Unit-level environment template (REF5b)

Institution: University of Bath

Unit of Assessment: UoA10: Mathematical Sciences

Section 1. Unit context and structure, research and impact strategy

The Department of Mathematical Sciences, which coincides with this Unit of Assessment (UoA), is strongly research-driven, evidenced by the volume, quality, and impact of its outputs. Research is internationally competitive both in mathematics (pure and applied, including probability and statistics), and in inter-disciplinary and industrial collaborations with real-world impact. The UoA has gone through a period of substantial growth over this REF period to meet its ambition of being one of the leading Mathematics Departments in the UK.

Highlights during this REF period include:

- **An increase in research active staff**: 64.9 FTE are being returned for this exercise, with an additional eight positions filled or advertised after the census date. This is compared to 45 FTE returned / 57 eligible in 2014 (section 2);
- **A substantial increase in research grant income**: during this REF period the Unit secured £13.5M, compared to £5M in the REF 2014 period (section 3);
- **The establishment of the EPSRC-funded single-site CDT "Statistical Applied Mathematics at Bath"**: SAMBa was first funded in 2014 and renewed in 2019. It has driven a growth in PhD student numbers to around 120. Additional investment from the University and industry takes the total commitment to SAMBa to £17M to date (section 2);
- **Creation of the Institute for Mathematical Innovation (IMI)**: in 2015 the University made a £3M investment in the future of the Unit by creating IMI to catalyse inter-disciplinary and industrial research collaborations with Mathematical Sciences and to enhance Knowledge Exchange (section 3);
- **Awarding of the LMS Symposia to Bath**: the first events of the newly designed format were successfully delivered in 2020, since its move from Durham (section 4).

In 2014, the University made a strategic decision to expand the Unit by 10 FTE. Filling these positions led to new research directions (for example number theory and compressed sensing) as well as growth of existing strengths (analysis, probability). An additional four FTE were hired by the Unit through the University's Prize Fellowship Scheme, which attracts exceptional early-career researchers from all disciplines (section 2).

A particular highlight was the Royal Society Research Professorship for del Pino, awarded upon arrival in Bath. These professorships are the Society's "premier research awards, which provide long term support to world-class researchers of outstanding achievement and promise''. Other drivers for growth in grant income were Haskins' and Nordström's involvement in the Simons Collaboration "Special Holonomy in Geometry, Analysis and Physics" and a substantial success in securing fellowships: members of the Unit secured 18

competitive fellowships from the Royal Society, EPSRC, NERC, and the Leverhulme Trust during the REF period.

This has been achieved whilst delivering excellence in equality, diversity and inclusion (ED&I). In 2019 the UoA received an Athena Swan Silver award, recognising success in moving towards gender equality. In 2018, the Unit was awarded £533K through the EPSRC Inclusion Matters Scheme (for the "Reimagining Recruitment" programme), which builds on best practice developed in the UoA with the aim of embedding more inclusive research in UK STEM (section 2).

The Unit's response to the COVID-19 pandemic has been effective, both in terms of staff and student support, research activity, and public engagement (section 4).

REVIEW OF THE 2014 PLANS AND OBJECTIVES FOR THE NEXT FIVE YEARS

Our 2014 submission states:

[W]e will firstly vigorously pursue our core activity, of advancing knowledge at the highest international level, within a unified vision of mathematics. […] Key strategic objectives for appointments in the immediate future are: (1) strengthening the analysis group, building on the appointment of Dooley, and (2) enhancing our activities at the interface of Statistics and Applied Mathematics. Key industrial collaborations such as with the Met Office and with Pharma companies will be continued and strengthened. We will propose and pursue the formation of a University Research Institute centred in Mathematical Sciences, which will promote inter-disciplinary collaboration, and enhance our external profile and industrial linkage. As a part of this project, we will further develop our industrial internship scheme, providing more industrial training for PhD students.

(1) has been achieved with three new Chair appointments in the Analysis group (Dávila, del Pino, Musso), creating a world-class group working on non-linear PDEs, and two appointments at lecturer level (Scardia, Wheeler). Links between Analysis and Probability have been strengthened by the appointment of Weber.

(2) has been more than fulfilled with the creation of the EPSRC Centre for Doctoral Training in Statistical Applied Mathematics (SAMBa) and a string of appointments in this area (e.g., Bartlett, Dolgov, Gazzola, Heine, Nunes, Peixoto, Poon, Pryer, Rohrbeck, Roy, Smith, Trinh, Yates).

Industrially driven research has been strengthened with the creation of IMI and SAMBa. Specific collaborations with the Met Office and with Pharma companies (Novartis, Roche) have continued successfully, as illustrated in Müller's and Jennison's Impact Case Studies.

Future Strategy: The research strategy for the next five years is focussed on leveraging the strong gains made recently. The Unit has undergone a demographic shift towards early- and mid-career academics and the primary aim is to support their career development in research while also aiming for a gradual increase in permanent staff in a few broad strategic priority areas.

The objectives for this future growth are to expand Mathematical Data Science and Statistics, Number Theory, and Analysis, particularly with links to Geometry and Probability.

Research quality will drive the appointment of new or replacement staff. The University is already committing to sustaining Unit excellence. Two new staff have been appointed since the census date and six positions are expected to be recruited in 2020-21 to replace retiring and departing staff. Further expansion posts will be sought through successful bids for University funded Prize Fellows, and mentoring applications to funding agencies for external fellows to join Bath.

The Unit's growing status as a leading centre of excellence in the UK will also encompass:

- Successful hosting of the LMS Symposia, in collaboration with INI and ICMS, enhancing the UK research landscape;
- Leading and partnering in a greater number of programme and other large grants, e.g., in Analysis, Probability or Data Science;
- Increasing funding for applied research, both directly from industry and through organisations such as InnovateUK;
- Supporting a growing community of PDRAs by launching a Post-Doctoral Researcher Centre;
- Strengthening and expanding international links, particularly with Latin America;
- Ensuring high PhD student numbers through continued evolution of core UKRI doctoral funding, and support from other sources.

Engagement with inter-disciplinary research will be strengthened, led by IMI and SAMBa, while the UoA continues to serve as a beacon for ED&I in Mathematics, including an ambition for Athena SWAN Gold and increasing diversity in all its forms.

UNIT STRUCTURE

The UoA has a comprehensive committee structure within the Department of Mathematical Sciences, both to support operational decisions and to shape its strategy in an informed and inclusive way. The main committees relevant to the UOA are:

- Research Committee (chaired by the Director of Research, currently Weber);
- Promotions Committee (Deputy Head of Department, currently Traustason);
- Equality and Diversity Committee (Roberts).

All committee members and chairs have an initial appointment of three years, and the composition of committees includes early career staff and those from underrepresented groups.

The Research Committee is formed by representatives from each research group, University Research and Innovation Services, IMI, and SAMBa. This committee is responsible for overarching research strategy with input into longer term hiring strategy.

The Department Executive (chaired by the Head of Department, currently Milewski) consists of the chairs of the committees listed above, the Director of Teaching and two Heads of

Group for Pure and Applied Mathematics, and Statistics and Probability, who oversee operational aspects of the Department.

Research in the UoA ranges from pure to applied mathematics and includes statistics. The UoA is organised in six interlinked research groups of comparable size: Algebra, Geometry and Number Theory (AGeNT), Analysis, Applied and Inter-disciplinary Mathematics (AIMS), Numerical Analysis and Scientific Computing, Probability, and Statistics. Every group runs a weekly research seminar series, oversees allocation of mentors for early-career staff (see below), and coordinates grant applications.

Interaction between groups is frequent and many members of the UoA are affiliated to one outside of their "home" group. Interaction with other UoAs is facilitated by five University Research Centres led by the UoA: the Centre for Mathematical Biology, the Centre for Networks and Collective Behaviour, the Centre for Nonlinear Mechanics, the Probability Laboratory (Prob-L@B) and, since 2019, the Centre for Mathematics and Algorithms of Data. These centres organise their own seminars and visitor programmes and foster collaboration, for example through joint PhD supervision.

