Institution: University of Surrey

Unit of Assessment: UOA 10 Mathematical Sciences

1. Unit context and structure, research and impact strategy

1.1. Organisation and structure of the Unit

The Department of Mathematics (DoM) is a thriving centre of expertise in dynamical systems, partial differential equations, nonlinear waves, geometry, data science, and their applications. Its backbone is an outstanding group of staff, who have excellent international profiles and publish in top-ranking journals. The DoM has a strong track record in creating and sustaining research partnerships, integrating PhD students and early career researchers into the department, and driving staff development via University promotions.

Research programmes are invariably inspired and nurtured at the level of individuals, but broader agendas, representing critical masses of activity, are embodied in the DoM's five research groups; Mathematics of Life and Social Sciences, Dynamical Systems and Partial Differential Equations, Nonlinear Waves and Geometric Fluid Dynamics, Fields, Strings, and Geometry, and Data Science and Dynamics. Some academics integrate their research across more than one group.

Mathematics of Life and Social Sciences (MoLSS)

Much of the research is interdisciplinary and group members typically collaborate closely with researchers and practitioners in biology, ecology, sociology, and medicine from a range of universities, research institutes and industries (see Section 4.2). MoLSS uses an exceptionally broad range of mathematical techniques, encompassing the full range of current applied mathematics, including dynamical systems and stochastic/statistical approaches in a combination of life and social sciences settings, which has expanded considerably since REF2014. The work spans a wide range of applications including developmental biology and tissue morphogenesis, epidemiology and ecology, sleep and circadian rhythms, systems pharmacology, design of experiments and data science. A notable development since REF2014 has been the interaction with the new School of Veterinary Medicine, whose purpose-built facility was opened in 2015. The activities of the MoLSS group are aligned with Lifelong Health, a university strategic research theme established in August 2019, and with the university-wide Centre for Mathematical and Computational Biology. A more recent development has been the creation of the Surrey Centre for Criminology, which is a joint venture between the DoM and Sociology.

Dynamical Systems and Partial Differential Equations (DSPDE)

Research in this area spans topics in analysis from pure to applied. On the pure side, topics include ergodic theory, functional and fractal analysis, and the rigorous analysis of ordinary and partial differential equations (PDEs). On the applied side, methods are used to analyse PDEs in various contexts such as nonlinear elastostatics, pattern formation, dispersive waves, Navier-Stokes equations, delay equations and liquid crystal theory. Analysis on unbounded domains is of particular interest. Among DSPDE's current research interests are:

- Quasiconvexity, elasticity and the calculus of variations
- Interaction of patterns
- Qualitative analysis of dissipative partial differential equations
- Interactions of fronts with localised inhomogeneities: existence and stability
- Hamiltonian systems with symmetry
- Time semidiscretizations of semilinear PDEs.

Nonlinear Waves and Geometric Fluid Dynamics (NWGFD)

The main themes are geometric mechanics, geophysical fluid dynamics, hydrodynamic stability, water waves, wave fronts and nonlinear patterns. NWGFD focuses on large scale environmental fluid flows such as atmospheric flows, oceanic flows, and plasma dynamics. Methodology includes

analysis, geometry, numerics and data analytics. A key area that is attracting attention internationally is data assimilation and its application to weather, crime modelling (an overlap with MoLSS), climate, and carbon budgeting. This area includes key links with both the National Physical Laboratory (NPL) and UK Met Office. In water waves, the University is now a leading centre for sloshing and its applications, and this area forms the basis for the analysis of wave energy extraction devices, joint with industry (OWEL, ITPower Ltd). These examples (data assimilation and sloshing) exemplify where both core mathematics and interdisciplinarity are important. Other links include the Advanced Technology Institute, the Centre for Environment and Sustainability, and EnFlo, all at Surrey; the NERC National Centre for Earth Observation (NCEO) and the NERC DTP SCENARIO (SCience of the Environment: Natural and Anthropogenic pRocesses, Impacts and Opportunities), with Reading.

Fields, Strings, and Geometry (FSG)

This group was formed in 2011-12 and has since expanded and flourished. Group members are primarily interested in fundamental aspects of quantum field theory, string theory, general relativity, and in the interplay between mathematics and physics. It is the synthesis between theoretical physics and mathematics that forms the foundation of FSG's research. The key strengths of this group are a high international profile and excellent outputs. The interests of the FSG group encompass differential geometry, black holes, integrability, twistor theory, categorified differential geometry and string theory phenomenology. Published papers number about 100, with 1800 citations. FSG is part of a network of six mathematical physics groups (Cambridge, City, Hertfordshire, Kent, Kings College and Surrey) running the LMS funded seminar series South-East Mathematical Physics Seminar (SEMPS). Surrey has organised two events so far (2015 and 2018). FSG and the Theoretical Physics group at the University of Milano- Bicocca (UNIMIB) have strong collaborative ties, which created the stimulus for a new International Dual Doctorate between the DoM and UNIMIB. A major ERC fellowship grant was awarded in 2014 to Pasquetti, who moved to UNIMIB in 2016, but continues to collaborate with FSG via a Visiting Professorship.

Data Science and Dynamics (DSD)

This is a new group, formed in 2019. The DoM made strategic appointments (Brody (2018) and Klus (2020)) to enhance both research and teaching activities in mathematical data science. These appointments complement the existing expertise of Aston, Santitissadeekorn and Roulstone. These additions will enhance research in mathematical data science, together with the development of new taught courses (particularly at master's level).

Among the new collaborations established during the REF period is a partnership with NPL. This arose from the strategic alliance, established in 2015, between Surrey and Strathclyde, and what is now the Department of Business, Energy and Industrial Strategy (BEIS). The DoM and NPL agreed to establish a joint appointment, which is designed to enhance expertise in mathematical modelling and data science, particularly methods of analysis of "big data". NPL invests in data science to enhance confidence in data and to address the scientific challenges that arise in all areas of society -- manufacturing, energy and environment, life and social sciences, health and wellbeing. In particular, NPL is expanding its research portfolio in data analytics to develop a mathematical, statistical and computational capability to improve our understanding of the world from measurement data. The role of the joint appointment (held by Aston) is to develop and lead projects in these areas, and to foster new collaborations with industry and academia within the UK and internationally.

