p> <p>A noteworthy development for the Department during the assessment period has been the strengthening of connections with cognate subject areas, first through the formation of the Institute of Mathematics, Physics and Computer Science in 2014 and by the establishment of the Faculty of Business and Physical Sciences (FBaPS) in 2018. Both processes involved the coordination and integration of research policies and research support and activities to facilitate cross-departmental collaboration, including two-minute research 'speed dating' events and grant sandpits. These activities have consolidated strong research links with Physics and Computer Science in particular, most notably in the fields of soft matter, quantum systems and applied statistics.</p> <p>Our commitment to interdisciplinary and collaborative research also extends to work with other Departments within the University, notably with Biological, Environmental and Rural Sciences (IBERS) in the areas of active matter and biostatistics. Our work with external partners in the UK and internationally is exemplified by our involvement in, and coordination of, Europe-wide projects, and there is extensive work with researchers in the US and Australia in solid mechanics, soft matter and quantum information. As a relatively small Department, collaborative research is essential to realising critical mass to ensure the sustainability of our research activities, and the vitality of our collaborations is reflected in the range of work supported in projects funded by UKRI and European sources, including in bio-mechanics (MatrixAssay), modelling the effects of climate change (ECHOES), minerals processing (PARM-2), analysis of the properties of composite materials with complex microstructure (TAMER), the design of ceramic materials (CERMAT2), the dynamics of foams (Soft Matter Dynamics), and quantum control (TheBlinQC).</p>

Within the framework of FBaPS, research policy and coordination are the responsibility of the Faculty Research Committee, on which Mathematics is represented by the Head of Department (currently *Cox*) and the Departmental Director of Research (currently *Gohm*). Research matters are an important focus of frequent Departmental staff meetings, and members of staff are engaged in the research strategy through two-yearly individual meetings with the Faculty Associate Dean for Research, Knowledge Exchange and Innovation, and in annual review meetings with the Head of Department. All members of staff in the Department are associated with at least one research group, which provide the context for the delivery of the research strategy. The incorporation of Mathematics in the FBaPS, and its representation on the Faculty Research Committee, has enabled improvements in training for postgraduates and early career researchers and provided a channel to successfully advocate for the return of a percentage of research grant overheads directly to the PI in order to provide support for research development and dissemination.

The Department's Research Group structure is regularly reviewed and has been modified during the assessment period to reflect developing research agendas and new appointments, and thus to support the ongoing sustainability of the research environment. The Mathematical Modelling of Structures, Solids and Fluids (MMSSF) and the Quantum Structures, Information and Control (QStIC) Groups have been strengthened with new appointments, and a new Group established in Statistics, extending the research capacity of the Department.

- i. The **Mathematical Modelling of Structures, Solids and Fluids** (MMSSF) Research Group brings together a broad range of interests in applied mathematics. *Douglas* is an analyst with interests in optimal mass transfer and its applications to rheology and meteorology. *Mishuris* and *Vellender* work in applied analysis, particularly in solid and fluid mechanics, with varied and extensive applications. *Cox*, *Davies* and *Mughal* work in soft matter, including modelling of foams, bubbles and sphere packings. The group has particular expertise in numerical simulation and supports a soft matter experimental laboratory.

This group, the largest of the three, has been successful in adapting to new challenges in modelling (for example in biorheology and the dynamics of discrete structures). It makes a significant contribution to the Department's research income, from both RCUK, Royal Society and European (FP7, H2020) sources, with key international collaborators in Tel Aviv, Minsk, Trento (solid mechanics), Dublin and Paris (soft matter), and industrial support from the UK (BTG for medical treatments using foams) and overseas (SINTEF, Shell, Gazprom Neft and others involved in the petroleum industry). This group also contributes both impact case studies to this submission; these cover the use of bubbles and foams for mathematical outreach activities and mathematical and numerical modelling of fracture propagation to improve the accuracy of hydraulic fracturing.

- ii. Members of the **Quantum Structures, Information and Control** (QStIC) Research Group have expertise in functional analysis and operator algebras, information theory and (non-commutative) stochastic analysis. *Burgarth*, *Kiukas* and *Pitchford* work in quantum control, information and statistics, and *Evans* and *Gohm* work in operator algebras and non-commutative probability, with particular expertise in applying techniques from mathematical physics and modern control theory to the emergent field of quantum control engineering. In his work on asymptotic completeness *Gohm* combines rigorous new results in operator algebras with applications to the preparation of states in quantum systems which are only indirectly accessible. This is of interest in quantum control and even for experimentalists and illustrates the potential of the specific combination of expertise that exists in this group, which has led to fruitful collaboration with researchers in Cork and Darmstadt, for example.
- iii. The **Statistics** research group has been revitalized during the assessment period, with a new appointment (*Kenobi*) in applied statistics. Applications to biological data sets have strengthened the Department's links with Aberystwyth's Computer Science and

Biological, Environmental and Rural Sciences Departments. For example, *Kenobi* is co-I on the species distribution modelling work package of the ECHOES project that has ERDF funding to work with researchers in Ireland to assess the effects of climate change on bird habitats. His collaborations with biologists have led to several highly-cited and visible papers, including a paper in Nature Communications on the circadian clock in the model organism *Arabidopsis thaliana*.