Algebra, Geometry and Number Theory (AGeNT): Research covers a wide range of topics with well-defined specialisms, especially in algebra where the focus is on cluster algebras and on Engel groups. Geometry includes discrete differential geometry, differential geometry of special types such as Einstein manifolds, G2 manifolds and Fano manifolds, moduli spaces of algebraic varieties, and quiver varieties and McKay correspondence. Number theory is centred on questions about rational points on varieties, on the borders of algebraic and analytic number theory, and on modular forms and their geometric interpretation. Many of these areas are interlinked.

During the review period the group was joined by Professor Haskins (who has since moved to a position at Duke University, retaining a 0.2 FTE appointment at Bath), and more recently by Loughran, whose appointment represents a move to establish research activity in number theory, and will enhance links to the Heilbronn Institute.

The group has strong international collaborations including Haskins' and Nordström's involvement in the Simons Collaboration "Special Holonomy in Geometry, Analysis and Physics".

The group is contributing 28 papers to the REF submission.

Professor (P): Burstall, Calderbank, Haskins, King, Sankaran, Traustason; Reader (R): Craw, Nordström; Senior Lecturer (SL): Su; Lecturer (L): Loughran

Analysis: Research specialisms include nonlinear elliptic and parabolic partial differential equations, harmonic analysis, multi-scale analysis, variational problems, infinite-dimensional dynamical systems, operator theory, control theory and mathematical fluid mechanics.

During the REF period, the group has strengthened its traditional areas and built up internationally leading research activity in nonlinear PDEs and calculus of variations by appointing Professors Musso, del Pino and Dávila as well as Scardia (since moved to Heriot-Watt) and Wheeler. Links with AIMS were strengthened with Cherednichenko's appointment.

Following his directorship at the Newton Institute, Toland FRS FRSE returned to Bath as visiting professor.

A Royal Society Professorship was awarded to del Pino for his work on singularities; Cherednichenko held an EPSRC Early-career Fellowship; Dávila and Zimmer won Wolfson Merit Awards.

The group contributes 34 papers to the REF submission.

P: Dávila, Del Pino, Moser, Musso, Sivaloganathan, Zimmer; R: Cherednichenko; SL: Fischer, Matthies, Opmeer; L: Wheeler; Visiting P: Burton, Logemann, Ryan, Toland.

Applied and Inter-disciplinary Mathematics (AIMS): Research is of considerable breadth both in methods and applications. Activities fall into three main areas: Mathematical Biology, Networks and Dynamical Systems, and Nonlinear Mechanics. There is significant collaboration between these areas and between AIMS and other UoA groups, particularly Analysis, Probability, and Numerical Analysis and Scientific Computing, and outside the Unit with academia, government and industry. The hiring strategy in the period sustained the strength in mechanics (Trinh) and mathematical biology (Ashby, Buck), and established a strong focus on networks (Rogers, Peixoto, Pizzoferrato).

Research in *Mathematical Biology* has focus on evolutionary ecology, evolutionary genetics, developmental biology and epidemiology, molecular and DNA biology, signalling and biochemistry. *Networks and Dynamical Systems* research encompasses stochastic modelling, non-smooth dynamics and bifurcation theory, networks and aspects of data science. *Nonlinear Mechanics* research spans across fluid mechanics, solid mechanics and soft matter with particular strengths in wave theory. The group leads the University Centres for Mathematical Biology, Networks & Collective Behaviour and Nonlinear Mechanics.

AIMS has hosted fellowships from Rogers, Dawes (both Royal Society), Ashby (NERC), Majumdar (EPSRC), and a Leverhulme programme grant (Buck). It has achieved external recognition including prestigious awards: Lee Segal Prizes (2016, Rogers, and 2020, Yates), Erdös-Rényi Prize for Network Science (2019, Peixoto), LMS Anne Bennett Prize (Majumdar, 2015), JPBM Communications Award (2020, Budd).

The AIMS group contributes 26 papers and one Impact Case Study to the REF submission.

P: Buck, Budd, Dawes, Milewski, Rogers; R: Evans; SL: Adams, Ashby, Schwetlick, White, Yates; L: Peixoto, Pizzoferrato, Trinh; Visiting P: Majumdar.

Numerical Analysis and Scientific Computing: In this REF period the group's strategy has focussed on renewal and expansion, both to secure its traditional reputation in rigorous numerical analysis, with focus on differential equations and numerical linear algebra, as well as to substantially diversify into modern emerging areas. To implement this strategy, new appointments have been made to expand research in: (i) inverse problems and compressed sensing (Gazzola, Ehrhardt and Poon), (ii) high dimensional problems, uncertainty quantification and machine learning (Dolgov and Hook) and (iii) scientific and high-performance computing (Müller and Pryer). Long-standing strength in PDEs has also been enhanced by the recent appointments of Pryer (nonlinear PDEs and applications in

geophysics) and Singh (Schrödinger equations and applications in quantum mechanics). Strategic funding initiatives by the University through its Prize Fellowship Scheme (three-year positions leading to a lectureship) brought Hook, and Ehrhardt into the group. The group co-leads (with Computer Science) the University research centre for Mathematics and Algorithms for Data.

A special accolade is Oberwolfach's John Todd Award to E. Spence in 2019. Members of the group have been very successful in competitive EPSRC funding rounds, with fellowship awards to E. Spence and Dolgov (both EPSRC), and Ehrhardt (Leverhulme Trust). The group has been heavily involved in industrial liaisons leading to direct research funding from the Met Office, Schlumberger, and Wood plc.

The Numerical Analysis and Scientific Computing group contributes 21 papers and one Impact Case Studies to the REF submission.

P: Graham, Scheichl, E. Spence; R: Hill, Pryer, Shardlow, SL: Müller, L: Dolgov, Gazzola, Poon, Singh; Fellow: Ehrhardt, Visiting P: Freitag, A. Spence.

Probability: The Probability group coincides with a University Research Centre, Prob-L@B. Over the last REF period the strategy has been to maintain traditional strengths in pure and applied probability theory - e.g., branching structures, random graphs and networks, statistical mechanics, and percolation, while establishing new directions and links to neighbouring groups, e.g., stochastic analysis and stochastic modelling, simulation and numerical analysis.

This strategy is reflected in recent hiring: Professor Weber was recruited to establish stochastic partial differential equations as a new major research direction and to strengthen links to the Analysis group. Ortgiese (random networks, stochastic analysis) and Kious (statistical mechanics) were also hired in this REF period. Mailler (branching processes, combinatorics), successfully obtained a Prize Fellowship and then moved on to a permanent post. Penington (population genetics) was newly appointed on a Prize Fellowship.

Prob-L@B has established a track record in attracting outstanding young researchers on Prize Fellowships who subsequently obtained externally funded fellowships: in this REF period Stauffer secured an EPSRC Early-career Fellowship; Roberts already held an EPSRC Postdoctoral Fellowship and was subsequently awarded a Royal Society URF, and Mailler secured an EPSRC Postdoctoral Fellowship. At the established career level, Kyprianou secured a Wolfson Merit Award.

The probability group contributes 36 papers to the REF submission.

P: Kyprianou, Penrose, Weber; R: Cox, Roberts, Stauffer; SL: Jarai, Ortgiese; L: Kious, Mailler; Fellow: Penington; Visiting P: Mörters

Statistics: A distinctive feature of this Unit is the integration of activity in Statistics with Probability and Applied Mathematics. Main research areas are statistical modelling and data analysis; medical statistics; Bayesian methods; and statistical computing. The Statistics group has increased in size from 11 to 14 since REF2014. The strategy has been to appoint candidates who combine an ability to develop new theory and methods with a genuine interest in applications. Specifically, new appointments were made to bridge with numerical

analysis/MCMC (Heine) and with networks and graphical methods (Roy). In addition, medical statistics has been expanded (Bartlett, Anaya-Izquierdo, T. Smith).

The breadth of the research interests is reflected in the diverse sources of funding, including MRC (Bartlett), NERC (Prosdocimi fellowship), EPSRC (Lindgren), InnovateUK/Mayden House (T. Smith Knowledge Transfer Partnership). Consultancy leads to innovative research that addresses problems of interest to practitioners (Pharmaceutical companies AstraZeneca, Roche, Novartis, Sanofi, NovoNordisk, Takeda, Grifols, Beigene (Jennison, Bartlett), Tokio Millennium Re (Evangelou)).

The Statistics group contributes 17 papers and three Impact Case Studies to the REF submission.