1.2. Research Objectives, Strategy and Impact

In 2017 the DoM conducted a five-year strategic review, and the leading mission statement captured the over-arching objectives: "*To exploit our expertise, as one of the UK's long-established research centres in nonlinear mathematics and dynamical systems, in the advancement of fundamental mathematics and its applications to engineering, physical, life and social sciences. To sustain our reputation for excellence in teaching through a lively, innovative and stimulating learning environment, thereby preparing our graduates for a numerate career and providing them with excellent employment prospects. To capitalise on our demonstrable and fundamental achievements in mathematics for collaboration across all faculties by bringing added value to the pursuit of the University of Surrey's strategic goals*".

Since 2014, the DoM has pursued the following goals with regards to research strategy and impact:

- Enhance the portfolio of research projects via **strategic collaborations across the University,** and with external partners, to create critical mass in key themes, thereby bringing added value to strategic investment at university level.
- **Expand our interdisciplinary expertise** to align the DoM with the priorities of the University and allow members of the DoM to maximise opportunities to extend collaborations within Surrey and beyond.
- Increase research grant income to support core mathematics and collaboration within research themes at the University of Surrey and with partners such as NPL.
- Enhance PGR (postgraduate research) funding via new opportunities for partnerships in doctoral training via activities in which we can contribute to critical mass, within the University, nationally, and internationally.
- Continue to focus on **sustaining the excellence in our core areas** (as demonstrated by the examples in Section 4 below). To achieve this, we have recruited strategically into key areas such as data science.
- **Nurture and recognise impact** by working closely with the University via the Impact Acceleration Account and via strategic partnerships.

Among the key targets of the 2017 plan, to achieve by 2022, were:

- A significant portfolio of interdisciplinary research collaborations, acting as a source of external funding (over and above EPSRC/NERC/STFC) and contributing to impact case studies (status: several established and others ongoing)
- New undergraduate and postgraduate programmes in data analytics and applications (status: programmes developed and commencing 2022)
- An elevated national and international profile evidenced by co-authorship of papers, research partnerships, plenary talks at international conferences, and student exchanges (status: positive progress made and activity rapidly increasing)
- Establish three permanent teaching-only posts, thereby creating more research time for lecturers (status: completed)

Since 2017, new partnerships have been established with NPL, Surrey Centre for Criminology, School of Veterinary Medicine, Surrey Police, Public Health England, Transport for London, utility companies (e.g. Scotia Gas Network), and SMEs in the University research park and beyond. These collaborations are starting to lead to future impact and grant initiatives, and the joint professorial position with NPL is part of this broad agenda. Meanwhile, existing partnerships continue to thrive and underpin our current impact. Among these partners are the Surrey Sleep Research Centre, the pharmaceutical industry (AstraZenica), and the Met Office.

A new MSc in data analytics and applications will commence in 2022, and our PGR programme is enhanced by a new international dual doctorate with the University of Milano-Bicocca. The SCENARIO (NERC DTP) run by Reading and Surrey, which includes the departments of

Mathematics, Civil and Environmental Engineering, and Centre for the Environment and Sustainability at Surrey, was funded for its second five-year period.

Sustained RG&C income (£4.3M) and over 325 outputs, with in excess of 68% produced with a national or international co-author, have resulted from the successful implementation of our research strategy over the REF period.

1.3. Faculty and University research support structures

The Head of Department (HoD), Director of Research (DoR), and Impact Champion, are responsible for defining strategic aims and coordinating the research programmes within the DoM. This activity is monitored and discussed at Faculty level by the Faculty Research Committee and the Faculty Research Strategy Group, whose membership is drawn from HoDs and DoRs. These groups are chaired by the Dean of Faculty, and provide a bridge between departments and the University Executive Board. The Pro-VC for Research and Innovation makes regular visits to all departments and developing the University's research strategy is a collective effort.

The Innovation Strategy Directorate have teams that work with university departments to help generate impact from research. As well as managing intellectual property matters (patents and licences) and supporting University start-ups and spin-outs (the Technology Transfer team), there is a Partnerships team that manages schemes such as the EPSRC Impact Acceleration Account (IAA). During this REF period, the DoM has received 12 grants from the IAA, totalling £201k, with matching funding from industrial partners worth £182k. Among our collaborators are the Surrey Police, Papworth Hospital, CrossRail (TfL), Ford Motor Company, the US Army Medical Research Institute, and the Royal College of General Practitioners.

1.4. Strategic priorities

The research groupings will continue to act as key mechanisms for ensuring that strategic aims are achieved (see above). The Head of Department (Derks) in collaboration with the Director of Research (Skeldon) and Group Leads (Lloyd (MoLSS), Zelik/Bevan (DSPDE), Gutowski (FSG), Bridges/Turner (NWGFD), Brody (DSD)) will ensure that these aims are reviewed and reflect on internal and external factors, ultimately ensuring the DoM continues to provide a sustainable environment producing world-leading research.

The key enablers include:

- Targeting appointments to maintain a balance between core mathematics and applications.
- Supporting and encouraging staff to make use of funding opportunities for impact, e.g. IAA.
- Targeting use of reduced teaching load/sabbatical (see Section 2) to give staff time to develop new programmes and industrial contacts.
- Emboldening staff to engage and develop new networks, creating critical masses of activity in key disciplines, thereby gaining traction in terms of research funding (e.g. Centre for Criminology, Surrey Sleep Research Centre, EPSRC Networks (see Section 4)).

1.5. Open research culture and ethics

The Department culture emphasises transparency, open communication and making research findings available to other researchers and the public. Since 2014, staff throughout the Department have uploaded 402 items in the University's repository, which have been accessed over 93,400 times. It also ensures research is undertaken within ethical and legal requirements, drawing on support and guidance offered by the University Ethics Committee and Research Integrity and Governance Office.

2. People

The Department's current Category A eligible staff includes two Lecturers, four Senior Lecturers, nine Readers, eight Professors, and one STFC Rutherford Research Fellow. All of these are permanent posts.

Four Category A eligible staff have joined the Department since 2014, including two lecturers (Klus, Santitissadeekorn), one Professor (Brody) and STFC Rutherford Fellow (Hanada). Further, Gutowski held a STFC Rutherford Fellowship in the DoM from 2012 to 2016, whereupon he was appointed to a permanent position as Reader.