Research and Impact Strategy

In our REF 2014 submission, the Department's research and impact strategies for the current assessment period focused on six key aims:

- i. Producing and publishing high-quality research and growing research income streams;
- ii. Recruiting and training junior researchers;
- iii. Offering staff the time and money to exploit the interdisciplinary environment;
- iv. Expanding international collaboration and organising international conferences;
- v. Strengthening the impact of the Department's research by supporting exploratory projects with potential to lead to research impact, and requiring that research proposals include a clear impact strategy, and recognising time committed to impact activity in workload allocations;
- vi. Enhancing public engagement activities.

The successful implementation of the research and impact strategies during the assessment period is demonstrated by the following achievements and outcomes:

- i. The Department's research output has remained high: staff have published over 200 articles in peer-reviewed articles during the assessment period, an average of more than 15 per FTE. These articles have already received over 1,000 citations, with an average of almost 6 citations per article (SciVal). *Mishuris* has published two books with Springer, and his edited proceedings of a Royal Society conference ran to two issues of Phil. Trans A. Our work has been highlighted by journals as of particular interest (for example, in Phys. Rev. Letts., Physics World, and Euro. Phys. J. E) or highly cited / most downloaded (e.g. Int. J. Eng. Sci.) and PhD students (*Perkowska*, *Peck*) have won prizes for their research. We have successfully fulfilled our ambition to win funding from Horizon 2020, for example through the projects MatrixAssay, FAANon and Effectfact (see Section 3).
- ii. The Department continues to new attract excellent young researchers, as demonstrated by the appointment of new permanent staff in all three research groups. Three Sêr Cymru fellowship holders (*Musolino* and *Dutko* in MMSSF, *McNulty* in QStIC), beneficiaries of a HEFCW competitive scheme to attract world-leading researchers to Wales, and a Marie Curie Incoming Fellow (*Dalla Riva*) have been hosted during the period, instigating new lines of research in collaboration with permanent staff (see Section 2). *Burgarth* participated in the Imperial CDT on quantum information, bringing excellent PhD students to the Department, and the number of PhD students graduating during the census period has increased (11.5 research doctoral degrees awarded for REF 2021, compared to 7 awarded for REF 2014, a 17% increase in the annualised completion rate).
- iii. Interdisciplinarity has been embedded in our approach to research: in our Research Groups (for example note the high proportion of QStIC papers in physics journals), within the University (exemplified by *Kenobi's* links with Computer Science and IBERS, and the QStIC group's links with Physics) and externally (for example *Mishuris's* MatrixAssay

project with biologists and industrialists) (see Section 4). This has been facilitated and enhanced through teaching buyout (*Mishuris*), secondments of PhD students to industrial and academic partners (for example Eurotech in Poland), and a Sêr Cymru Industrial Future Generations Fellowship bringing *Dutko* (Rockfield) to the Department on a half-time basis.

- iv. International collaboration has become central to our research ethos, with examples including *Mishuris*' Horizon2020 funding, *Burgarth*'s participation in a QuantERA network, *Kenobi*'s involvement in the Wales-Ireland ECHOES project, and *Cox*'s participation in an ESA-funded project to perform microgravity foam experiments on the International Space Station in 2020. These have led to secondments of staff and PhD students abroad (see Section 4). In addition, staff have been involved in conference organisation across Europe (see Section 4).
- v. Within the MMSSF and QStIC groups we have built critical mass to ensure that our research has greater impact. In the MMSSF group successful examples include *Mishuris*' work with a succession of PhD students on numerical algorithms for fracture; this has resulted in one of the submitted case studies. Impact activities are now recognised in the University's Workload Allocation Model, and *Mishuris* has benefited from "impact leave" funding to pursue applications of his research.
- vi. We have engaged the public through a range of outreach activities, with a particular emphasis on stimulating understanding of, and enthusiasm for, mathematics with young people. *Davies* and *Cox*'s use of research on area-minimising "foam" structures to engage audiences with ideas associated with optimisation and geometry are described in one of our impact case studies.

In addition, we have engaged with the open science agenda, encouraging researchers in the Department to make publications open access, through either the 'gold' or 'green' routes, and where appropriate to make datasets and computer code publicly available. This has been supported by University policies and support services for open science, as described in REF5a, including funding for article processing charges for UKRI-funded research, through JISC agreements with publishers, and through the requirement for copies of author's final manuscripts to be archived within the University Research Portal repository on acceptance for publication.