P: Faraway, Jennison; R: Bartlett, Nunes; SL: Hurn; L: Anaya-Izquierdo, Evangelou, Heine, Rohrbeck, Roy, Shaw, T. Smith; Visiting L: Moraga; Visiting P: Shaddick.

Achieving Impact: The UoA has a tradition of including impact in its research agenda and has developed long-standing relationships with a wide range of industrial partners. Ongoing relationships of more than 10 years (including jointly delivered and funded research projects and PhD studentships) exist with Wood (Graham, Scheichl, Kyprianou, Cox), Schlumberger (Graham, E. Spence, Gazzola, Budd), BT (Budd, Jarai, Dawes), Met Office (Müller, Scheichl, Budd), Roche, Astra Zeneca (Jennison, Bartlett). This is reflected in the submitted Case Studies.

In this REF period, the Unit has developed infrastructure to ensure that, as the volume and reach of the research has grown, the impact has accelerated accordingly. The Unit has two dedicated Impact Champions (Budd and Jennison), who identify research with impact potential and work with individuals to develop and maximise it. SAMBa and IMI, major developments during the current REF period, facilitate development of the Unit's outward-facing research profile.

SAMBa (section 2) has given the Unit the opportunity to nurture a new generation of mathematicians, fluent in the inter-disciplinary fusion of stochastic, computational, applied, industrial, statistical and data rich mathematical modelling. In particular SAMBa's twice-yearly problem formulation workshops in collaboration with external partners, known as **Integrative Think Tanks (ITTs),** have proved to be a successful mechanism for academic staff and doctoral students to experience working on outward facing and inter-disciplinary mathematical projects.

IMI (section 3) has built relationships with a wide base of companies that have fed into other activities in the UoA, including partnering in ITTs, Knowledge Transfer Partnerships, and support for the MSc in Modern Applications of Mathematics. IMI also has strong links into other research areas in the University.

Open Access and Open Data: The University Library hosts an open access team which supports researchers in making their research available via open access. In 2011 this team published the Open Access Publications Deposit Mandate, emphasising a commitment to this publishing form and stating that a full text version should always be made available via PURE. The University expects researchers to comply with the principles laid out in the

Concordat on Open Research Data and the FAIR principles, and the library's data management service supports researchers in doing so. The use of github is promoted through training given to PhD students, and as a tool for sharing research and impact across the department.

Ethics: Members of staff are required to submit an ethics form for all research activity. This ensures that they reflect on ethical issues of research and that it is conducted to the highest standards of research integrity and ethics. Staff are encouraged to discuss with the Department's research ethics officer if they have research in which there may be particular ethical concerns (e.g., studies involving personal data) and the ethics officer is deliberately chosen to have experience with ethical implications of working with data. The need to consider the ethical implications of their work is highlighted to students, both undergraduate and postgraduate, before they conduct research projects.

Section 2: People

Attracting, motivating and retaining academics of the highest quality is the central aim of recruitment policy. As mentioned above, the Unit has grown substantially over the REF period. It has succeeded in attracting both high-calibre academics for senior roles and highly talented early-career researchers. Supporting the development of all staff is a priority. Leadership at all career stages is encouraged and rapid career progression is enabled when appropriate. The Researcher Development Concordat principle, which recognises that excellent research *requires a supportive and inclusive research culture,* is part of the Unit's outlook and underpins its approach to research and research management (further references to Concordat principles in italics below).

STAFF RECRUITMENT

The Departmental Executive Committee monitors the level of staffing and considerable thought goes into maintaining a healthy balance within and between disciplines, as well as appropriate levels of leadership in each research group.

The University approved support for expansion of academic staff numbers in this Unit by 10 between 2015 and 2018 in order to boost research activity, increase grant capture, and reduce the student-staff ratio.

The University's Prize Fellowship scheme recruits talented early-career researchers to two-year research-focused positions, with the expectation that recruits will assume permanent positions. Recruitment to a limited number of positions is run across the Faculty; the process runs across strategically important areas and the most exceptional applicants are appointed across the whole process regardless of their research discipline. Mathematical Sciences has recruited four fellows over the REF period and has retained three (as well as retaining the two appointed prior to this REF period).

Over the REF period there were 37 hires at L/SL/R level and six at Professor level.

Hires at L/SL/R during this REF period are Anaya-Izquierdo, Ashby, Bartlett, Cherednichenko[+], Dolgov, Ehrhardt~, Fischer, Gazzola, Guiver*, Heine, Hook*~, Kious, Loughran, Nordstrom[+], Nunes, Mailler~, Moraga, Müller[+], Ortgiese[+], Peixoto, Penington~, Prosdocimi*, Roberts~[+], Rogers~[+], Pizzoferrato, Poon, Pryer, Rohrbeck, Roy, Scardia[+]*, Simpson[+]*, Singh, T. Smith, Trinh, Wang*, Wheeler and Yates[+].

[*have now moved on, ~recruited as Prize Fellows, [+]since promoted].

The Unit has made exceptional appointments at Professorial level: Buck, Dávila, Haskins, Musso, del Pino, and Weber. Individuals were supported in making successful applications for a Royal Society Professorship (del Pino) and a Wolfson Merit award (Dávila). When exciting hiring opportunities arise, the University provides additional support, for example with the simultaneous appointment of Buck, del Pino, Haskins, and Musso when only two professorial positions had been advertised and the appointment of Weber (Rollo Davidson Prize 2016, Philip Leverhulme Prize 2017, Royal Society URF 2016-2020).

After Bath: During the REF period the following 18 staff left Bath to pursue their career elsewhere: Augustin (to University of Edinburgh), Di Francesco (Università degli Studi dell'Aquila), Dooley (University of Technology Sydney), Melina Freitag (Universität Potsdam), Guiver (Napier University), Harris (University of Auckland), Hilker (Universität Osnabrück), Hook (Jump Trading), Lindgren (University of Edinburgh), Majumdar (University of Strathclyde), Moraga (KAUST), Mörters (Universität zu Köln), Prosdocimi (Università Ca' Foscari di Venezia), Scardia (Heriot-Watt University), Shaddick (University of Exeter), Simpson (University of Toronto), Wang (Chinese Academy of Sciences), and Wood (University of Bristol). Staff often retain a visiting position in the Department once they leave, enabling them to complete PhD supervision and remain active in departmental activities.

Buck, Haskins, Peixoto, and Scheichl retained 0.2 FTE appointments concurrent to their appointments at Duke University (Buck and Haskins), the Central European University (Peixoto) and Ruprecht-Karls-Universität Heidelberg (Scheichl). These part-time appointments are based on substantial continuing PhD supervision or participation in ongoing research grants.

Britton, Burton, Galaktionov, Logemann, Ryan, A. Spence, and G. Smith retired.

Recruitment process: During the REF period the Unit has reviewed its recruitment and appointment procedures to ensure they are *transparent and merit-based, fair and inclusive*.

Job adverts are carefully worded to be maximally inclusive, and widely disseminated. All adverts have both a male and female point of enquiry listed. Hiring committees are expected to reach out to minority candidates via all available channels, and this is monitored by the Department's Equality and Diversity Committee. Large numbers of excellent applications are typical (e.g., advertisements for lecturer/senior lecturer routinely receive over 100 applicants).

Members of the Unit are actively engaged in the inclusive hiring procedure: the shortlisting panels are large, with early-career staff actively involved. The whole Department is invited to provide comments at the shortlisting stage and to attend interview talks and provide feedback to the interview panel afterwards. Interviewees are invited to visit for at least a full day; they

are assigned a local host who, in consultation with the candidate, arranges meetings with a range of staff members.

Succession planning: Leaving senior staff are replaced by growing existing staff into leadership roles and by directly hiring outstanding academics as professors, as evidenced above. The Unit places a particular emphasis on enabling career progression to build leadership profiles. For example, over the REF period both E. Spence and Rogers have been promoted from lecturer to professor.

PDRAs: Suitable PDRA candidates are competitively recruited with a process that includes an interview with a panel that reflects the diversity of the department.

STAFF DEVELOPMENT

Focus is on enhancing and strengthening the research profile of existing staff. *Excellent people management is championed and embedded in the department culture, through annual appraisals, transparent promotion criteria, and effective workload allocation*.