2.1. Staffing strategy

Since REF2014 the DoM has prioritised recruitment in key areas to support the research agenda, while utilising strategic partnerships to augment collaborations. The professoriate recognises and promotes leadership potential to ensure the long-term vitality of the Department. Over the REF period mentoring, managing, training, promoting, and the provision of sabbaticals, have all been instrumental to ensuring the DoM has a supportive staff environment. The academic staff comprise 11 different nationalities. For line management, all academic staff and the administrator report to the HoD. PDRAs report to a member of academic staff, normally the principal investigator or co-investigator on the research project on which they are employed.

At department level, equality of opportunity is promoted effectively and applies to all research activities including bidding, conference attendance, promotion, and flexible/remote working. For example, all meetings are held between the core hours of 10am and 4pm and the University flexible work policy considers a wide range of arrangements (including part-time working, term-time working, job-sharing, annualised hours and additional planned unpaid leave).

The DoM was granted (summer 2020) an Athena Swan Bronze Award. An Implementation Team has been formed and among the actions planned, we are aiming to:

- increase the numbers of female students at all levels by improving the appeal of recruitment and admissions processes to women applicants
- maximize women's promotion and career prospects by creating a supportive and welcoming work environment, which better respects gender equality within the DoM
- identify and support high-performing female undergraduates, raising their awareness of opportunities for further study, including at PhD level.

In 2014 the DoM had only one member of staff on a permanent teaching-only contract, and now has four (3.3FTE) posts with this type of contract, who play a crucial role in freeing research time for other colleagues and ensuring top-quality research-led teaching. To ameliorate imbalances between individual responsibilities, revised job descriptions of key managerial roles were agreed, which resulted in a more equitable division of labour. Our female colleagues are well-represented in these roles (including the current HoD and DoR), but without over-burdensome commitments.

Two members of REF eligible staff have taken maternity leave during the latest REF period. One member of staff returned to full time working in January 2014, having previously been part-time for many years; she has subsequently been promoted to Reader (2015) and Professor (2018). Another member of staff took one period of maternity leave (Sept. 2015-April 2016); and has since been promoted to Senior Lecturer.

The DoM paid full regard to equality, diversity and inclusion in the construction of the REF2021 submission. Output selection adhered to guidance set by the University's REF2021 Team. Membership of the output selection panels included suitable representation from across the areas of speciality within the UOA and took account of the population characteristics of the UOA. Membership was reviewed by the Equality, Diversity and Inclusion (ED&I) Working Group ahead of scheduled meetings and all attendees completed REF2021 ED&I training. A member of the REF2021 Team was present at all output selection meetings.

The Department remains committed to advancing equality and diversity. Members of the Department have taken up leadership roles within Faculty and University equality initiatives, for example Bridges sat on the REF 2021 Staff Circumstances Committee.

2.2. Staff Development

The Department considers its collegial environment and approach to the development and support of staff as crucial to sustaining a thriving research culture, and utilises institutional development opportunities, such as dedicated research time and staff development courses.

A total of 23 staff promotions have occurred in the period, including five to Professor and nine to Reader. Female staff have been promoted to Professor (2), Reader (3), and Senior Lecturer (1). The gender balance of the department is broadly in line with the sector but as recruiting opportunities present themselves, we will aim to augment the proportion of women.

Research time is built into a transparent workload allocation model (WAM). Where research time is specified in funding applications, this is also built into the WAM irrespective of whether the funder directly covers overheads or salary costs. The Department continues to operate an informal **sabbatical system** and all academic staff (part-time and full-time) are eligible for one semester of research leave every five years. All staff have an annual appraisal with their managers which focuses on progress towards meeting targets and career development. Colleagues within the Department are also invited to attend mid-year reviews to discuss progress against targets, and to have one-to-one meetings with the DoR. As noted in the Concordat to Support the Career Development of Researchers, promoting good mental health and wellbeing is a core component of good research. During the assessment period the Department established the role of 'wellbeing officer' who ensures that colleagues are aware of wider support mechanisms.

Mentoring is a key part of the staff development process for new appointments. New lecturers are assigned a senior colleague as a mentor, and appraisals are conducted by the senior colleague and the HoD. Annual targets will typically include a first grant application and recruitment of a PhD student, and to support the pursuit of these targets, light teaching and administrative loads are given to new staff. New professors are given a start-up fund (which will include discretionary research and travel funds, computing facilities, and internally-funded PhD students).

The Department proactively supports staff in carrying out research and achieving impact. All new bids have to be approved and logged at Faculty level, and signed off by the HoD. Depending on the amount of resource requested, formal or informal peer reviews are carried out. Importantly, detailed discussions take place at an early stage if a proposal includes extended leave from the Department. To facilitate research networking, both within the UK and overseas, the DoM provides a modest travel budget for all staff, supplemented by the Faculty Research Support Fund.

In addition to regular staff meetings to discuss routine departmental business, away days are held on an annual basis to discuss strategy and policy for research and teaching. These events facilitate the sharing of best practice and raise general awareness of challenges and opportunities facing the department.

2.3. Recruitment

As a strategic appointment to strengthen data assimilation, especially in meteorology and crime modelling, Santitissadeekorn was appointed to a lectureship in August 2014. He came with a PhD from Clarkson University and nearly six years of postdoctoral experience at universities in Australia and the USA. He is co-author of the SIAM monograph *Applied and Computational Measureable Dynamics* which establishes his reputation in bridging the gap between dynamical systems, data analysis and machine learning.

Brody (formerly Brunel) joined in April 2018. Brody's wide-ranging interests include geometry, information theory, quantum foundations, the Riemann hypothesis and mathematical finance. Brody is a Visiting Professor at Imperial College London and at St Petersburg National Research University of Information Technologies, Mechanics and Optics. He is a Fellow of the Institute of Physics. Since joining Surrey, Brody has become a founding member of the newly created Centre for Quantum Foundations. This is a joint venture between the Physics and Mathematics Departments initiated by Al-Khalili OBE FRS in Physics, with Brody leading the Mathematics contribution.

Gutowski held a STFC Ernest Rutherford Fellowship in the DoM from 2012-16, and was then appointed to a permanent position as Reader.

Hanada, formerly Southampton University and a pioneer in the numerical study of gauge theories, joined us in April 2020. Hanada holds a Rutherford Fellowship (10/2018 – 10/2023) "Computational Approach to Quantum Gravity via Holography" (£447k). This post is destined to become permanent at the end of the fellowship.

Klus (formerly FU, Berlin) joined as a lecturer in July 2020. This appointment strengthens the department's expertise in a number of areas including data driven model reduction, molecular dynamics, tensor decompositions, graph theory and high-performance computing.