In the next assessment period, the Department aims to further consolidate its research impact and its interdisciplinary and collaborative profiles, improve support for staff to obtain external research funding, and pursue research addressing significant societal, health and environmental challenges. In particular, we will adopt the following priorities:

- i. To contribute to Welsh, UK and Global research challenges:
The Department's over-riding goal is to support staff to pursue world-leading research contributing to Welsh, UK and Global research challenges. *Mishuris*' work on hydraulic fracture, relevant to the EPSRC energy theme and the related context of energy security, has continued through this assessment period, following EU funding, and now has Sêr Cymru support for himself and *Dutko*, and *Cox*'s work on varicose vein treatments, relevant to the EPSRC Healthcare Technologies theme, show that we have successfully started to move in this direction. In biomechanics and medicine, we plan to further address UKRI challenges in healthcare (for example, in relation to non-invasive diagnosis of osteoporosis), and in statistics to investigate the effects of climate change. We will use our expertise in factorisation techniques to analyse the catastrophic destruction of defensive constructions and contribute, for example, to protection against earthquakes.
- ii. To better support staff in seeking research funding:
Our use of dedicated teaching staff has increased over the last REF cycle, providing research-active staff with more time for research. For example, *Mishuris* spent academic

year 2019-2020 on “impact leave” to develop his impact profile and improve our impact cases, and *Kiukas* was awarded a centrally-funded Graduate Teaching Assistant for 2020-2021 to allow time for research. We plan to build on this success with further capture of income to offset teaching loads, and improve the frequency and quality of research grant applications. We will develop new sources of funding for PhD students, for example from large collaborative grants.

- iii. To encourage international collaborative research across disciplines:
We facilitate collaboration using internal funds for travel, visitors, and to encourage new collaborations leading to large grant applications. We will use the increased familiarity with online meetings to extend our joint work with partners for whom travel has previously proved too costly or time-consuming. A significant proportion of the overheads from any UKRI-funded grant is returned directly to the PI, which will allow the purchase of equipment and travel.
- iv. To enhance our research impact:
We will deepen the impact of our research by pursuing collaborations with end-users, for example in the micromechanics of complex materials, applications of factorisation techniques, and statistics applied to ecology. One way to achieve this will be to organise workshops and conferences with industrial participation. We will also broaden our outreach work in schools, at festivals and other events to bring more of our research to the attention of young people and the general public; our work on hydraulic fracturing, foams, and marine mammal sightings provide excellent research on which to base this.

Collectively, these actions will support the future sustainability of the research environment in the Department and its continuing vitality, whilst working towards increased inclusivity and diversity.

2. People

Staffing Strategy

The Department’s staffing strategy aims to enrich the vitality of its research environment by **retaining, developing and rewarding** excellent researchers, and to ensure sustainability by recruiting new researchers with a commitment to undertaking high-quality research with impact. The Department has made two new research appointments (*Kenobi*, *Kiukas*) in the assessment period and the total number of research active staff has increased on REF 2014, with 12 FTE staff in post. An emphasis on recruiting strong early career researchers has produced a forward-looking community with potential, consisting of two Professors, one Senior Lecturer, seven Lecturers and three independent Research Fellows (two of whom are 0.5 FTE).

Of particular note has been the Department’s success in recruiting three excellent **Research Fellows**: *Dalla Riva* as a Marie Skłodowska-Curie Individual Fellow and *McNulty* and *Musolino* through the Sêr Cymru COFUND scheme. In addition, the Department’s collaborative links have been strengthened by the secondment of *Dutko* from the SME Rockfield to work with *Mishuris* through a Sêr Cymru Industrial Fellowship.

Additionally, six PDRAs have been employed to work on research projects in the Department on **fixed-term contracts** during the assessment period (*Cooray*, *Kiukas*, *Peck*, *Pitchford*, *Vitasari*, *Wrobel*). *Kiukas*, *Peck* and *Pitchford* have subsequently been appointed to academic posts in the Department; *Cooray* was appointed to a further PDRA post at UCL, *Wrobel* succeeded in obtaining a Marie Skłodowska Curie Research Fellowship in Cyprus, and *Vitasari* returned to a lectureship in Indonesia. Sêr Cymru COFUND Fellow *Musolino* gained a permanent academic position in Venice and MSC Fellow *Dalla Riva* a tenure-track position in Tulsa. These appointments demonstrate the excellence of the Department as an environment for developing the potential of early career researchers.