Welcome and Mentoring: All new staff are assigned a mentor who helps them integrate into the Department and the University. For probationary lecturers, mentors additionally provide support in University reviews and career development. PDRAs are allocated to research groups, and encouraged to participate in all departmental activities, such as seminar series and ITTs.

New academics are encouraged to develop their research by a variety of mechanisms. This includes zero teaching load for at least two years for Prize Fellows, two years of 50% teaching load for lecturers, plus light or no administrative duties. Tailored start-up packages for all appointments include travel and equipment costs and University-funded PhD studentships to commence within their first two years.

All staff are supported when preparing research grants or fellowship proposals. As well as general mentoring by the Director of Research, experienced members of research groups act as expert mentors helping early-career researchers with drafts and the understanding of the review process.

Research support: The Unit aims to allow staff as much uninterrupted research time as possible, and workload is monitored annually to ensure that this is achieved within the balance of teaching and administration commitments. A typical teaching load is two courses per year for staff without other significant duties (research or management). The Department has a mechanism to provide travel support for permanent members of staff.

Training: Probationary lecturers receive guidance during their three-year probation, which includes annual strategic discussions on research directions, research support and funding, informal peer feedback from teaching observations, participation in the Bath Course in Enhancing Academic Practice (a work-based course for lecturers and teaching fellows that enables participants to gain a teaching qualification and become fellows of the Higher Education Academy).

All staff including PDRAs are encouraged to participate in SAMBa's ITTs, many do: more than half of the members of the UoA have participated in at least one ITT. ITTs provide the opportunity to form collaborative research relationships with colleagues in the Unit and external partners. This is a valuable experience for all career stages, but particularly helps those early in their academic career grow their experience and reach.

Promotion: The Departmental promotion procedure has been redesigned completely in the last three years with the introduction of a Departmental Promotion Committee (DPC), involving representatives from all career stages. The DPC proactively identifies candidates through annual review of CVs rather than relying on self-nomination. The promotion pathways *recognise the full range of researchers' contributions* to the department (research, teaching, leadership). Candidates identified by DPC are supported through the promotion process, with mentoring from senior staff.

Sabbatical scheme: Members of the Unit have the opportunity to apply for a six-month sabbatical every three years. Individuals (including part-time) are encouraged by mentors and the Head of Department to consider applying when appropriate. Twelve members applied to the University's sabbatical scheme in the REF period and all applications were successful. In addition, the Department can arrange teaching flexibly to allow for semesters in which staff can focus on research without teaching obligations.

POSTGRADUATE ACTIVITY AND SUPPORT

The PhD student body is growing substantially with 92 awarded degrees in this REF period, compared to 63 in the previous period. 21 of the 92 were awarded within the last year and this upward trajectory is expected to continue. Currently there are around 120 PhD students as part of the department.

SAMBa: The EPSRC Centre for Doctoral Training in Statistical Applied Mathematics (SAMBa) fuses research in statistics, stochastics and computation in industrial and applied mathematics. The goal of the centre is to prepare PhD graduates to work in either industry or academia, in an environment which brings together big models and big data. So far, graduates from SAMBa are following careers in industry and academia in roughly equal numbers.

An important feature of SAMBa is providing PhD students with the ability to distil industrial and interdisciplinary problems into mathematical ones and solve them. This is delivered through Integrative Think Tanks (ITTs), pioneered by SAMBa. These week-long workshops focus on the formulation of mathematical questions arising from high-level challenges set by external partners and the development of the approach to be worked on by small teams of academics, partners and PhD students.

ITTs draw in partners and cement deep, long-term relationships through the co-creation and co-supervision of PhD projects. 27 PhD projects have been generated in this way (Airbus/N12, AVL, BT (3 projects), Department of Chemical Engineering, Diamond Light Source, DNV GL, Environment Agency (2), GKN (3), Met Office, NHS, NPL, Novartis, Roche (2), Schlumberger (3), Syngenta (2), Wood (3)) with others still in preparation. 18 are co-

funded by these companies (£720K). In reaction to the COVID-19 pandemic, ITT12 in collaboration with Novartis and Rolls-Royce was successfully delivered online.

SAMBa students work with academics during their first year to scope their own PhD research, which they then pursue in years two to four. This is often designed in collaboration with supervisors from other departments or industry partners, with approximately 40% of SAMBa students having a co-supervisor outside of the Unit.

Recruitment of doctoral research students: The Unit receives of the order of 130 PhD applications (~40% from outside of the UK) for roughly 25 PhD places each year. It attracts students from top UK and international institutions, and most are supported on fully funded studentships from the University (~34%) or UKRI (~55%). PhD students are supported by: SAMBa (~50%), the University as part of start-up packages for new members of staff or as support for large grants, EPSRC DTP, Royal Society, Leverhulme, EPSRC Case Awards, and foreign government scholarships. A number of PhDs (currently 8) receive matched funding from industry partners to deliver collaborative research. Some students (1-2 per year) self-fund.

Potential doctoral research students submit applications through a University application system. The recruitment process is managed by the Unit but overseen by the Doctoral College which has a Code of Practice for the recruitment, selection and admission of students. All applicants are assessed on their academic achievement, their understanding of the research, and their self-motivation. Excellence is the primary criterion. Diversity (across all protected characteristics) in the PhD cohort is valued as a more diverse cohort leads to more creativity and a better environment.

Monitoring and support: To nurture a supportive and non-hierarchical environment, a dedicated Director of Studies oversees the PhD student body and supports administrative processes, as well as delivering pastoral care. There is a tailored induction programme (including specialist software training delivered by existing PhD students), and there is information on progression, skills training, suspension (for health, parental leave, internships), mental health resources, careers advice etc. on a dedicated Moodle page.

A review and monitoring system is in place to identify potential problems early on and provide support to students and supervisors. Students submit six-monthly progress reports and must perform satisfactorily in a confirmation examination part way through their programme.

PhD researchers who need to suspend for ill-health or personal reasons maintain contact with supervisors, the DoS, and/or the SAMBa team and, upon return, have the support they need, including the option to work part-time.

The University runs a range of specialist support departments, including a public engagement unit, library services, high performance computing, and careers support which includes 1:1 support sessions.

PhD training and skills development: There are many advanced level courses available, including those offered by the EPSRC-funded Taught Course Centre, shared between Bath,

Bristol, Imperial, Oxford and Warwick, and through enrolment on the Academy for PhD Training in Statistics. The department offers around 20-25 “reading courses” each year.

Students are strongly encouraged to participate in research seminars and the numerous scientific events organised by the Unit (see section 4). Several of the events held during the REF period were aimed specifically at early-career researchers, for example the conference GAeL (Géométrie Algébrique en Liberté) 2017, the Summer School on Probabilistic and Statistical Methods for Networks 2017 (joint between SAMBa, the Berlin Mathematical School and WIAS, and held in Berlin), or the LMS Probability Research School in 2019.

During training which leads to an MRes in their first year, SAMBa students choose their supervisors, and write a thesis formulation report to set the context and scope of their intended PhD research. Part of the training is participation in ITTs, to which all departmental PhD students are invited.

The Doctoral College offers training courses in fundamental skills (presentation, entrepreneurship, writing papers, managing data, etc.) which are available to all PhD students, including visitors. The Unit offers training, delivered by the academic faculty and other PhD researchers, for example in parallel computing (SAMBa researchers have dedicated access to the University’s HPC) and modern software development practices, writing maths, using github, and introducing programming languages (R, Matlab, Python).

Student-led activities: The PhD cohort has a strong sense of collective identity. They support each other in research, in developing skills in organising conferences, seminars, workshops, away days, and social activities, as well as on a personal level. There is an active SIAM-IMA Chapter and student organisers (Green, Robinson, Pembery, Sabaté Landman) have won Certificates of Recognition from SIAM over the last three years for their contribution to the chapter activities. All these activities have continued during the COVID-19 pandemic, successfully moving to online delivery.

Secondments: Many PhD researchers take up placements or internships with industry, funded by the host. Companies who have hosted students in the last two years include BT, HSBC, Mango Solutions, G-Research, Cytel, Roche, Mediatek, and Cummins Turbo. There is also the opportunity to spend time in academic institutions (including MIT (US), National Informatics Institute (Tokyo), the Alan Turing Institute (UK), Emory (US), Bonn (Germany)), usually with additional costs shared between the Unit and the host. Communication with supervisory teams is maintained throughout the time the student is away.