2.4. Utilising strategic partnerships to expand collaboration

The Department encourages exchanges between academia, business and industry. Over the assessment period we have increased the number of Visiting Professors and Visiting Researchers in the Department and facilitated staff secondments (see Section 4). The Visiting Professors are Gentile (Roma Tre), E Godolphin (formerly Royal Holloway), Lorenc (Met Office), Pasquetti and Penati (Milano-Bicocca), Timokha (NTNU), and A White (formerly Met Office). Pasquetti and Penati are key partners in the International Dual Doctorate that the DoM runs with Milano-Bicocca. Lorenc, Timokha and White have contributed to research and impact in NWGFD; Gentile and Godolphin have contributed to research in DSPDE and MoLSS, respectively.

2.5. Early Career Researchers

Working within the framework of the HR Excellence in Research framework, all staff within the Department are offered a mentor/senior colleague and encouraged to meet with them at least twice a year. ECRs are encouraged to use their mentor for peer review of papers and research proposals. Peer feedback is required of all grant applications prior to submission and many staff act as peer reviewers, reinforcing the transfer of expertise between more experienced staff and ECRs. Where a grant is unsuccessful, colleagues are invited to discuss this with senior colleagues and the DoR (for both support and advice on where else to target). Evidencing the success of these strategies, since REF2014 colleagues have had considerable success in securing fellowship and development grants at an early career stage (see Section 3).

More informally, the Department continues to encourage more established staff to collaborate with early career colleagues, including Research Fellows and PhD students, in submitting bids and writing journal articles. Two former ECRs were recruited by Exeter and Hertfordshire as lecturers, and another is now a scientist at NPL.

2.6. PGRs

Currently the Department has 22 students registered for a doctoral degree (20 full-time and 2 part-time), and co-supervision of students in other departments at the University is undertaken as part of collaborative projects (e.g. Skeldon co-supervises two PhD students with the Surrey Sleep Research Centre director Prof Dijk). Recruitment is governed by a postgraduate research admissions policy which makes clear that the University is committed to equality of opportunity.

The PGR programme in the DoM is managed by the PGR Director (PGRD). The PGRD is responsible for overseeing recruitment, admissions, research training, transferable skills training, progress monitoring, PhD confirmation examination, fundraising, and the overall welfare of students within the DoM. The Faculty PGR Committee reports to the University's Doctoral College (DC) Board, chaired by the Director of the DC. Awards are confirmed at Senate Progression and Conferment Executive.

The DoM recruits PGRs through PGR Open Days, organised by the Department and the Faculty. Project-specific adverts are placed on jobs.ac.uk, findaphd.com, and on the DoM's website. Internal targeting of excellent students and contacts at other institutions aid the recruitment drives. Application and admission of research students are subject to the University's Equality and Diversity Policy, the associated Code of Practice for Students and the University Student Disability Policy. Prospective students are interviewed prior to admission, with the use of video-link technology as appropriate.

All PGR students are members of the DC. The recruitment and progression monitoring of PhD students is carried out via the Surrey Self-Service system (SITS). The students, along with their supervisors and co-supervisors, complete progress reports on a six-monthly basis, and these are checked and signed off by PGRD before being submitted for approval at Faculty level. All students undergo a formal assessment within the first 12 to 15 months in order to have their status as a PhD student confirmed. The DC also coordinates a range of training modules and runs an annual flagship event for the University's PGR and ECR community. Additionally, the DC also runs a scholarship competition and an internal PGR conference.

Thirty PhD students have graduated during the REF period, and of these nine have proceeded to postdoctoral positions. The supportive research environment at Surrey significantly benefits PGR students, and has also assisted with the supervision of a graduate student with complex neurodiversity requirements.

Several PhD students have been nominated and awarded prizes at Faculty and University level, and beyond. In 2016 the Faculty PhD Student of the Year award went to DSPDE student Kostianko. PhD student Ratliff (NWGFD) was awarded Faculty and University PhD student of the year in 2017. Lyle (MoLSS) won the JRSM Cardiovascular Disease Young Investigator of the Year Award. Hill (DSPDE/NWGFD) has been nominated for the 2021 IMA Lighthill-Thwaites Prize. Recognition for our PGR students beyond the university is evident from the invited presentations by Solowiej-Wedderburn and Lyle at STEM for Britain events in the Houses of Parliament.

SCENARIO (NERC DTP) students are hosted by the University of Reading, the University of Surrey, the Centre for Ecology and Hydrology, the British Geological Survey and the Institute of Zoology. Their projects involve a wide range of industry and public sector partners. "SCENARIO@SURREY" students benefit from cohort-building events and programmes at both Surrey and Reading.

Research students receive subject specific and generic training. For subject specific training, students are sent on the intensive one-week courses organised by LMS & EPSRC, the MAGIC consortium courses via video link, as well as internal training courses organised during the period. The DoM runs an MSc in Mathematics, which provides further training for current PhD students, and a forum for sharing staff expertise. A new MSc in Mathematics for Data Science will commence in autumn 2022 and draws very naturally on the many Level 6 and 7 modules on dynamical systems and applications, in addition to new bespoke modules being created for the MMath and MSc.

The DoM has consistently performed well in PRES, scoring 100% satisfaction for a number of years (and 91% running average over 5 years). The University ranked 7th in the first PRES league table released in 2020.

3. Income, infrastructure and facilities

Over £4.3M in income was generated over this REF period, with all Category A staff having had successful bids.

3.1. Income strategy and coordination

A key element of the DoM's strategy to augment research income is to network with other groups within the university, and with other institutions, in order to create programmes with critical masses of activity. This increases leverage and facilitates bids for significant levels of funding. This has been successful over the years and resulted in awards such as MILES, ERIE, NCEO, SCENARIO DTP, and other grant awards listed below.

Since 2014, colleagues within the Department have received support from a Research Facilitation Officer (RFO, employed by the University) keeping staff informed of opportunities as and when they arise. Funding bids must undergo formal peer review, as part of institutional quality assurance measures, if:
- The PI has not been awarded a successful grant as PI over the past 3 years
- It is an EPSRC New Investigator Grant
- The value of the proposal to Surrey is over £500k FEC
- The HoD/C requires that the proposal has a formal peer review.