The Department’s research environment is also enhanced by the contribution of **emeritus and honorary staff**, including *Walters*, *Binding*, and *A R Davies* in Rheology, *Abrahams* in

Factorisation Techniques (Wiener Hopf), *Mavron*, *McDonough*, *Key* in algebraic combinatorics, and now *Burgarth* in quantum control. These colleagues contribute by organising research conferences (for example, an annual rheology conference in Wales with significant international participation), publishing research (for example, *Burgarth* continues to publish with *Pitchford*), and providing guidance on funding opportunities (for example, *Abrahams* is a key contributor to collaborative EU bids that *Mishuris* is developing) and links with industry.

Staff Development

The Department supports Aberystwyth University's implementation of the **Concordat to Support the Career Development of Researchers**. Research staff, including PDRAs and research fellows, are assigned mentors within their Research Group, complete a probation agreement with targets for publications and conference presentations, and are encouraged to engage in internal and external professional development courses as well as a small amount of teaching to prepare them for permanent positions. At any one time during the census period there have been between two and four PDRAs in the Department, and up to two Research Fellows.

All research-active staff can request **research leave**, at roughly one semester in eight, subject to an appropriate research plan for the leave period and a report giving the highlights of any previous periods of leave, enabling intense periods of research, the development of research grant applications, research impact (e.g. *Mishuris* in 2019-2020), and writing of major pieces of work. The research leave policy also provides for buy-outs funded by external grant income (*Mishuris* 2020-2021). Successful use of research leave is monitored and informs future decisions on leave allocation.

Our use of dedicated teaching staff has increased over the last REF cycle, providing research-active staff with more time for research. In particular, the Department now has a full-time Teaching Fellow (*Pitchford*), who completed his PhD in quantum information during the assessment period.

Applications for **promotion** are encouraged: candidates for promotion are mentored as they prepare their application. During the assessment period *Burgarth* was promoted to Reader, *Gohm* to Senior Lecturer, and *Davies* was made permanent. *Kiukas* and *Kenobi* successfully passed probation.

All staff are expected to complete three days of personal **staff development and training** each year. This includes courses run locally, for example a compulsory course on financial management of research grants for successful applicants; and those run elsewhere, for example the HoDoMS Induction Course for New Lecturers in the Mathematical Sciences and the recent TALMO initiative. Staff development is supported by regular research planning and monitoring meetings at Department and Faculty level. Staff have an annual review meeting with the Head of Department as part of the Effective Contribution Scheme, which includes research; and research planning meetings with the Faculty Associate Dean for Research at least once every two years.

Postgraduate Research Students

An important and ongoing objective of our Research and Impact Strategy is to increase the number of postgraduate research students in the Department. This has been advanced by engaging with Centre for Doctoral Training (CDT) bids and EU-funded Initial Training Networks (ITNs). The Faculty offers **postgraduate scholarships** to attract outstanding international and home students, in addition to the full AberDoc Scholarships (one of which is currently held by a maths PhD student) offered by the University. Additional scholarships have also come from both industry and EU sources, and through the Coleg Cymraeg Cenedlaethol scheme for students wishing to study in Welsh, as well as self-financed students from both the UK and overseas. Joint supervision of students in other departments (Computer Science and IBERS) has also strengthened collaborative links with these Departments, resulting in joint publications. Additionally, *Burgarth* was involved in external co-supervision of several students from the Imperial CDT prior to his move to Macquarie University in 2018.

A total of 22 PhD students studied in the Department during the assessment period: the **submission rate** was over 85%, with 11.5 research doctoral awards being made. This is an annualised improvement of 17% in the number of PhD awards relative to the seven awards reported in REF 2014. Destinations of completed PhD students include PDRA positions and Research Fellowships in Marseille, Louvain, Paris and Princeton, teaching posts in schools and universities, and jobs in banking and software engineering.

All PGR students are given a desktop computer and shared office space within the Department to encourage close contact with each other and with staff. They are encouraged to use the staff common room to contribute to the Departmental research culture. Students are assigned a primary supervisor in their main research area and a second supervisor whose role varies within a spectrum that includes expertise in the subject of the thesis and pastoral support, depending on the needs of the student, the need for new academic staff to be mentored in research supervision, and Departmental practice in monitoring. For example, inexperienced primary supervisors are often paired with an experienced second supervisor, and vice versa.

Internal academic training for PhD students is provided through regular **research seminars** given by internal and prominent external speakers, at regular Research Group meetings, and through giving research presentations (poster in year 2, talk in year 3) to all students and staff at an annual Faculty event. Students have the opportunity to participate in an annual University-wide PGR Conference, which incorporates the local competition for the national Vitae 3MT event.

The Faculty provides further **research training and skills development** in a compulsory first year 20-credit generic postgraduate skills module, which includes courses on LaTeX and reading, writing and presentation skills for research. *Kenobi* and at least one other member of maths staff (currently *Peck*) contribute to the teaching on this module. All PhD students also receive centrally-provided research training, with modules ranging from public engagement to grant development workshops, and a compulsory module on responsible research, EDI, ethics and data management. An added benefit of the research training module provision is the networking with students from different disciplines.