COMMITMENT TO EQUALITY AND DIVERSITY

The Unit is a vibrant and diverse community of academics, PDRAs and PhD students, with more than twenty-five nationalities. Since the previous REF exercise, it has invested considerable effort in the promotion of equality, diversity and inclusion (ED&I), with very positive results. The Unit has shown substantial increases in the number of female staff and PhD students, and progress towards gender equality was recognised by the award of Athena SWAN bronze in 2016 and silver in 2019. The department is regularly highlighted by staff and

PhD students as being a supportive place to work. In the 2018 staff survey, 94% of staff agreed with the statement “my department has a positive working culture”.

Based on the success of the ITT model, and the observation that they promote an open and inclusive environment for diverse participants, the Unit successfully led an application in collaboration with the Department of Psychology to EPSRC’s Inclusion Matters scheme resulting in the award of the “Reimagining Recruitment” grant (£533K) in 2018. The funding enables the department to run a highly ambitious research programme, which explores staff-student interactions in collaborative environments, and identifies lessons for recruitment and retention.

Departmental ED&I efforts are led by the Department Equality and Diversity Committee (DEDC), the membership of which includes staff at all levels, including PDRA and support staff, as well as PhD and undergraduate students. The Department is supported by the University-wide Equality and Diversity Network, which also serves as a route to dissemination of good practice (for example, the Code of Conduct for events developed by Maths in 2018 has been widely shared with other departments).

New hiring procedures and search committee guidance include a targeted search for excellent female candidates. Since 2014, 35% of new appointments have been female, and the number of female staff in the department has doubled from nine (13%) to 18 (21%). The first two female mathematicians were appointed as professor in the Unit in 2018. Grouping available positions and advertising them simultaneously has greatly increased the possibility of applicants with partner considerations.

Similar success has been achieved in diversifying PhD student intake. Promotional materials and interview processes have equality and inclusion in mind; applicants visit the department in groups and are invited to meet with a broad cross-section of staff and students. Evidence of the increasing diversity of the PhD student cohort is to be seen in the proportion of female students which, since 2014, has risen from 22%, to a steady state of around 30% above the national average of 28%. Meaningful data on other diverse characteristics is not available.

Both staff and PGR students returning after extended periods of leave receive individual support from line managers or supervisors. This may include reduced workloads for staff and, where appropriate, a phased return with hours increasing to an agreed level over a period of weeks or months. PDRAs and PhDs receive the same option of returning to their standard working pattern by building up workload over time.

The UoA had a transparent process in place to select outputs for the REF submission. Staff involved in the output selection undertook appropriate ED&I training to ensure they were mindful of unconscious bias. At the start of the exercise each member of the UoA was invited to propose up to seven pieces of published research and each was assessed independently by at least two referees within the UoA. Where it was deemed that there was not sufficient expertise within the UoA, external referees were consulted. As the exercise progressed, staff were periodically invited, to propose new submissions. The final selection reflects the diversity of the department; for example, 15% of the research outputs (24 of 162

submissions) and one of five (20%) Impact Case Studies were proposed by female members of staff (13.7% of staff submitted).

Section 3. Income infrastructure and facilities

GRANT INCOME

The Unit has significantly increased research funding during the REF 2021 assessment period to £13.5M compared to £5M in the REF 2014 period. The largest funders are EPSRC (£8.3M, 32 grants), and the Royal Society (£3M, 21 grants).

The Unit has secured a Royal Society Research Professorship (del Pino, £1.2M) and holds £1M of a Simons Collaboration "Special Holonomy in Geometry, Analysis and Physics" (Haskins and Nordström). The Unit has been particularly successful at winning fellowships; having secured eighteen fellowships during the period, which range from large awards for established staff, to support for postdoctoral visitors from overseas or industry. Six from the Royal Society (including University Research Fellowships for Roberts and Rogers), seven from EPSRC (Cherednichenko, Cooper, Stauffer, Dolgov, Karmazyn, Mailler and E. Spence), two from both NERC (Ashby and Prosdocimi) and the Leverhulme Trust (Ehrhardt and Constable), and one from the Heilbronn Institute (Aldrich). There has also been direct industry funding (£500K) for research including from Mayden House Ltd (InnovateUK Knowledge Transfer Partnership of £164K to T. Smith) and EDF (Wood, £100K).

RESEARCH INFRASTRUCTURE

Institute for Mathematical Innovation (IMI): IMI was established by the University in 2015 to deliver mathematically grounded research with links to real-world, societal and industrial challenges; it has been led by academics from the UoA since its establishment. The University makes a substantial annual investment (~£400K) in academic and administrative posts. The IMI was highlighted in the Bond Review as an example for good practice in knowledge exchange (see section 4).

The backbone of IMI activity is delivered by postdoctoral level researchers known as Mathematical Innovation Research Associates (MIRAs) (previously Commercial Research Associates). MIRAs are a key innovation for delivery of mathematical impact: a team dedicated to working on mathematics that enables impact in academic disciplines or the commercial sector (three full-time contracts). MIRAs provide an agile and flexible resource that meets a variety of application needs.

IMI provides a mechanism for Bath to provide consultancy in the mathematical sciences to companies (e.g., Airbus, PepsiCo), and support large grant applications from other departments (in e.g., dynamic engine modelling (Burke, funded by InnovateUK) and building energy design (Natarajan, funded by EPSRC)). It provides an entry point for further and longer-term strategic engagement with UK and overseas government policy (funding from Unicef, Carnegie Corporation).

In collaboration with the Department and SAMBa, IMI has managed a summer internships scheme for around 15 undergraduates per year. These stimulate research within the Unit and generate collaborations with other research groups. IMI Public Lectures (each over 100 attendees) have been given by Andrew Blake, Ottoline Leyser, and Tadashi Tokieda.

Looking towards the next REF period, IMI will also embed success of the SAMBa model, which has demonstrated the benefit of a broad training with access to industrial and applied research, and the Unit's established relationship with external partners to develop a *Centre for Post-Doctoral Training in Applied Mathematics*.

University Research Centre engagement: Members of the Unit actively collaborate with research institutes across the University, including:

- *The Institute for Advanced Automotive Propulsion (IAAPS)*, a £70M institute funded by the West of England Combined Authority, the West of England Local Enterprise Partnership, Research England, and the University of Bath. It delivers research, innovation, enterprise and education for the future automotive industry. Nunes, Milewski, and T. Smith have research collaborations with IAAPS through PhD research projects, and Budd is co-I on the CDT within the Institute.
- *The Institute for Policy Research (IPR)*, which conducts research which leads to influence on government policy and decision-making. Faraway, T. Smith, and Kyprianou have worked with IPR in exploring public health strategy in relation to air pollution in the UK and worldwide. To support this, IPR funded a three-month internship for a Maths PhD student, committed time (0.1 FTE over 12 months) of two research associates, the expertise of one professor (Barnett), and paid travel costs, to deliver capacity building activities in Mongolia. A relationship between Kyprianou and the UK Government's Cabinet Office was facilitated by IPR and supported by secondment funding.
- *The Milner Centre for Evolution*, a cross-faculty research centre bridging biology, health, and education with a mission to perform fundamental evolutionary research. It provides a focal point for the interaction between mathematical biologists from the Unit and experimental biologists. Over the REF period Buck and Ashby have been strongly involved in joint research with the centre, including supervision of PhD students and PDRAs.

Infrastructure provision and facilities: The Unit occupies two adjacent buildings in the centre of the University campus. There is a social space, some small kitchen areas, a meeting room, and an 80-seat lecture theatre. There is bookable University space based within the Maths buildings, including two more lecture rooms, and a large atrium for public events.
During the Covid-19 disruption, whilst delivering teaching and research activities in a socially distanced and safe environment, the Unit has been given sole use of the lecture rooms, along with priority access to the University's largest lecture theatre. Through SAMBa, a large space in the city centre has been booked two days a week, allowing staff and PhD students to meet safely in small research groups.

High performance computing (HPC): Throughout the REF period Bath ran its own High-Performance Cluster, "Balena". Balena has over 3500 CPU cores and several high-end GPU

nodes, from investments totalling over £1.8M. Balena was essential in delivering the research underlying Müller's impact case study. Researchers in the Unit have also made use of the Tier-2 regional supercomputer ISAMBARD, and the UK supercomputing service ARCHER.