Informal mechanisms are also in place to help staff as all colleagues are offered a mentor and are encouraged to use this person for informal discussions and review prior to submitting their proposal. This system has proved particularly useful for early career colleagues as evidenced by successes – **Dunlop**: £96k EPSRC First Grant: Modelling the mechanics of epithelial sheets on soft substrates: nonlinearity, feedback, and dissipation; **Morris**: £92k EPSRC First Grant: Distributional analysis of GCD algorithms via the ergodic theory of random dynamical systems; **Santitissadeekorn**: £101k EPSRC First Grant: Data assimilation and forecasting for urban crime models.

A key component of our strategy for generating grant income has been encouraging and supporting colleagues to build interdisciplinary research applications. Examples include **Gourley**: £45k from Leverhulme Trust, Research Fellowship for 2014-15 providing teaching and administration buy-out. Project: Larval competition and its intriguing role in malaria spread; **Tronci**: £253k from Leverhulme. Project: From geometry to kinetic-fluid systems (and back); **Gourley** (Co-I): £560k from Medical Research Council. Project: Zoonotic transmission of intestinal parasites: implications for control and elimination. PI: Martha Betson (School of Veterinary Medicine, Surrey).

3.2. Research income

Since 2014, colleagues have received competitive awards from the ERC, STFC and EPSRC, amongst others.

Significant grants:

Consolidation grants of £296k from **STFC** to the Fields, Strings and Geometry Group. Project: Fundamental Implications of Fields, Strings and Gravity. Grant, Gutowski, McOrist, Pasquetti, Torrielli, Wolf. Two STFC Advanced Fellowships (£857k) for Gutowski and Hanada, and three JSPS grants (£106k).

Pasquetti (left in 2016 for Milano-Bicocca): £1.03m from **ERC**, five-year starter grant: Holomorphic Blocks in Quantum Field Theory: New Constructions of Exact Results.

Morris: £268k from **Leverhulme**: Lower bounds for Lyapunov exponents.

Zelik: £385k from **EPSRC**: Finite-dimensional reduction, inertial manifolds, and homoclinic structures in dissipative PDEs (joint with ICL).

Torrielli was awarded an **EPSRC-SFI** standard grant "Solving spins and strings", jointly with De Leeuw (Trinity College Dublin). The total value to Surrey is £488k, with a commensurate amount from SFI to Trinity College.

The **Leverhulme** Trust awarded Cheng (PI) a four-year grant (£281k) in 2017 "Mathematical analysis of near resonance in the physical world of finiteness", with co-applicants Wingate (Exeter), Mahalov (Arizona State), and Schochet (Tel Aviv). Cheng (co-I), with Wingate (PI) and Cotter (co-I, ICL), were awarded £850k from **EPSRC** in 2018 for "On the way to the asymptotic limit: mathematics of slow-fast coupling in PDEs". These projects employ mathematical analysis to explore finiteness of small physical parameters and its effects on resonances for systems of nonlinear partial differential equations modelling multi-dimensional geophysical fluid dynamics.

NERC, via NCEO, have funded a PDRA in the Department (Co-I Roulstone) from 12/08 to 03/20.

Tronci: Fellowship from the Alexander von **Humboldt Foundation** in Germany, paying for salary and expenses for a 10 month visit to the Max Planck Institut für Plasmaphysik.

In his capacity as a Visiting Professor, Brody applied (via St Petersburg National Research University of Information Technologies, Mechanics and Optics) for two research grants from the Russian Science Foundation (as sole PI), both of which were successful: (1) "Quantum Computing and Non-Hermitian Quantum Theory" (Contract: 16-11-10218, Value: £157k, Duration: 2016-2018); (2) "Quantum Navigation for Open Systems" (May 2020; same value; but due to Covid-19 the awarding process is on hold).

The DSPDE group is to become part of an **EPSRC network** (£55k) grant 'Generalised and Low-Regularity Solutions of Nonlinear PDE', which is led by Bath. Surrey is a part of the south-east node (Reading, Sussex, Surrey). The application was made by Moser and Matthies (Bath), and includes Heriot-Watt, Edinburgh, Warwick, Oxford, Cambridge, Cardiff and Swansea. The grant runs for three years from July 2021.

Conference Contributions

1 Galileo Galilei Institute, Florence, Conference Grant (£150k)
1 EPSRC/LMS Durham Symposium Grant + 1 EU Cost Action Conference Grant (£9k + full board for 50 participants), Durham.
1 Clay Institute Conference Grant (£18k) in Oxford
1 LMS Conference Grant (£4.4k) in Kings College London

Infrastructure and Facilities

The Department occupies the entire fourth floor of the Thomas Telford Building, which includes a common room, with additional capacity (moveable partition) to accommodate informal seminars. All Category A staff have their own offices, with a state-of-the-art computing environment and PC-Linux machines on every desk for staff, RAs and postgraduates, supplemented by laptops or tablets where appropriate. It also owns three multi-processor servers for CPU-intensive numerical computations, and access is available to the Faculty High Performance Computing facilities. Support is provided for all IT by a team of specialists (Faculty Computing Service). Smart whiteboards are now mounted in the main mathematics seminar room and the main tutorial room, and DoM has access to a range of shared video link setups, including a state-of-the-art, high definition, screen videoconferencing system for hosting seminars and meetings. In 2019, a new undergraduate common room/study room was created within the department, which provides a valuable home base for our students.

A departmental intranet system was developed by a member of staff (Wolf) and this serves as a focal point for all administrative matters from student records to research grants and recording

annual leave. It has proven to be a valuable time-saving resource, which has been implemented in various forms in other departments within the University.

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

4.1. Academic Collaborations and Contributions

The DoM maintains a research blog, https://blogs.surrey.ac.uk/mathsresearch/ , which is used to disseminate the most up-to-date news about the research activities of staff and PGR students.
Morris has been a major contributor to the recent flowering of research in **fractal geometry**, particularly in the field of self-affine fractals. A fundamental problem in this area is the construction of measures on self-affine sets which have maximal Hausdorff dimension. In the last five years Morris has established himself as the world's leading authority on **Käenmäki measures**, which are the class of measures expected to typically have this property. Additional to his work in fractal geometry, Morris has worked on applications of **ergodic theory** to diverse problems including the joint spectral theory of sets of matrices, the combinatorial geometry of measurable subsets of the plane, and the study of **arithmetical algorithms**; in the latter field Morris resolved a 40 year old open problem posed by Richard Brent and Donald Knuth on the running time of the binary Euclidean algorithm, resulting in an article published in Advances in Mathematics and which is cited in current editions of Knuth's celebrated textbook series *The Art of Computer Programming*.

