

**Institution:** University of Leicester

**Unit of Assessment:** UoA10

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

Leicester's School of Mathematics is internationally recognised for its vibrancy in a wide range of pure and applied fields in mathematical science. Our research activity thrives through a collegial atmosphere among a team of outstanding research staff and students, a diverse funding portfolio, cutting-edge interdisciplinarity research, and a collaborative approach to seeking solutions to major mathematical, societal, and economic challenges.

Our research is both curiosity driven and challenge led. We address key questions around algebra, geometry, and algebraic topology, focusing on new connections and interactions between these disciplines, as well as new adaptive finite element methods, methods for higher dimensional data analysis, and fundamental limits of machine learning and artificial intelligence (AI). We engage with real-world challenges relating to ecological complexity, modelling granular matters with applications to physics and astronomy, and predictive modelling in healthcare.

Headline achievements during the REF period include:

- A new model of mathematical structures called weak  $n$ -categories (**Paoli**).
- Introduction of decomposition spaces, which unify coalgebraic constructions in combinatorics, K-theory, and representation theory through categorification (**Tonks**).
- Development of geometric models in representation theory connecting representation theory, geometry and combinatorics (**Schroll**).
- Development of finite elements methods for grids with arbitrary shapes (**Georgoulis**).
- Discovery of new concentration of measure phenomenon: stochastic separation (**Gorban, Tyukin**).
- A new state of active matter discovery: swirlons (**Brilliantov**).
- Delivery of significant societal and economic impact, ranging from increased predictive modelling accuracy in the NHS (Mirkes ICS1) to implementing innovative chip development with advanced image processing (**Tyukin** ICS2) to improving efficiency of natural resource extraction (Levesley).

The School's research activity is organised functionally into three Research Groups: (1) **Algebra and Geometry (AG)**; (2) **Data Analytics and Artificial Intelligence (DAAI)**; and (3) **Mathematical Modelling and Numerical Analysis (MMNA)**. The Groups operate as nuclei for research staff and students with related interests and specialisms. Researchers also work across and beyond these groups, stimulating interdisciplinary interactions and developing long-lasting collaborations in health technologies and healthcare, security, and space and earth observation sectors.

By revising our research and impact strategy since REF2014, we have increased our research income per FTE by 260% and number of doctoral completions by 204% and led more than a third of the University's Innovate UK portfolio. Our research has been widely published, including in journals such as *Science*, *Nature Communications*, *Physical Review Letters*, and *Advances in Mathematics*, and 66% of our outputs are published with international co-authors (SciVal). We are also playing a significant role in the development of Space Park, Leicester (Institutional Environment Statement (IES), 2.1), leading work on data analytics and AI.

**RESEARCH AND IMPACT STRATEGY**

**Objective.** Our overarching objective is to provide a vibrant, cohesive, and inclusive environment that supports and enables our researchers to produce high-quality and impactful research. The UoA is distinct for its exploration of key questions, pursuit of novel ideas, and connecting ground-breaking advancements in representation theory, numerical analysis, modelling, and mathematical foundations of AI to real-world application.

**Principles.** The 7 guiding principles of our research and impact strategy are to:

1. Provide leadership at the forefront of research bridging modern algebra and geometry, particularly in representation theory.
2. Develop emergent areas of excellence in DAAI and MMNA.
3. Maximise the impact of our research by utilising our expertise in AI, data analytics, and modelling to solve real-world problems and by working with industry to identify areas of applied research.
4. Support interdisciplinarity collaboration by facilitating links between the School and local, national, and international hubs, projects, centres, institutes, and universities.
5. Recruit and develop outstanding research staff to provide leadership and expertise in key and emerging research areas and facilitate impact, as well as nurture early career researchers.
6. Recruit and develop research students from the UK and overseas to ensure the continued growth of our PhD cohort and produce well-rounded researchers.
7. Increase the diversity and volume of our funding portfolio to support research and impact activities, and provide support for the preparation of large cross-disciplinary and consortium-led research proposals.

**Approach to impact**

During REF2021, there has been a step change in the School's outward-facing research activity. Impact is an inherent part of our research planning, with over £1M of external research funding coming from 7 Innovate UK projects. The principal beneficiaries of our research are schools, the public, government bodies, health authorities, NHS patients, and industry. We have grown industrial and health mathematics, with a 13-fold increase in industrial-related income (£430k) and 7-fold increase in funding from the UK government and health and hospital authorities (£526k) since REF2014.