Students are encouraged to attend workshops and conferences, and they are each entitled to a **bursary** of up to £1000 for conference travel, with preference given to events at which they are presenting. Of particular importance for their development have been summer/winter schools organised by us (particularly *Mishuris* and *Vellender*) and by our research collaborators. They have also benefitted from workshops at the Isaac Newton Institute, and smaller workshops in partner universities such as Bath, Liverpool, Manchester, Cardiff and Swansea. PhD students have won conference prizes (for example *Perkowska* at Euromech 2015), been nominated for best paper awards (for example *Peck* in *Phil. Mag.*), and had their published work highlighted by journals (most recently *Gorbushin* in *Phys. Rev. Letts.*).

Research students are offered the opportunity to contribute to teaching, for example by delivering problem classes / tutorials and demonstrating in computer programming classes. For those with a strong commitment to teaching, the University's Teaching for Postgraduates at Aberystwyth University (TPAU) course leads to Associate Fellowship of the Higher Education Academy (e.g. *Roberts* in 2019). Research students gain experience in conference organisation by assisting with the conferences organised by staff.

Research progress is monitored annually, and satisfactory progress after one year is a necessary pre-requisite to move from the MPhil to the PhD programme. The monitoring takes the form of brief reports from the student and both supervisors and a substantial research report from the student, confirming that progress is being made and that the future direction of the project is clear and understood by the student. This is assessed by the Departmental Director of Research, the student's second supervisor, and a board of academic staff from the Faculty.

Equality, Diversity and Inclusion

The Department is a supporter of the LMS Good Practice Scheme for equality, and the University was awarded an Athena Swan Bronze award in 2014. *Kenobi*, the Department's **Equality Champion**, is part of the team preparing the University's next Athena Swan submission. Our commitment to Equality, Diversity and Inclusion (EDI) issues is recognised by Aberystwyth University's Disability Confident Employer accreditation and inclusion in Stonewall's Top 100 UK Employers for a LGBT+ friendly workplace. All staff are required to have completed Equality and Diversity Training and a number of networks promote equality issues and provide support for researchers, including the Women in Research Network, BAME Network and LGBT Network. *Kenobi* also contributed to the University's Strategic Equality Plan 2020-2024, liaising with the Diversity and Inclusion Manager in Human Resources. He also oversees a series of events for Mental Health awareness week each year, as well as helping to set up the University's Disability and Wellbeing Network. The Department has adopted policies and practices to facilitate inclusive engagement, for example scheduling meetings between 9.30am and 3pm in order to provide flexibility for those with childcare responsibilities.

Principles of equality and inclusion 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 has also included an independent member 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.

Diversity is high within the Department: 30% of permanent full-time T&R staff were awarded their first degree outside the UK and over 80% of PDRAs/research fellows have overseas research experience. In addition, 20% of PDRAs/research fellows and 17% of PhD students are female.

The University operates **bilingually** in English and Welsh, and staff are welcome to contribute in either language. This broadens the outlook of the Department and brings new initiatives: staff organise an annual science conference in Aberystwyth for Welsh-speakers, and we have initiated a Welsh-medium session at the annual Gregynog Mathematics Colloquium, while *Davies* published the first Mathematics paper in the Welsh-language research journal *Gwerddon* (and prepared the journal's LaTeX template).

Section 3: Income, infrastructure and facilities**Income**

Research in the Department is supported by external grant income, including participation in large collaborative projects with partners elsewhere in the UK and internationally, and increasing research grant capture is a key ongoing objective of our Research Strategy. In the assessment period, the total research income is £3.04M plus £4.2M income-in-kind, compared to £1.67M in REF 2014. This represents an average research income of £435k per annum from various sources (excluding income-in-kind), a 30% increase compared to the average research income of £334k per annum in REF 2014. The research income per FTE is over £36k per annum, an increase of 16% per FTE compared to the annualised income per FTE for REF 2014.

EU funding from FP7 and Horizon 2020 awards has been an important contributor to our research income, especially at the start of the assessment period. Funded projects have included:

- Matrixassay (2015-2019): £217k from H2020 for work on biomechanics, particularly in indentation testing of cartilage for diagnosis of arthritis;
- PARM-2 (2012-2015): £503k from FP7 to use parametric resonance to increase the efficiency of minerals processing;
- TAMER (2014-2018): £119k from FP7 to analyse the properties of composite materials with complex microstructure;

- CERMAT2 (2013-2017): £424k from FP7 to model the design of ceramic materials.