Bevan's research centres on the **calculus of variations** and its applications to problems arising in nonlinear elasticity theory as well as on "purer" variational problems in which a change of topology can exert an influence. His 2017 paper, published in the Archive for Rational Mechanics and Analysis, on the Holder regularity of strong local minimizers in nonlinear elasticity in two dimensions, makes definitive progress towards solving the 40-year-old problem of the regularity of minimizers. Bevan collaborates with Kružík (UTIA, Prague) on novel variational problems which explore concentration/oscillation effects in polyconvex functionals. This work is supported by a Royal Society International Exchanges grant (IES/R3/193278). A separate strand of research includes detailed modelling of physical phenomena, such as the Wirtz pump and the shape of a flowing rope fountain, and is part of a long-running and productive collaboration with Deane, in which analysis and **innovative computing** join forces. The most prominent work in this direction appeared in SIMA, and has been presented at numerous international conferences and workshops, including in the Czech Academy of Science, UTIA, Prague (October 2019). The work builds on Bevan and Zeppieri (CVPDE 2016) and characterises, explicitly in terms of parameters dictated by the elastic material being modelled, bounds on the class of radial, affine boundary conditions at which the stored-energy function is quasiconvex. The results can be interpreted from both analytical and materials science perspectives.

Lloyd's paper, *Invasion fronts outside the homoclinic snaking region in the planar Swift-Hohenberg equation* (SIAM J. Appl. Dyn. Sys. 18(4), 1892– 1933 (2019)), solves the open problem of how to carry out a numerical bifurcation analysis of the depinning of fronts near but outside the **homoclinic snaking** region. It involves a spatial stripe cellular pattern embedded in a quiescent state, in two space dimensions. This problem was flagged by Knobloch as an open question at his 2016 Lorentz Centre talk (Workshop on Analysis and Applications of Localized Structures in Nonlinear Media). The idea was that invasion fronts cover most of parameter space in the bistable region, but no one knew if there were any interesting instabilities or bifurcations associated with them. Indeed, prior to Lloyd's work, there was no numerical method available to compute multi-space dimension localised patterns where the quiescent state was periodic with an unknown wavenumber and frame speed that have to be selected as part of the solution. Joint work with Scheel (Minnesota) provided a rigorous mathematical explanation of why localised patterns should be seen in a **ferrofluid** experiment, together with an explanation for the existence of localised hexagon patches seen in the ferrofluid experiment of Richter (Bayreuth).

Interests of some NWGFD members overlap with those of FSG, especially in the areas of large scale atmospheric flows, optimal transport and complex geometry. Wolf, McOrist and Roulstone organised a **Clay Mathematics Institute** workshop on Geometry and Fluids in 2014 that focussed on elliptic Monge-Ampere equations, hyper-Kahler geometry, optimal transport on manifolds and applications to **atmosphere/ocean flows**.

In June 2020, Tronci was appointed Adjunct Professor at Tulane University (USA) within the Department of Physics & Engineering Physics. As part of his Leverhulme grant (2014), Tronci led an international collaboration composed of Tassi (Marseille), Lapenta (KU Leuven), and Philip J. Morrison (UT Austin), which focussed on applications of geometry to kinetic-fluid systems. Further collaborations with Bondar (Tulane, New Orelans), Gay-Balmaz (CNRS/ENS Paris), and Rawlinson (Leeds) spawned new results on quantum-classical dynamical models in chemical physics. Under a London Mathematical Society Scheme 3 award, Tronci is the coordinator of a national **Network in Applied Geometric Mechanics** involving three groups working on core topics in geometric mechanics: geometric quantum dynamics (Brunel), geometric imaging science (Imperial College), and geometric fluid dynamics (Surrey).

Cheng is a co-I (EPSRC grant) with Wingate (Exeter) and Cotter (Imperial) studying oscillations in fluid dynamics associated with large but finite restoring forces. This entails the less studied notion of "near resonance" for which some exciting results have been discovered. PDRAs are involved on all three sides, with the Surrey effort further supported by Cheng's Leverhulme grant. The Surrey team is the theoretical pillar focussing on rigorous analysis, informing and informed by teams in Exeter (GFD and computing) and Imperial (computing). This interdisciplinary endeavour really serves as an intellectual highway that links deep mathematical theory all the way to applications such as **numerical weather prediction**. Results so far have also suggested new fundamental understanding of the predictability of fluid motions in geophysics.

Continuing with the theme of geophysical flows, Turner collaborated with Norbury (Oxford) and Cheng on problems relating to moist convection in the atmosphere. This is driven by the need to better represent convective processes in numerical forecasting models. In collaboration with Cullen and colleagues at the Met Office, and the **EPSRC Network Maths Foresees** (led by Bokhove (Leeds)), a small team tackled fundamental issues in the modelling and analysis of moist convection. The Department, under the auspices of Maths Foresees, organized and hosted a two-day meeting on `Coupling convection and large-scale dynamics in numerical weather prediction models', held in March 2016.

The fluid mechanics theme is further continued as the DoM is part of the **EPSRC UK Fluids Network** (led by Juniper and Linden (Cambridge)). This network comprises of 42 Special Interest Groups (SIGs), spanning 66 institutions, which address industrial, scientific and societal challenges as joint efforts. Turner is a member of the SIG `Boundary layers and complex rotating flows', while Turner and Bridges are members of `Surface and internal waves'. Under this latter SIG the Department organised and hosted a two-day meeting on `Wave Structure Interaction' held in January 2020.

Hanada, working with Tezuka (Kyoto), Gharibyan (Stanford), and Swingle (Maryland) have pioneered **numerical study of supersymmetric gauge theories**. The numerical precision achieved enables testing the gauge/gravity duality, including the quantum gravitational corrections, which has had significant impact in the field. Torrielli and collaborators have established themselves as a leading group working on lower dimensional **AdS/CFT integrability**, with application to the massless scattering of excitations in AdS2 and AdS3 backgrounds. They have solidified collaboration with researchers in the UK (City, King's College) and internationally (Utrecht, Torino, Berlin, ETH), and attracted major funding (EPSRC-SFI and Galileo Galilei Institute, Florence) to reinforce a program now in an intense phase.