The mechanisms employed to achieve this step change include:

1. *Interdisciplinary collaboration.* We recognise the benefits of an interdisciplinary approach to addressing social or industrial problems. We build and sustain strategic partnerships with stakeholders across interdisciplinary research networks, including Leicester's College of Life Sciences, the Leicester Institute for Advanced Studies (IES, 2.2), Institute and Faculty of Actuaries, the Trauma Audit and Research Network, and Space Park Leicester. This activity enabled, for instance, improved predictive modelling in the NHS (Mirkes, ICS1).
2. *Fostering new industrial partnerships.* Our work in applied mathematics involves extensive engagement with partners and research users. Since 2014, we have developed and strengthened relationships with more than 80 individuals across more than 40 organisations and companies, including Procter and Gamble, GlaxoSmithKline, AstraZeneca, Nestle, KPSnacks, and NTT. We engage with partners via Innovation

forums and workshops at the Leicester Innovation Hub (IES, 2.5), focused hackathons, and pilot Space Research and Innovation Network for Technology (SPRINT) projects, totalling £150k (UK Space Agency). Partnerships with industrial stakeholders have led to significant economic impact, including the creation of novel computer vision technology with ARM whose products reach up to 70% of the global population (**Tyukin**, ICS2).

3. *Impact leadership and support.* We created a new post of Impact Coordinator (**Tyukin**) who is responsible for liaising with business and industry for the purpose of communicating departmental capability, as well as providing advice and support to colleagues to improve understandings of impact, impact planning, and generating and gathering robust impact data. In addition, we benefit greatly from the expertise and support provided by the University's Research Impact team. We have also been awarded ~£22k of internal funding specifically to pump-prime enterprising and impactful research.
4. *Public engagement and mathematics communication.* We have orchestrated a comprehensive programme of community engagement activities to make mathematics accessible to the public. Examples include: a collaborative project, led by **Leschke**, exploring the communication of mathematics through art (£112k, Wellcome Trust/Leverhulme/UoL) and contributions to BBC radio Leicester on a number of topics aiming to popularise mathematics (**Schroll**).

**Achievement of key aims outlined in REF2014.** Overall, our aim was to support staff to build their research portfolio, generate high-quality outputs, and develop significant impact. Below, we list our key strategic priorities, with corresponding major achievements:

*REF2014 Aim: Recruit RAs for fundamental research and to work on industrially-funded projects.*

Through EPSRC and Leverhulme funding, EPSRC fellowships, and a Royal Society fellowship, we established a vibrant community of 13 Research Associates. In addition to RAs working on fundamental research, we secured 6 Knowledge Transfer Partnerships funding 6 RAs working on challenge-led research across high-energy physics, smart materials, and security in image processing and chip development. The School further collaborated with industry on 7 SPRINT projects, and other externally-funded projects, all partly funding RAs.

*REF2014 Aim: Develop research with economic, cultural and scientific impact.*

Over the REF period, we have developed and delivered significant social and economic impact. This includes but is not limited to: creating more accurate and robust decision making models in medical applications for the NHS (Mirkes ICS1); novel concentration of measure theorems leading to robust, high-accuracy, affordable technologies for smart video analytics (**Tyukin** ICS2); and improving oil services provision (Levesley).

*REF2014 Aim: Engagement with the research community through the organisation of workshops and conferences involving world leading experts.* We have hosted over 13 conferences and workshops, including several large conferences such as the 31<sup>st</sup> Summer Conference on Topology and Its Applications and the 32<sup>nd</sup> British Topology Meeting. In addition, the School hosts an annual Colloquium which has featured Jacob Lurie (Breakthrough Prize Winner) and Martin Hairer (Fields Medallist). We actively promote equality and diversity by hosting a diverse range of speakers and organising thematic public lectures, such as Black Heroes in Mathematics.

*REF2014 Aim: Build up research in visualisation.*

In 2015, we secured £200k (UoL/Innovate UK/industry) to launch the Visual Intelligence Laboratory. The VisLab provides working space and high-tech equipment to support research and teaching in visualisation in geometry and modelling. We have built expertise in areas such as data mining and visualisation, geometry and visualisation, and intelligent image processing. The facility has strengthened our relationships with industry, leading to 3 Innovate UK KTP partnerships, and supported impact development through improvements to AI systems.

**Achievements by research group.** The following are brief descriptions of the three Research Groups (including lists of both participating Category A staff and those who have made significant contributions to research) and selected research and impact highlights, as evidence of the effectiveness of our research strategy.