In addition, European funding has supported the ECHOES project (£822k for all Aberystwyth investigators, including £27k for *Kenobi*, through INTERREG) for modelling the effects of climate change with an emphasis on the effects of changes in land use on declining bird species; and the Soft Matter Dynamics project (£42k from the European Space Agency) to exploit microgravity to improve predictive modelling of foam evolution.

In response to uncertainty over the continuation of access to European research funds after Brexit, we have more recently strategically targeted UK funding and have increased income from UKRI grants. For example, the balance between UKRI and EU income has shifted from £10k vs. £508k in 2013-2014, to £104k vs. £267k in 2016-2017, to £145k vs. £250k in 2018-2019.

The Department's **UKRI funding** has included research on quantum information (*Burgarth*, £96k in 2015, £277k in 2019) and the flow of soft matter (*Cox*, £255k, 2016-19). Research funding for QStIC has also included support for students working with *Burgarth* through the Imperial CDT in Controlled Quantum Dynamics.

Recent funding for research on foams also came via the GCRF for work in protein recycling from tofu production (£4.4k). *Cox* is part of the modelling team for microgravity foam experiments that were performed on the International Space Station in 2020, contributing £4.2M to the Department's in-kind income. The University Research Fund supported *Mughal's* instigation of an international conference series on Packing Problems.

We encourage **fellowship** applications, offering scholarships for PhD students to work with staff who are successful in EPSRC proposals. *Mishuris* was awarded a Wolfson Research Merit Award in 2016 and a Sêr Cymru Industrial Fellowship in 2020 with *Dutko*. *Musolino* (2017-2019) and *McNulty* (2018-2020) received Sêr Cymru COFUND Fellowships, co-funded by the Welsh Government and the EU's Horizon 2020 programme, and *Dalla Riva* was awarded a Marie Curie Skłodowska Incoming Fellowship (FAANon) in 2015.

Industry funding came from BTG for a PhD student to work on varicose vein sclerotherapy with *Cox*. This, and *Mishuris'* HYDROFRAC project (for which EU funding ended in 2014, but which benefited from further internal funding to generate greater impact), are the culmination of a concerted effort to develop **applications of our research** (see Section 4)

Strategies for identifying research opportunities, developing applications, and generating grant income involve support at both a Departmental level, using the expertise of senior staff, and at a University level, through Aberystwyth's Department of Research Business and Innovation (RBI). The latter offers resources including an internal library of successful grant applications, facilitation of strategic bids for large research grants, and interaction with UKRI/EPSRC and UKRO.

All research proposals are peer-reviewed by a senior member of the Department, as well as a Research Support Officer in RBI. Mentors, selected from among the senior staff in the Department, also advise Early Career Researchers on grant application processes, the funding landscape, and internal University procedures, particularly during the probationary period.

Infrastructure and facilities

Research in the Department is supported by access to excellent research facilities and equipment, with investment in upgrades received during the assessment period. Staff and students undertaking numerical computing have powerful desktop computers and ample storage provided by the Faculty. This is supplemented by universal access to Supercomputing Wales, the second generation of Welsh **high-performance computing**, a £16 million investment in high performance computing infrastructure, training and support at Aberystwyth, Bangor, Cardiff and Swansea universities by the European Regional Development Fund and Welsh Government, which replaced the first generation HPC Wales project in 2018.

Experimental research on complex fluids, granular materials and foams is based in the Soft Matter Laboratory, which is a joint facility with the Physics Department that has evolved from the Mathematics Department's Rheology Laboratory. Equipment includes a rotational rheometer, replaced in 2020 with a TA HR30 instrument (through £60k of investment from HEFCW capital funding), allowing characterisation of a wide range of complex fluids and soft solids, and a Vision Research Phantom V7.3 colour high speed camera, allowing features such as bubble bursting and other transient effects in soft matter to be visualised. The laboratory is supported by a mechanical workshop and an electronics workshop.

Research is well supported by the **Physical Sciences Library**, with specialised texts and journals (including online access) for Mathematics, Physics and Computer Science co-located with staff offices. The Department hosts the **Scott Blair Collection** of books and papers on rheology, on behalf of the British Society of Rheology and with the support of library staff. This houses almost 600 books on rheology, conference proceedings and journals, and research articles, some of them annotated by Scott Blair, providing a rich resource for the University and the Society, particularly those with an interest in the history of the subject. We also enjoy access to the National Library of Wales, a copyright-deposit library located adjacent to the University campus.

In addition to the centralised RBI team, described in the Institutional Environment Statement REF5a, administrative support for research is shared across the Faculty. This team provides support for grant applications, grant maintenance, and research monitoring of staff and students.