Grant has a long-standing collaboration with Mathematics (Kunzinger, Steinbauer) and Physics (Chrusciel) in the **University of Vienna**. Recently, papers with Kunzinger and collaborators have resolved long-standing issues relating to **low-regularity singularity theorems** (Graf-Grant-Kunzinger-Steinbauer 2018) and causality theory (Grant-Kunzinger-Saemann-Steinbauer 2020). These papers were produced while Grant was an International Coworker on Kunzinger's 329k Euro FWF research grant (P28770). Grant's collaborative projects with Vienna are ongoing, and he is now involved in the 389k Euro FWF research grant (P33594) of Steinbauer, until 2025.

Brody's work on the classical **Zermelo navigation problem** is concerned with finding the time-optimal navigation under external, uncontrollable current. The quantum counterpart of the problem concerns time-optimal control of quantum state under external field. This has an important application in the implementation of quantum technologies. Brody obtained an exact solution to the problem, published in four papers including one in PRL. He has also made substantial progress in studying an operator for the nontrivial Riemann zeros. The **Hilbert-Polya programme** is concerned with (a) finding an operator whose eigenvalues correspond to the "imaginary" parts of the nontrivial zeros of the Riemann zeta function, and (b) establishing the self-adjointness of the operator.

4.2. Contributions outside academia

The **MoLSS** group has made significant contributions to projects that include partners outside academia. The EPSRC and TfL (Transport for London) funded work on sleep and circadian rhythms has contributed significantly to impact. As detailed in the case study, the work has been widely reported in the media including the New York Times, Die Welt and The Times and was referenced in the California Senate Bill 328 on pupil attendance and school start times and also quoted in parliament by two MPs (documented in Hansard).

Skeldon is a Co-I on the Care and Technologies Centre, Dementia Research Institute, a £20M Imperial/Surrey project which began in June 2019 and will run initially for six years. She has also worked with TfL on an IAA funded project on **biomathematical models of fatigue**. Skeldon will run the two-day workshop *Multilevel dynamics of human and animal sleep: mathematical models meet data* (Surrey, 30-31 March 2020, but postponed to summer 2021), funded jointly by the Surrey Institute of Advanced Studies, Surrey Sleep Research Centre and DoM. She also ran an interdisciplinary seminar series called DREAMS (Data and Rhythms: Expertise, Analysis, Modelling and Simulation) from 2015-2017, which involved 18 cross-disciplinary seminars.

Lloyd and his collaborators in the **Surrey Centre of Criminology** develop and apply continuum and agent-based modelling techniques. Lloyd has been involved in the development of a novel algorithm known as the **Ensemble Poisson Kalman Filter** (EnPKF). This improves our ability to provide forecasts of crime rates, particularly for short-term crime hotspots. This information will be valuable to the police in allocating resources. EnPKF also has the potential to monitor train delays, earthquake aftershocks and insurance claims.

Aston and Godolphin, working in data science and statistical design, have focussed on experimental design, data assimilation and the application of techniques of **attractor reconstruction** and **machine learning** to time series analysis with applications in medical diagnoses and cardiology.

Derks is co-investigator on the EPSRC/MRC funded Quantitative Systems Pharmacology network (led by Reading, in collaboration with Warwick and AstraZenica, GSK and Pfizer), and is part of the LMS-funded network **Mathematics in Life Sciences** (Nottingham, Southampton, Surrey). Non-academic collaborators include Pfizer (CASE-like PhD studentship and MMath integrated projects), APHA (CASE-like PhD studentship), McLaren (PhD studentship), Data Sciences International and AD Instruments (partners in IAA project), AstraZenica (MMath integrated projects) and Medimmune.

Work in the areas of epidemiology, ecology and population genetics, includes the genetics of rapidly growing populations, vector-borne diseases such as malaria and bluetongue and intestinal helminths in association with the **School of Veterinary Medicine**. Future plans in this research theme are likely to involve NPL, who have expressed an interest in issues relating to surveillance data and remote sensing/climate monitoring which is important in modelling the spread of infectious diseases.

Further evidence for the contribution that research in the DoM makes to society can be found in our three impact case studies: *Mathematical models for sleep, light and the body clock: influencing school start times, permanent daylight saving and shiftworkers* (led by Skeldon); *Advancing the development, public understanding and benefits of global weather forecasting* (led by Roulstone); and *Symmetric Projection Attractor Reconstruction (SPAR) improves the quality and relevance of respiration monitoring device data* (led by Aston).

4.3. Wider influence and contributions to the discipline

Members of the department have undertaken over 65 talks at International Conferences/Schools and have been involved in organising a range of international events, notably;

- Bridges was a plenary speaker at the SIAM Nonlinear Waves Conference in Cambridge in August 2014.
- The department hosted the **British Applied Mathematics Colloquium** at Surrey, 10-12 April 2017. Organisers were Lloyd, Roulstone and Skeldon and there were 335 attendees, one of the largest outside Oxbridge.
- Aston was on the organising committee for the workshop The Mathematics of Machine Learning, University of Bath, 3-8 August 2020.
- Bridges was the principal organiser of a Summer School for PhD students titled Theory of Water Waves held at the INI, Cambridge in July 2014, and was co-organiser of the four-week INI programme on water waves in Summer 2014.
- Derks is on the organising committee of the QSP-UK (Qualitative Systems Pharmacology) network, EPSRC funded from 2015-2018 and still ongoing, and was on the organising committee of the LMS funded network Mathematics in Life Sciences (2015-2018). Derks was on the programme committee of the 2018 SIAM Conference on Nonlinear Waves and Coherent Structures, and co-organised the Mathematical Pharmacology workshop at the Lorentz Centre,NL (December 2015).
- Lloyd co-organised (with Short (Georgia Tech) and Kolokolnikov (Dalhousie University)) the workshop on Mathematical Criminology and Security at the Banff International Research Station, Canada, March 2019. Lloyd co-organised the ICMS workshop on Mathematical Criminology 2020. Lloyd was on the organising committee for Advanced Mathematical and Computation Tools in Metrology and Testing (29-31 August, 2017), University of Strathclyde.
- Skeldon organised a multidisciplinary workshop at the Lorentz Centre on Human Circadian Rhythms (co-organisers: Forger, Michigan, and Dijk, Surrey).
- Torrielli has been a principal or key organiser of several international events, including the Hamilton Institute workshop Integrability in Lower Dimensional AdS/CFT at Trinity College, Dublin, May 18-22, 2020; with Gutowski and Roulstone (Surrey), Penati and Pasquetti (Milan), the Bicocca-Surrey School on Prospects in Strings, Fields and Related Topics, Milano, September 2018; scientific advisor (with Gutowski) for the String Geometry, Supersymmetric Theories and Dualities conference, Summer 2017, Surrey; co-organiser of the Galileo Galilei Institute - GGI programme New Developments in AdS3/CFT2 Holography, March 20 - May 12, 2017; co-organiser (with Prinsloo) of SEMPS at Surrey, 2015 and 2018 editions; co-organiser (with Pasquetti and former postdoc Regelskis) of the conference New Trends in Quantum Integrability, 18-22 August 2014.
- In addition, Torrielli was co-organiser of the **Tomorrow's Mathematicians Today** National Undergraduate Conference at Surrey. Torrielli also gave five lectures at the Durham YRIS school on integrable systems in 2015 and received the best lecturer award.