**Algebra and Geometry** [Baranov, Leschke, Neumann, Mudrov, Paoli, Pirashvili, Schroll, Semeraro, Tonks: 9 staff, 12 PhD students]. The Algebra and Geometry group conducts research at the intersection of modern algebra and geometry. This spans research in algebraic topology, homological algebra, representation theory, algebraic geometry, differential geometry, combinatorics, category theory, and mathematical physics. At the centre of this group is modern algebra, a fast-developing emerging discipline based on the systematic use of homological algebra and representation theory in other areas of mathematics, such as homological mirror symmetry, categorification, combinatorics, and mathematical physics.

Highlights include:

1. **Paoli's** monograph, *Simplicial Methods for Higher Categories: Segal-type Models of Weak  $n$ -Categories* (Springer 2019), which presents a new model of mathematical structures called weak  $n$ -categories.
2. Connecting the representation theory of finite dimensional algebras with the homological mirror symmetry programme (**Schroll**), supported by an EPSRC Early Career Fellowship, a Royal Society Newton International Fellowship, and a Horizon 2020 MSCA.
3. Leading and participation in international and national research networks such as Leverhulme Research networks, LMS networks, and the Royal Society International Exchanges.
4. A programme of public engagement events centred on expressing mathematics through the arts (**Leschke**), £110k (Wellcome Trust/Leverhulme Trust/UoL).
5. Leading the mathematical research coming out of 'Landscape Decisions' (UKRI Strategic Priorities Fund, £10.5M), a programme that will address the challenge of delivering better evidence-based decisions through research collaboration to inform decision-making about landscape, land-use, and land assets (**Petrovskii, Schroll, Tyukin**).

**Data Analytics and Artificial Intelligence** [Gorban, Grechuk, Paganini, Tyukin, Wang, Mirkes: 6 staff, 14 PhD students]. The DAAI group conducts research in mathematical foundations and applications of machine learning, AI, and data analysis. The research focus of the group includes the concentration of measure phenomena in high-dimensional spaces, methods for dimensionality reduction, inverse problems, and optimization.

Highlights include:

1. Discoveries of novel concentration of measure phenomena, stochastic separation theorems, have underpinned new methods and algorithms for fast, scalable, and reliable handling and removal of errors in AI systems, as well as learning in low-sample high-dimensional settings. This research led to 2 US patents and a novel video processing chip licensed by ARM to Ingenic Semiconductors and Foxconn (**Tyukin** ICS2), and has been widely published (e.g. **Gorban, Grechuk, Tyukin: Information Sciences** 2019, *Neural Networks* 2017, *Proceedings of the Royal Society* 2018, and *Physics of Life Reviews* 2019). The excellence and transformative potential of this research is recognised through the EPSRC Turing AI Acceleration Fellowship (£1.4M, **Tyukin**), major grants such as the EPSRC UK Trustworthy Autonomous Systems Verifiability Node (£2.9M, **Tyukin**), AHRC Arch-I-Scan (£0.8M, **Gorban, Mirkes, Tyukin**), and through the UK-Malaysia MRC Long-Term anatomical fluid dynamics for new Univentricular Heart Palliation project (£318k, **Tyukin**).
2. **Gorban, Mirkes** and Levesley's monograph, *Personality Traits and Drug Consumption* (Springer 2020), is the first to demonstrate that certain personality traits, together with simple demographic data, make it possible to predict the risk of drug consumption.
3. Improved understandings about data inaccuracies within medical applications and predictive models in the NHS led to more accurate and robust performance-related assessments of, and decision making about, NHS hospitals and services (**Mirkes/Gorban** ICS1).
4. Establishment of the Artificial Intelligence and Data Analytics and Modelling Centre.
5. Leading AI and data analytics work packages for the new Manufacturing, Engineering, Technology and Earth Observation Research Centre at Space Park Leicester (**Georgoulis, Gorban, Levesley, Paganini, Tyukin**).

**Mathematical Modelling and Numerical Analysis** [**Brilliantov, Davidchack, Georgoulis, Gorban, Morozov, Paganini, Petrovskii, Utev, Levesley**: 8 staff, 20 PhD students]. The group conducts multidisciplinary research in mathematical physics, mathematical ecology, and biology underpinned by fundamental research in numerical analysis.