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

Collaboration

The Department has an ethos of outward-looking collaborative work, with colleagues in other subject areas in Aberystwyth University, with industrial partners in Wales, the UK and Europe, and with scientific collaborators across the globe. Projects funded by Horizon 2020, UKRI and other sources have stimulated joint research and publications with colleagues in more than 25 countries worldwide, with 79% (according to SciVal) of the Department's research outputs including an overseas co-author.

International collaborations include work by members of the MMSSF Group with researchers at Trinity College Dublin (Ireland), Paris Diderot (France) and Murdoch University (Australia) for soft matter, and in TU Berlin (Germany), Trento, Modena e Reggio Emilia (Italy), Tel Aviv (Israel), NTNU Trondheim (Norway), Paris Sciences et Lettres (France) and Tufts (US) for solid mechanics; and by the QStIC Group with colleagues in Cork (Ireland), Darmstadt (Germany), Turku (Finland), Bombay (India), Macquarie (Australia) and Hanyang (South Korea).

Exemplars include *Mishuris'* coordination of an EU-funded IAPP partnership (PARM-2) and an IRSES exchange scheme (TAMER) with institutions across Europe, and his leading roles in an ITN doctoral training project (CERMAT2) and a RISE staff exchange project (MatrixAssay). Staff working on foams are supporters of a biennial European conference on the subject, which was held "virtually" in Aberystwyth in 2020; this network is the basis for *Cox's* involvement in the "Soft Matter Dynamics" European Space Agency project. *Burgarth's* QuantERA project included researchers from many European countries and the INTERREG-funded ECHOES project involves academics at Aberystwyth and Cork as well as non-academic partners.

The sustainability of the Department's international collaborations is supported by networking activity. Our international outlook is sustained by **sabbaticals** to overseas institutions; these include visiting researcher positions at TU Darmstadt (*Gohm*), Université Paris Diderot (*Cox*), and the Italian universities of Trento, Modena and Emilia Reggio, and Cagliari (*Mishuris*) and Skoltech, Moscow (*Mishuris*). *Mishuris* has given presentations about the Department to university officials, students and school pupils in Poland and Abu-Dhabi. Conversely, we welcome visitors to Aberystwyth for extended periods of time, many of them funded by our

collaborative grants (for example PhD students from St. Petersburg and Padova) and others from external sources such as the Royal Society (e.g. Vrid (Kiev), a collaboration which supported the impact of *Mishuris*' fracking research in the Ukraine).

Impactful work with **industry** includes *Mishuris*'s hydraulic fracture codes, which have been taken up by SINTEF in Norway and Rockfield in Swansea (the latter as part of a Sêr Cymru Industrial Fellowship with *Dutko*), among others, providing one of our impact case studies. *Mishuris* has also provided consultancy work for SINTEF (Norway) and *Cox* has worked with the biomedical company BTG on the use of foams for medical treatments. Partners on the ECHOES project include Compass Bioinformatics in Ireland and a GIS and remote sensing consultancy in Wales, as well as conservationists in Wales and Ireland. This latter collaboration builds on *Kenobi*'s close work with the New Quay Seawatch Foundation on marine mammal sightings, which now involves a self-funded PhD student.

Internally, researchers in the Department frequently work with each other: all but one of the permanent research staff in the Department have co-authored publications with a colleague during the assessment period. Researchers in the QStIC Group work closely with staff in the Physics Department (for example *Gohm* has published with *Gough* on quantum control), with whom they organise joint seminars and group meetings. *Kenobi*'s statistical expertise is much in demand from the university's biological scientists, resulting in several joint papers, joint supervision of PhD students in bioinformatics, and leading the statistics work package of the ECHOES project on climate change. Following the creation of the FBaPS in 2018, opportunities for expanding interdisciplinary research collaborations have been explored through research 'speed dating' and sandpit events organised by the Faculty.

Contributions to the Discipline and Research Base

Members of the Department make significant contributions to the vitality and sustainability of the research base in Mathematical Sciences through participation in learned societies, leading roles in conferences, and editorial roles with scientific journals. The research contribution of staff and their standing in the discipline has been recognised in **awards**, including the Royal Society's Wolfson Research Merit Award to *Mishuris*, and the Eilir Hedd Morgan Memorial Prize from the Coleg Cymraeg Cenedlaethol to *Davies*.

Members of the Department are active in **Learned Societies**. *Cox* was Honorary Secretary of the British Society of Rheology (BSR) (until 2016) and is now the BSR President-elect (2020-2024). *Cox* and *Mishuris* are fellows of the Learned Society of Wales and *Mishuris* sits on the scrutiny committee (2018-2022) for the election of new fellows in Mathematics and Computer Science.