- Tronci was on the organizing committee of the International Conference on New Trends in Applied Geometric Mechanics, ICMAT Madrid, 3-7 July 2017, and was on the scientific committee of the International Conference on Geometry, Mechanics and Dynamics at the Bernoulli Center, Ecole Polytechnique Federale de Lausanne, Switzerland, 20-24 July 2020.

Wolf was principal organiser (with Jurco (Charles), Saemann (Heriot-Watt) and Schreiber (Czech Academy of the Sciences)) of the 2018 **LMS-EPSRC Durham Symposium** Higher Structures in M-Theory.

4.4. Fellowships and other marks of esteem

Zelik was awarded the title "Thousand Talents Plan Distinguished Professor" by the Chinese government's Thousand Talents Program. The award includes 5 Million RMB for research expenditure over three years, and Zelik spends six months each year at Lanzhou University.

For three years from August 2014 until his retirement, **Roberts** was seconded from the DoM to the **African Institute for Mathematical Sciences** (AIMS), a network of six postgraduate training and research centres across Africa that recruits students from the whole continent. As Rector of AIMS Tanzania he had overall responsibility for establishing and leading a new centre established in partnership with the Tanzanian government. Over the three years the centre graduated 140 masters' students from 18 African countries, most of whom continued to further research training in Africa or overseas. Roberts continues to support the development of mathematics through his membership of the board for the London Mathematical Society's Mentoring African Research in Mathematics (**MARM**) scheme.

Derks has been awarded a Hedda Andersson Visiting Professorship at Lund (Sweden), from April 2020 for three years.

Editorial representation

- Bridges is an associate editor of Discrete and Continuous Dynamical Systems – Series S, and Water Waves, an Interdisciplinary Journal.
- Brody is an editor of the International Journal of Theoretical and Applied Finance, Journal of Physics A, and Information Geometry.
- Derks is an editor of the Journal of Geometric Mechanics.
- Wulff is on the editorial board of SIAM Review's Survey and Review section and was re-appointed to a 3-year term of office (2016-2019) as Associate Editor of the SIAM Journal of Applied Dynamical Systems, having served as an editor since 2013.
- Zelik is on the editorial board of Proceedings of the Royal Society of Edinburgh, Section A: Mathematics.

Peer review

- Bridges is a member of the UKRI Future Leadership Fellowships Peer Review College (2018-19).
- Derks: LMS Research Grant Committee (2015 onwards) and EPSRC mathematics prioritisation panels in Nov 2018, Feb 2018 (interviews for programme grants), Feb 2017, June 2016 and March 2016. She also chaired the prioritisation panel for the Hubs for Mathematical Sciences in Health Care in Dec 2019; chaired the interview panel in February 2020 and was due to chair the mathematics prioritisation panel in June 2020 (postponed due to Covid).
- Dunlop was a member of the EPSRC prioritisation panels in June 2015 and Nov 2017, and interview panel for UKRI future leader fellowships (June 2019).
- Skeldon has been a member of the EPSRC College since 1998 and was a member of the EPSRC mathematics prioritisation panel Sep 2016, fellowship interview panel, Jul 2018 and DTC interview panel, Nov 2018.
- Derks, Dunlop and Turner are also EPSRC Associate College members.

- Roulstone remains a member of the NERC Peer Review College, and chaired the EPSRC Fellowship panel in July 2017.
- Wulff sat on the EPSRC mathematics prioritisation panel, Feb 2017.

Prize Committees

Aston was a member of the IMA Lighthill-Thwaites prize committee at BAMC 2017. Bridges was Chair of the prize committee for the SIAM Kruskal Prize 2014. Derks Chaired the J.D. Crawford Prize, awarded at the 2015 SIAM meeting May 17-21, Snowbird and was also a member of the selection committee for the 2017 prize.

Roles in professional bodies or committees

- Aston was **Chair of HoDoMS** (2017-20) and was a member of the **Bond Committee** formed by EPSRC to support a "Review of Knowledge Exchange in the Mathematical Sciences".
- Skeldon represented Surrey on the BAMC committee 2015-2019.
- Roulstone is a member of the IMA's Research Committee. Roulstone has also chaired the Scientific Steering Committee, and the Strategic Advisory Committee, of Mathematics of Planet Earth (EPSRC CDT, ICL and Reading).
- Torrielli is the contact person for the Surrey node of the GATIS+ (Gauge Theory as an Integrable System) network.
- Bridges was Chair of the SIAM activity group on Nonlinear Waves and Coherent Structures (NWCS) from 2014-16.

Books

Aston is an editor of *UK Success Stories in Industrial Mathematics,* which is based on impact case studies submitted to REF2014. Santitissadeekorn is co-author of *Applied and Computational Measurable Dynamics (Mathematical Modeling and Computation)* SIAM 2014. *Symmetry, Phase Modulation, and Nonlinear Waves* by Bridges was published by Cambridge University Press in 2017 and Hanada has recently published the Japanese edition of *Foundations of Markov Chain Monte Carlo* with S. Matsuura, and an English edition will follow.

At an annual meeting of the American Meteorological Society, Roulstone was awarded the 2015 Louis J. Battan Award for his book *Invisible in the storm: the role of mathematics in understanding weather.* The citation reads "For Invisible in the Storm, which illuminates the mathematical foundation of weather prediction with lucid prose that provides a bridge between meteorologists and the public." German and Chinese translations are in production (see impact case study).