Highlights include:

1. Advancements in Hilbert's Sixth Problem through research on hydrodynamic manifolds for kinetic equations, with a special issue in the *Proceedings of the Royal Society A* 2018 and an article in the *Bulletin of the AMS* 2014 (**Gorban**).
2. To underpin modelling, the group has developed new numerical methods accepting general meshes (**Georgoulis: SIAM Scientific Computing** 2017, *IMA Journal of Numerical Analysis* 2019, and *Numerische Mathematik* 2017).
3. Improved understanding of mathematical ecology centring on animal behavioural responses, kinesis of animals, and microorganisms and plankton-oxygen dynamics under global climate change (**Morozov, Petrovskii: Science** 2018 and *Physics of Life Reviews* 2020). This research received media attention from national outlets such as the *Mirror*.
4. Derived generalized Smoluchowski equations have enabled the explanation of size distribution of particles in Saturn's Rings (**Brilliantov: PNAS** 2015 and *Physics Review Letters* 2017) and predictions of a novel natural phenomenon, such as an increasing temperature of cooling in granular gases (**Brilliantov: Nature Communications** 2018). These results have attracted extensive press coverage such as in *Daily Mail*, *Huffington Post*, and *The Telegraph*.
5. New applications of mathematical modelling of flows, and numerical analysis of PDEs, have improved the efficiency of terrain exploration and provision of oil services. This led



to significant impact in the profitability, technological developments, and the recruitment strategy of Weatherford International, one of the largest oil and gas companies in the world (Levesley).

**Governance and integrity.** Review, development, and implementation of our research and impact strategy is the responsibility of the unit's Research and Enterprise Committee, comprising a cross-section of representatives from early-career researchers to Chairs. The Committee is also responsible for promoting a culture of research integrity, ensuring that researchers—particularly students and ECRs—understand the expected standards and obligations, as outlined in the Concordat to Support Research Integrity. We adhere to institutional requirements (IES, 2.7) and support researchers to embed best practice in all aspects of their work.

**Open research.** In addition to observing REF policy and institutional requirements (IES, 2.6), we have embedded a culture of open research. In Leicester's first Open Research Survey, 100% of mathematics researchers agreed that they believed there is value in anyone being able to access their research and 70% agreed that they had actively made more of their research freely available and accessible since 2014. During the assessment period, 73% of our outputs were published open access, compared to the Russell Group average of 63% (SciVal). We have further made conference papers, reports, and a book, *Personality Traits and Drug Consumption* (Levesley and Mirkes, 2019), openly accessible. Many of our researchers are editors and/or on the editorial board of open-access peer-reviewed journals, including Diamond OA journal *Compositionality* (Paoli), and share code and preprints via platforms such as *Github*, *arXiv*, *bioRxiv*, and *zenodo*.

### Future research strategy plans

Our aim is to grow impactful and internationally-leading research by focusing resources around key points of research excellence and by expanding collaborations across the University, as well as locally, nationally, and globally. We aspire to:

- Work closely with computer scientists to form an interdisciplinary world-leading group centred on AI and machine learning through Artificial Intelligence, Data Analytics, and Modelling Centre.
- Establish a strong interdisciplinary computational modelling group by exploiting existing high-quality and impactful research at the frontier of numerical analysis methods, mathematical ecology, and ecological complexity.
- Broaden our industry collaborations to deliver significant economic and societal impact and develop existing collaborations, including: Space Park Leicester; spearheading work ensuring that autonomous systems are reliable and dependable as part of the EPSRC Trustworthy Autonomous Systems programme; and the AHRC Arch-I-Scan project to develop a first-of-a-kind tool for automatic classification of archaeological artefacts and revolutionise how artefacts are identified and recorded.

## 2. People

### STAFFING STRATEGY AND STAFF DEVELOPMENT

**Staffing strategy.** Our overarching goal is to recruit and retain exceptional mathematical scientists to deliver world-class research in our Research Groups. To achieve this, we have developed the following strategy:

1. We recruit outstanding staff at all career stages to enhance research and impact objectives.
2. We secure externally-funded positions, including through UKRI, Royal Society, Horizon 2020, Leverhulme Trust, Health Foundation, and Wellcome Trust.
3. We target appointments that will facilitate links between disciplines and develop relationships with industry.
4. We retain staff by providing robust support, career development opportunities, and recognise and reward success.
5. We ensure staff can flourish in an equal and inclusive working environment.