Cox and *Mishuris* are on the editorial boards of high-profile international **journals** (*Cox*: J. Eng. Math; and *Mishuris*: Proc. Roy. Soc., Intl. J. Eng. Sci., Math. Mech. Solids), and all staff act as reviewers for journals. *Cox* and *Mishuris* also serve on grant awarding panels in the UK (EPSRC) and overseas (Italy, Poland, Germany, Israel, Portugal), and as external advisors for both UK and overseas institutions (e.g. *Mishuris* at Skoltech, Moscow). *Mishuris* has edited Special Issues of Phil. Trans. Royal. Soc., Proc. Royal Soc., Acta Mechanica, Geotechnics and Computers.

We have also contributed to the mathematics community by **organising conferences and training events for PhD students**, bringing together mathematicians and scientists with a broad range of specialisms. *Mughal* organises a series of conferences on Packing Problems (Erlangen 2014, Shanghai 2016, Yale in 2019) and staff have organised two meetings at the Isaac Newton Institute (Weiner Hopf Techniques (WHT), *Mishuris*, 2019 and Foams and Minimal Surfaces (FMS), *Cox*, 2014). Foam researchers (*Cox*, *Davies*, *Mughal*) hosted Eufoam2020 in Aberystwyth and the INNFM Spring Meeting on Structured Fluids in north Wales in 2015. *Mishuris* has organised many workshops, including events in Portugal (on Wiener Hopf techniques), Italy (on dynamic fracture), Poland (on hydraulic fracture), and St Petersburg (on advanced mechanics). In 2020 our emphasis switched to online events, such as the

EUFoam2020 conference, and also a Mathematical Physics - Physical Mathematics seminar series (*Evans, Gohm*).

Mishuris and *Cox* have organised and contributed to schools for PhD students and early career researchers on Micromechanics, Poland and Italy (2015), Ceramic Materials, Italy (2016), and Foam Mechanics, Indonesia (2019). Staff have acted as external examiner for PhD theses in four countries as well as the UK.

Staff from the Department have been invited to speak at numerous **conferences and workshops** during the census period. Examples include the International Symposium on Applied Rheology (South Korea, *Cox*, 2016), Analysis in Quantum Information Theory (Institut Henri Poincaré, Paris, *Gohm*, 2017), Three days in Quantum Mechanics (Genova, *Kiukas*, 2018) and Fracture in solid mechanics: mathematical and physical aspects (Sorbonne Université, Paris, *Mishuris*, 2019). Staff have also participated in programmes at the Isaac Newton Institute (OAS-*Gohm*; WHT-*Mishuris*, *Peck* and *Vellender*; CAT-*Mishuris*; SIP-*Mishuris*; FMS-*Davies*, *Cox* and *Mughal*), the ICMS (*Cox*) and BIRS (*Mishuris*).

Contributions to Economy and Society

The Department is committed to enhancing the application and impact of its research, as well as to contributing to public understanding of mathematics through public engagement and outreach activities.

For example, *Mishuris*' HYDROFRAC project has stimulated **impact in the oil industry**, where the research is improving the accuracy of predictions of the path of a moving crack. The Norwegian research organisation SINTEF, the Russian oil company Gazprom Neft, and the SME Rockfield, based in South Wales, are all implementing the analytic framework to accurately track the tip of a fracture (derived in the project) in their simulation codes; this research forms one of our impact case studies.

Our expertise in modelling the flow of non-Newtonian fluids has led to *Cox*'s collaboration with BTG to characterise the delivery and to assess the efficiency of their foam-based varicose vein treatment. This treatment is a less-invasive, less-costly alternative to treatments for this painful condition such as laser ablation, but required a new mathematical model of foam flow in veins to determine the optimal parameter space in which to operate.

Contributions to society including *Kenobi*'s collaboration with conservationists and the contribution of his work to marine mammal conservation in Cardigan Bay and the Irish Sea, as well as participation by *Mishuris* in a British Council **policy-making** event on Energy Security, bringing together views from Russia, the Ukraine and the EU (2014). Three PDRAs/research fellows, *McNulty*, *Musolino* and *Pitchford*, and a PhD student have represented the Department at Parliament via the STEM for Britain competition (2016, 2018, 2019).

Public engagement and outreach activities to enhance public understanding of science have included talks and demonstrations in schools, science festivals and eisteddfods, notably activities created by *Davies* and *Cox* on foams and optimisation. This effort to relate intuition about familiar objects (bubbles) to mathematical ideas, drawing praise from teachers and national organisations in Wales, and inspiring an interest in Mathematics for children in particular, forms the second of our impact case studies.

We are also using our expertise to contribute to debates around new and developing technologies. For example, *Gohm*, *Pitchford* and *Kiukas* are able to explain their research and its possible implications for society in the context of quantum computing, which formed the basis of a webinar for A-level students. In addition, *Cox* has written for The Conversation on water waves, now translated into Spanish and Japanese, and recorded a video on the geometry of the new pound coin with over 2000 views on YouTube.