Library: Academics and students in the Unit have full access to the library which has a collection of over 270,000 printed books, over 350,000 e-books (among them more than 46,000 printed and 11,000 e-books subject specific to Mathematics), more than 110,000 academic journals (1,300 subject specific), and more than 100 subscription electronic databases across all disciplines.

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

As a large department with an outward looking and successful research strategy, the Unit makes important contributions to the infrastructure, globalisation, impact, dissemination, and sustainability of the discipline. In additional to the natural collaborations that develop between individual researchers and groups, the Unit actively plans, supports and delivers sustained engagement with academic, industrial and government entities across all fields in the UK and overseas.

RESEARCH COLLABORATIONS AND NETWORKS

The Unit actively engages with academic and non-academic institutions in the UK and overseas. Highlights during this REF period include:

- Events at Bath: The LMS Symposia, previously held in Durham, were awarded to Bath and first events were held in 2020. The Unit has hosted several large international conferences including BAMC 2019.
- International collaborations: more than 60% of research papers published by members of the Unit (Scopus 2016-2020) had international co-authors. The Unit has hosted long term visitors of high calibre through the University's David Parkin and Global Chair programmes.
- Interdisciplinary and industry collaboration: Members of the UoA have co-authored 171 papers and co-supervised 19 PhD projects with researchers from other disciplines, and secured 26 inter-disciplinary grants. 18 SAMBa PhD projects were developed in collaboration with industry partners and government agencies and funded jointly.
- Global challenges: The UoA has built a large number of partnerships with the developing world with specific training components for local stakeholders to ensure sustainability of impact.

Bath-based research activities*:* Following an open call in 2018, the LMS awarded their series (formerly the Durham Symposia) to Bath as host. The Bath Symposia are structured in a newly designed format, with events over two or three weeks combining a traditional workshop or school format, with collaborative research events ("incubators"), or courses (summer schools) to integrate early-career researchers. The first Bath LMS Symposia ran in

2020. Due to the COVID-19 pandemic, the two symposia "*Mathematics of Machine Learning"* and "*PDEs and Randomness"* were delivered partially and online with high attendances (over 450 and 150 sustained participants, respectively). The 2021 Symposia, awarded after a competitive call, are in Algebraic Geometry and K-Theory.

In recent years, the Unit has hosted many large, international events, notably the International Conference on Scientific Computation and Differential Equations (SciCADE) in 2017 with approximately 350 participants, the 138th European Study Group with Industry in 2018 with approximately 100 participants, and BAMC 2019 with approximately 400 participants.

The Unit is instrumental in delivering broader research networks, including the COW algebraic geometry seminar series and the biennial Bath-Paris-Beijing meetings in branching structures.

International collaboration: As with any leading department, members of this Unit collaborate and publish with scientists from distinguished institutions worldwide, including MIT, Courant, Princeton, Berkley, ETH, National University of Singapore, Paris, Columbia, Toronto, Michigan, Peking, UBC, EPFL, Washington, and Cornell.

The University's *David Parkin Professorship scheme* (typically two awards per year) enables leading international researchers to spend several months collaborating with colleagues in Bath. In addition to travel and subsistence, the scheme provides campus accommodation, including for families if required. Mathematics received six awards during the REF period. The visitors were Prof. Andre Nachbin (IMPA Brazil), Prof. Kaushik Dayal (Carnegie Mellon), Prof. Esteban Tabak (Courant Institute), Prof. Vladas Sidoravicius (Courant and NYU Shanghai), Prof. Juan Carlos Pardo Millán (CIMAT Mexico) and Prof. Milton Jara (IMPA Brazil).

In this REF period, the University initiated a new *Global Chairs Programme*, designed to attract distinguished international visiting professors to engage in high-profile research and networking activities at Bath. Again, Mathematics has been particularly successful in securing three appointments to date, hosting Prof. Jim Zidek (University of British Columbia), Prof. Colin Fox (University of Otago) and Prof. Ramsés Mena Chávez (Universidad Nacional Autónoma de México).

Mexican network: Bath is actively developing mathematical research links with partners in Mexico through the Bath-UNAM-CIMAT (BUC) research platform, which was initiated in 2015 to foster research collaboration. To date it has attracted £420K of funding from the Newton Fellowship scheme, the Royal Society, EPSRC, UUKi, and University internationalisation competitions, enabling the delivery of 18 collaborative workshops which have led to more than 15 articles, and four joint PhD supervisions. Bath has hosted three postdoctoral visitors and two high-profile professors (listed above). The profile of the platform has also brought six Mexican PhD students to the Department, funded through CONACyT, with additional support from the University of Bath.

High level agreements: Several Mathematical collaborations have been formalised as Memoranda of Understanding (MoUs), signed at University level. These enable the delivery of collaborative research, training and strategic initiatives, e.g., through the provision of data or the exchange of people. MoUs are in place with: UNAM (Mexico), CONACyT (Mexico),

IMPA (Brazil), UNICEF Mongolia, National University of Mongolia, National Development Agency (Mongolia).

Global challenges: The Unit has embraced the importance of using its research in the context of tackling societal challenges in the developing world. To achieve this, members of the Unit have been working through the Government's Global Challenges Research Fund (GCRF) and related activities, establishing collaborations with Mongolia (GCRF funding from University, Research England, EPSRC), Paraguay (seed funding from University, World Bank), Ghana (GCRF funding from University, Research England), Nigeria and South Africa (GCRF funding from UKRI) and supporting the creation of an Africa-UK network for collaborative research in applied algebraic and arithmetic geometry (GCRF funding from EPSRC).

Following successful recruitment and support of a Schlumberger Foundation Faculty for the Future PhD student, the Foundation is piloting an innovative postdoctoral programme which will fund women in STEM from developing countries to collaborate with the Unit, including reciprocal visits. The first positions start in 2021 and the Unit expects that this will lead to three postdoctoral researchers joining the department from Rwanda, Botswana, and Ghana, with research collaborations developing between Bath and the home institutions.

International ITT programme: SAMBa has recently begun a programme of delivering ITTs in collaboration with overseas partners. The first of these took place in Mexico in 2019, with over 60 participants (staff and PhD students) from Bath, UNAM and CIMAT and partners Samsung Mexico and two Mexican Government agencies. A follow-up ITT, likely to be on-line, is scheduled in Mexico with the Disaster Management agency in May 2021, bringing in expertise in Artificial Intelligence and Social Policy.

An ITT-style event was delivered in Ulaanbaatar, in collaboration with the University of Bath's Institute for Policy Research and the National University of Mongolia (NUM) in 2019. This brought academics and policy makers together to explore how data-driven modelling could influence the strategy for dealing with the city's crippling effects of air pollution on health. A further programme of ITTs is planned with NUM, funded through capacity building grants from EPSRC and Research England, and bringing in broader applied science and engineering academic expertise.

Joint ITTs are planned over the next three years with partners at the Centre for Mathematical Modelling in Chile, the University of São Paolo, and Universität Heidelberg.

Inter-disciplinary collaborations: In total, Unit academics have co-authored 171 papers with researchers from other disciplines during the REF period. There are 26 inter-disciplinary grants (including a £6.5M programme grant led by Bristol Engineering with Scheichl). 19/102 completed PhD students were co-supervised with colleagues from another department (Biology & Biochemistry, Computer Science, Electronic & Electrical Engineering, Mechanical Engineering, Physics, Pharmacy & Pharmacology) during the REF period.

Industrial collaboration: Staff and PhD researchers are offered many opportunities for industrial engagement. Over the REF period, the establishment of SAMBa and IMI have helped channel and formalise many industrial collaborations, generating new relationships

and associated funding. SAMBa has leveraged £785K of funding from industry partners (Wood, BT, Schlumberger, Syngenta, Novartis, DNV GL, GKN,) through ITTs, which has been matched from the University and EPSRC to create 16 studentships. These projects involve committed research co-supervision from the partner organisations. Two EPSRC research projects, developed in collaboration with industry partners following ITTs, have been supported (£543K awarded with Wood as partner, £707K awarded with Schlumberger as partner).