**Staff composition and recruitment.** All recruitment is conducted in a fair, transparent, and flexible way in order to attract a diverse pool of candidates. Appointments are made on merit with reference to the Unit's research and impact strategy and assessed by diverse selection panels adhering to DORA-compliant principles. We value breadth and specialisation across a range of activities. Of the 20 UoA10 staff, 7 are lecturers, 5 are Associate Professors, and 8 are Professors. Our research activity is supported by 9 PDRAs, 2 teaching fellows, and 5 teaching-focused staff. New appointments were made in Algebra (**Semeraro**), Algebraic Topology (**Tonks**), Data Analysis and Statistical Modelling (**Wang**), and Numerical Analysis (**Paganini**). We have also created new permanent roles to support our challenge-led research and knowledge transfer activities, including a Research Associate (Mirkes), a Research Software Engineering Specialist (Kappas), and Data technician (Tyukina).

**Staff development and promotion.** We ensure that the principles of the Concordat to Support the Development of Researchers are implemented at School level. All staff have an annual Performance Development Discussion (PDD) with the Head of School. Evaluating individual research and impact performance and future ambitions are core components of these discussions. Bespoke training and support needs are also identified and action plans created accordingly. PDD reports are reviewed by the Head of School to identify candidates for promotion and consider whether interventions are required, e.g. workload adjustments and additional mentoring. Leicester's most recent staff survey (2019) showed that 88% of respondents from the School of Mathematics agreed that their PDD objectives were SMART and helpful.

We have an active and fully-paid study leave programme to focus on research and impact, which staff can take one semester in every seven. There are rigorous application and evaluation procedures for study leave involving the Head of School and the Research Committee, with subsequent review and approval by the College to ensure that staff achieve maximal benefit and that study leave goals are ambitious and deliverable. This has led to, for example, a £1.2M EPSRC Fellowship in Graphs in Representation Theory (**Schroll**).

All academic staff have access to a dedicated School research, impact, and travel fund to support a range of activities. This is done by redirecting a fraction of grant overheads and QR funds to individual researchers and research groups. During the REF period, we have allocated £70k to support conference attendance and organisation, research dissemination, networking, knowledge exchange, and outreach activities.

We encourage all staff to utilise the professional development programme provided by the Doctoral College (IES, 3.2). Four staff (1 female) have taken part in the Leicester Future Leaders' Programme, which aims to foster a community of diverse leadership talent by nurturing individual strengths and valuing different leadership skills and styles.

Knowledge exchange, enterprise, and impact, as well as high-quality research, are a key part of the assessment criteria for promotion cases. During the assessment period, 11 academic staff have been promoted to senior positions, including 7 to Associate Professor (**Tyukin, Wang, Leschke, Morozov, Schroll, Paoli**, and Cangiani) and 4 to Professor (**Georgoulis, Schroll, Tyukin**, and Clark).

**Early career researchers (ECRs) and fixed-term staff.** ECRs, RAs, and fixed-term staff are given additional support to help begin mapping their future career path. This includes assigning them a mentor with whom they meet regularly to discuss research and impact goals.

We strongly encourage our ECRs to apply to one or more of the University's internal grant schemes, where priority is given to early-career scholars, and all ECRs/RAs who applied for the Proof-of-Concept Fund (IES, 2.5) were supported. These schemes provide opportunities to gain experience in grant writing, independently manage self-directed projects, and secure University-funded extensions for existing fellowships. To increase visibility and integrate them into the department, ECRs/RAs are invited to organise and speak at departmental research seminars. We also provide logistical and financial support to ECRs/RAs organising research events and conferences to facilitate new and lucrative networks outside of Leicester. In 2019, for example, Treffinger organised an international research school on 'Representation Theory Meets Tropic Geometry', which was attended by 30 international delegates. We also utilise institutional funding to support ECRs, including Health Foundation Accelerator Fellowships (**Wang**) and LD3 funding for Research Fellows on innovative projects (**Wang**), as well as interdisciplinary research projects (Meshkinfamfard, Wilson, Burton, Kolesnikov). Several ECRs/RAs have gone on to secure highly competitive permanent academic and postdoctoral positions at Leicester and beyond.

**Visiting Scholars.** During the REF period, we have hosted more than 300 visiting academics from more than 20 countries, including Yuri Matiyasevich (negative solution of Hilbert's tenth problem), Jacob Lurie (Breakthrough prize 2014 winner), and Martin Hairer (Fields Medal).

## RESEARCH STUDENTS

We highly value our research students and their contribution to the research environment. During the REF period, 70 research students have completed their doctorates—representing a 204% increase since REF2014. The significant improvement in the size and success of our PhD community is a reflection of both the talent and ambition of the research students we attract and a marked improvement in our research activity. In the Postgraduate Research Experience Surveys (PRES 2013-2020), an average of 91% of mathematics PGR respondents at Leicester agreed that they were 'overall, satisfied with the experience of my research degree programme'.