Short-term research projects in collaboration with industry (e.g. BT, PepsiCo, Airbus) have been generated through participation in, and hosting of, European Study Groups with Industry, through research projects of the MSc in Modern Applications of Mathematics (at least 50 including with the Met Office, BT, Barclays, Nationwide, Tesco, DSTL, Schlumberger, Emmerson Oil, Qinetiq, Quintessa, Airbus, Mondelez, BAe systems, Raytheon, DNV GL, CraftyTech, CCFRA, National Grid, EDF, PHE, PepsiCo, Scott-Bader), and through consultancy activity with IMI (Atlas Genetics, Tokio Millennium Re, PepsiCo, Airbus, Western Power Distribution, AS Watson, Zenith Global) . A large KTP project (T. Smith) has been funded by Mayden House and InnovateUK. IMI engagement and consultancy has led to partners participating in SAMBa ITTs (Syngenta, PepsiCo and Willis Towers Watson).

Collaboration with governments and agencies: Diamond Light Source and NPL have co-funded PhDs following participation in ITTs. The Met Office contributes to a NERC DTP studentship developed from an ITT idea. As a result of the ITT in which they participated, the Environment Agency supports two PhD projects in the Unit through data and co-supervision and contributed data and funding to help leverage a NERC fellowship (Prosdocimi). The Paraguayan Ministry of Development participated in one of SAMBa's ITTs resulting in a training camp run by SAMBa students in the Ministry two months later. This led to the successful application for further funding from the World Bank (US$150,000)) to run a series of training activities involving department staff and students.

Collaboration with other bodies: Bath hosted a Heilbronn fellow (Aldridge) whose work on group testing, was listed as a Heilbronn Highlight Paper. Interaction with the Alan Turing Institute includes PhD placements (Gianluca Detommaso and Lizhi Zhang each spent a year at the Institute via the Turing Enrichment Scheme).

Contributions to economy and society: *Study groups and similar*: Through Budd, and IMI, Bath is heavily involved in delivering and participating in study groups with industry. Staff and PhD students participate in the events and have continued to do so online in the last few months. In its first five years, IMI was partnered to the European MI-NET grant, which hosted a number of study groups around Europe, including at Bath. A team of four PhD students won the first in a series of NERC hackathons addressing the impact of COVID-19 on the environment.

Members of the Unit were heavily involved (four academic staff out of 30 participants) in a collaborative workshop delivered with Bath and North East Somerset Council (Public Health and Transport teams), and the Bath community, exploring how to mitigate the health effects of air pollution in Bath. Research collaborations from this workshop have continued, funded by the UKRI strategic priorities fund.

PUBLIC ENGAGEMENT AND OUTREACH

The Unit delivers exceptional public engagement linked to mathematical research, as demonstrated by Budd's Impact Case Study; Budd received an OBE for his contributions in this area, to add to that already awarded to G. Smith (MBE).

The Unit delivers outreach and public engagement activities such as Bath Taps into Science (a four-day annual science festival), Royal Institution Masterclasses (six per year), and Bathematicians (a local schools' programme), which involve staff and PhD students. These activities are supported by the University's Public Engagement Unit and Widening Participation Office, which provide specialised training and vital structure and connections.

Engagement with a wide variety of audiences and engagement activity is coordinated by an Outreach Committee which seeks opportunities and supports staff keen to present their work to a public audience (e.g., presenting at New Scientist Live, contributing to the Radio 4 Today quiz, writing for The Conversation, working with artists (Jean Baynham, Leonie Bradley and Silvia Rimat) to conceptualise mathematical ideas into works of art, including displays at Bath's Holbourne museum).

Budd was the Gresham Professor of Geometry from 2016 to 2020, giving six research level talks in applied mathematics per year, and is now a Gresham Fellow. Budd was also Chair of the UK Mathematics Trust and is Professor of Mathematics at the Royal Institution. He has won prizes from the Joint Policy Board for Mathematics from all USA societies in recognition of his impact in communicating mathematics.

G. Smith was the leader of the UK International Mathematics Olympiad team from 2002 to 2010 and took on the role again from 2013 to 2019. In 2019, the University of Bath hosted the hugely successful International Mathematics Olympiad, organised by Smith, and welcoming 621 competitors from 112 countries.

In 2019 Yates launched a popular book based on his work in mathematical biology: 'The Maths of Life and Death'. During the first year of the Covid-19 pandemic, Yates has been a vocal proponent for of the use of mathematical modelling to inform policy in the media and has appeared on mainstream outlets (Sky News, BBC R4, BBC World, BBC News, Huffington Post, Daily Mail, Telegraph, Guardian, Wired, Daily Express, Radio 5 Live, Talk Radio, LBC, Panorama) describing the need for appropriate modelling of the virus, and the importance of critically analysing and interpreting advice. As a consequence, Yates was invited to join independent SAGE, which is made up of members of the scientific community offering independent analysis to SAGE (Scientific Advisory Group for Emergencies) and the government.

CONTRIBUTION TO SUSTAINABILITY OF THE DISCIPLINE

Knowledge Exchange: The department is recognised as playing a leading role in knowledge exchange (KE). EPSRC's Bond Review "*The Era of Mathematics*" stated: "The University of Bath provides a good example of the embedding of a specialised KE function that works alongside a Mathematics CDT and engages across a wide range of academic disciplines within the university as well as SMEs in the Bath region". The Bond review also noted "Funds

should be made available for regional KE centres and/or thematic KE networks following successful models such as the Turing Gateway to Mathematics, the UK fluids network (ERCOFTAC), the University of Bath's IMI and the University of Oxford's OCIAM".

Response to COVID-19 pandemic: The Unit reacted quickly and positively to the challenges posed by the pandemic in the following ways.

One World seminars: Within weeks of the UK moving into lockdown, Kyprianou with a colleague at Mannheim, established the One World Probability Series, an online platform for research seminars, workshops, and schools in probability theory. At its peak, the seminars were attracting an audience of over 400 participants worldwide and the initiative is now supported by the Bernoulli Society and the Institute of Mathematical Statistics. The success of the series and the broad promotion quickly led to over 20 new One World series in mathematics being established worldwide, several of which are organised from the Unit.

Knowledge Exchange: Budd was a founder member of V-KEMS, the Virtual Forum for Knowledge Exchange in the Mathematical Sciences, formed with the intention of tackling COVID-19 and COVID-19-related problems through the organisation of virtual workshops (VSGs) consisting of mathematicians and others, including users. Studies have included exploration of how to facilitate return to work and higher education, and food security. The outcomes of these VSGs are published on a website and promoted to UK Government and the media.

Ingram Olkin Forum Series: Jennison and Bartlett are two of the five main members of the organising committee of the (US) National Institute of Statistical Sciences' Unplanned Clinical Trial Disruptions forum, which brings together leaders from government agencies, clinical trial practitioners, and expert methodological statisticians. The purpose of these meetings is to identify open research questions and establish working groups to tackle the challenges in continuing clinical trials, given the impact of the COVID-19 pandemic.

University Calls to Arms: In June 2020, the University instigated two sandpit type events, focused on developing inter-disciplinary submissions to the UKRI COVID-19 fund. They were run over a series of weeks and were designed to develop new collaborations between academics across the University. Kyprianou was part of the leadership team driving the initiatives and departmental academics were actively involved. The activities resulted in submission of eight grants totalling £7.4M, five with investigators from the Unit.

RAMP: members of the Unit (Trinh, Milewski, Budd, plus five PhD students) were selected to take part in the Royal Society's Rapid Assistance in Modelling the Pandemic (RAMP) initiative in 2020, working on environmental and aerosol transmission. This delivered a report which will be published in Proceedings of the Royal Society, and at least two further publications. One PhD student (Llambias Johnson) has been awarded a UKRI internship with the UK Government's Office for Science, building on his experience with RAMP.

CONTRIBUTION TO THE RESEARCH BASE

The Unit's contributions to the research base are extensive including editorial duties in over 25 top journals, organisation of over 10 large conferences and a large number of workshops

at recognised international centres, leadership and active participation in learned societies, advisory bodies to funding agencies, and steering committees discipline wide. High profile plenary lectures and long-term visiting positions are further indication of the Unit's research reach.

Journal editorship: The following journals have or had main editors/editor in chiefs at Bath: Acta Applicandae Mathematicae (*Kyprianou*), Discrete and Continuous Dynamical Systems A (*del Pino*), Electronic Journal of Probability (*Kyprianou*), Journal of the London Mathematical Society (*Haskins*).

There are or were numerous associate editorships and board memberships including for the following 25 journals which are listed as A* or A on the Journal ranking for the ARC: Annals of Applied Probability (*Penrose*), Annals of Probability (*Jarai*), Annales d'IHP (*Weber*), Biometrics (*Bartlett*), Biostatistics (*Bartlett*), Calculus of Variations and Partial Differential Equations (*del Pino*), Discrete and Continuous Dynamical Systems A *(Dávila, Musso, Weber)*, IMA Journal of Applied Mathematics (*Milewski*), Journal of Elasticity (*Sivaloganathan*), Journal of Engineering Mathematics (*Milewski*), Journal of Mathematical Analysis and Applications (*Musso*), Journal of Theoretical Biology (Ashby, *White*), LMS journals (*Craw, del Pino*), Mathematics of Computation (*Graham*), Nonlinear Analysis (*Dávila*), Philosophical Transactions of the Royal Society A (*Milewski*), Physica D (*Dawes*), Proceedings of the Royal Society of London A (*Zimmer*), Scandinavian Journal of Statistics (*Jennison*), SIAM Journal on Matrix Analysis and Applications (*Freitag*), SIAM Journal on Numerical Analysis (*Scheichl*), SIAM Journal on Scientific Computing (*Scheichl, Shardlow*), SIAM Review (*Budd, Graham*), Stochastic Processes and their Applications (*Weber)*, Studies in Applied Mathematics (*Milewski*). Staff are also on editorial boards of top journals in other disciplines such as IEEE Transactions on Automatic Control (*Opmeer*).

Prizes: Prizes and honours awarded to members of the Unit in this REF period include: **Erdös-Rényi Prize** 2019 (*Peixoto*), Oberwolfach **John Todd Award** 2019 (*E. Spence*), **Philip Leverhulme Prize** 2017 (*Weber*), **Rollo Davidson Prize** 2016 (*Weber*), **Thomas Henry Huxley Award and Marsh Prize** 2014 (*Ashby*), **Lee Segel Prize** for Best Paper 2014-2016, Society for Mathematical Biology (*Rogers*), three **Wolfson Research Merit Awards** (*Dávila, Kyprianou, Zimmer*). *Budd* was awarded the **LMS Prize** for Communicating Mathematics (2015), the **IMA Dedicated Service Award** 2015 and the 2020 **JPBM** (Joint Policy Board for Mathematics, between AMS, MAA, SIAM, ASA) **Communications Award**. *Majumdar* received the 2015 **LMS Anne Bennett Prize** and in 2019 the FDM Everywoman in **Technology Academic Award**. An **OBE** was awarded in 2017 to *Budd* for services to mathematics and science education.

Membership of Research Council or similar committees: Members of the Unit are heavily involved with the mathematical sciences research infrastructures in the UK:

EPSRC: *Dawes* chairs the Mathematical Sciences Strategic Advisory Team (SAT). Member of SAT have also included *Milewski* (2013-2016) and *Sankaran* (since 2020). *Dawes* is a member of the Advisory Board for the Additional Funding Programme in Mathematical Sciences.

LMS: Early Career Research Committee (*Roy*, since 2020), Education Committee (*White*, 2014-2020), Research Grants Committee (*Zimmer*, since 2020), Women in Mathematics Committee (*Buck*).

IMA: Vice-President (*Budd*, until 2015).

SIAM: *Graham*, Elected President of UK and Republic of Ireland Section of SIAM (2017-19), *Freitag,* Elected Vice Chair of SIAM Activity Group on Linear Algebra (2019-2021), *Freitag,* Elected Program Director of SIAM Activity Group on Linear Algebra (2016-2018), *Scheichl* Member of Membership committee (2014-2019).

Royal Statistical Society: Chair of the Research Section (*Jennison*, 2013-2015).

ICMS: *Majumdar, Milewski* and *Sankaran* serve on the Programme Committee.

Other roles include Secretary of the RSS Applied Probability section (*Cox*, 2019), Elected membership of the Executive Committee of the International Society for Clinical Biostatistics (*Bartlett*, 2020), UKMT Chair (*Budd*, 2016-2019), Royal Society Research Grants Board Physical Sciences (Dawes, 2013-2018), Royal Society Summer Science Exhibition Committee (Dawes, 2012-2015), membership of the Global Challenges Research Funding Strategic Advisory Group (*Majumdar*, since 2018), and Elected President of the International Mathematical Olympiad (*G. Smith*, since 2014).

Calderbank serves on the REF 2021 panel and *Budd* and *Toland* served on the REF 2014 panel.

Addresses to international congresses: Every member of the Unit has presented at international conferences. Some highlights of keynote addresses at major conferences include: Americas Conference on Differential Equations and Nonlinear Analysis, 2015 Buenos Aires (*Musso*), 26th Biennial Conference on Numerical Analysis 2015, Glasgow (*Scheichl*), British Mathematical Colloquium 2018, Morning lecture (*Weber*), EQUADIFF 2019, Leiden (*del Pino*), 12th European Conference on Numerical Mathematics 2017, Bergen (*Scheichl*), 90th GAMM annual meeting 2019, Vienna (*Scheichl*), Heidelberg Laureate Forum 2019 (*Budd*), 20th International Conference on Computational Methods for Water Resources 14 (*Scheichl*), 7th International Conference on Differential and Functional Differential Equations 2014, Moscow (*del Pino*), IMA Conference on Nonlinearity and Coherent Structures 2019 (*Milewski*), 24th International Conference on Domain Decomposition, Svalbard 2017 (*Graham*), 10th International Conference on Multiple Comparison Procedures, Riverside 2017 (*Jennison*), 14th International Conference on Mathematical and Numerical Aspects of Wave Propagation, Vienna 2019 (*E. Spence*), Mathematical Congress of the Americas 2017, Montreal (*del Pino*), Opening talk at the London Mathematical Society's Annual General Meeting 2018, (*del Pino*), 3rd Pacific Rim Mathematical Association Congress 2017, Oaxaca (*del Pino*), SANUM Meetings (*Milewski*, Stellenbosch 2018; *Freitag*, Pretoria 2019), SIAM Conference on Applied Linear Algebra 2015 (*Freitag*), SIAM Conference on Analysis of Partial Differential Equations 2019, La Quinta, USA (*del Pino*).

Members of the Unit have delivered more than 60 lectures at international research centres including BIRS, CIRM, ICMS, INI, KIAS, MSRI, Oberwolfach, and RIMS.

Visiting professorships: Unit staff have held international visiting positions of at least one month in the REF period at Centro de Investigación en Matemáticas (CIMAT) (*Kyprianou*), Instituto de Matematica Pura e Aplicada (IMPA) (*Milewski),* Universität Heidelberg (*Scheichl*), Université d'Orsay (*Weber*), Université de Poitiers (*Sankaran*), Université Paul Sabatier, Toulouse (*Moser*), University of Pennsylvania (*Zimmer*), WIAS (*Penrose*).

Conferences at Bath: As mentioned above, the Unit hosted large conferences including the International Conference on Scientific Computation and Differential Equations (SciCADE) 2017 (*Budd, Freitag, Müller, Hill, Shardlow*), the 138th European Study Group with Industry 2018 (*Budd*), and the British Applied Mathematics Colloquium (BAMC) 2019 (*Budd, Dawes, Milewski*). Additionally, *Weber* was co-organiser of a four-month programme at the Isaac Newton Institute; *Freitag* and *Opmeer* were organisers of an LMS Durham Symposium (2017); *Milewski* co-chaired the SIAM Meeting on Nonlinear Waves and Coherent Structures 2014; *Peixoto* was co-Chair of the SIAM Workshop on Network Science (NS18). *Freitag* served on the Scientific Committee for the SIAM Applied Linear Algebra Conference (2016-18) and was on the organising team of the SIAM UK & Ireland Annual meeting 2015. *Augustin* served as scientific committee member and local organiser for the International Workshop on Statistical Modelling (2018). Members of this Unit co-organised a large number of additional workshops and conferences, including events at international research centres BIRS, ICMS, IPAM, and Oberwolfach.