**Recruitment.** Attracting both national and international research students through studentships (including 16 EPSRC studentships), robust support mechanisms, and developmental opportunities is a strategic priority. Industrial partnerships are also key to how we attract high-quality research students who may not be eligible for traditional routes available to home/EU. Industrial research funding and waiver of tuition fees enabled us to support and retain one further international student suffering from political persecution in their country of origin and who has been subsequently granted refugee status.

PhD students are recruited via open competition. Applications are centrally administered and a diverse panel interviews short-listed candidates. Successful applicants are selected primarily based on research potential, performance during interview, academic experience, and mapping



research projects to Research Groups. We further ensure new staff have access to PhD students as they begin to grow their teams.

**Supervision, training, and development.** An average of 94% of PGRs agreed that their 'supervisor/s provide feedback that helps me direct my research' (PRES 2013-2020). All students are allocated two supervisors. Students meet with their Director of Research at least once a month and notes are kept so that we can monitor engagement and attendance. Secondary supervisors are closely involved in the conception and development of the project. Progress is also monitored more formally by a panel independent of the supervisory team at three and six months, and then annually until the viva. For the reviews, students are required to submit a written report detailing their progress and future research plans, as well as a training needs analysis form to inform a tailored training plan.

In addition to central PGR training provide by the Doctoral College, the School aims to train doctoral students in line with the Vitae Researcher Development Framework. All three of our Research Groups mimic successful NSF-funded VIGRE projects and training networks by providing various weekly research seminars and meetings, in which PGRs present their research to peers and staff. These sessions are an opportunity for students to discuss their progress and receive comments and feedback on their research in an inclusive and supportive environment.

Leicester is also one of the nodes of the MAGIC consortium, shared by 21 universities, which provides postgraduate-level lectures in mathematics by video conference. All PhD students are required to take at least 3 MAGIC courses. Courses typically entail 40-80 hours of study and an extensive range of discipline-specific topics are offered, from algebraic geometry to functional analysis.

In PRES 2013-2020, an average of 92% of PGRs agreed that both their skills in 'critically analysing and evaluating findings and results' and 'applying appropriate research methodologies, tools and techniques' had developed during their programme.

**Employability and next destination.** Since 2014, our PGR graduates have progressed onto a wide range of highly competitive academic, industry, and related professional roles. Around half have gone on to secure Postdoctoral positions in the UK (Durham, Nottingham, Exeter, and Loughborough, Newcastle, UCL) and the US (Harvard, Michigan), and Lectureships at universities across the UK, Europe, Turkey, Iraq, and Saudi Arabia. A number have also progressed to industry posts, such as data science and data analysis, actuarial consultancy, and R&D roles in companies linked to Leicester research (ARM and Barclays) and international SMEs.

### **EQUALITY, DIVERSITY, AND INCLUSION (EDI)**

EDI is a priority in the unit. We adhere to Leicester's institutional EDI strategy and policies (IES, 3.1) and acknowledge that we cannot reach our potential unless we can benefit from the talents of all.

Our work towards tackling gender inequality was recognised by an Athena Swan Bronze award (2015, 2018). During the REF period, promoting female leaders and increasing the visibility of female role models in Mathematics has been a key aim. We promoted three female staff to senior roles: one to Professor (**Schroll**) and two to Associate Professor (**Paoli**, **Leschke**). 12% of Professorial staff are female (UK average is 6%) and 33% of Senior Lecturers are female. We have a dedicated budget for staff to attend women in mathematics events. In addition to

actively seeking out potential female candidates, we provide enhanced support to RAs, particularly through grant writing and encouraging female participation in KTP projects. Since 2019, we have increased the number of women participating in KTPS from 0 to 3.

While we have a highly international staff profile, we recognise that we need to greatly improve our BAME representation (currently at 10%). By engaging with the Race Equality Charter, we have created an action plan to increase BAME representation and visibility. Our action plan includes establishing Fellowships through the new Artificial Intelligence and Data Analytics and Modelling Centre specifically targeting BAME candidates; increasing the diversity of external speakers; and exploiting links with the Mentoring African Research in Mathematics network (through **Neumann**) by training, mentoring, and collaborating with students and staff from various African universities.

We hope the diversity of our PhD community indicates a snapshot of the profile of our School in the future. During the REF period, 42% of our PhD cohort were female and 47% were BAME. This is a reflection of our recruitment practices, which actively seek out talent from underrepresented and underprivileged groups. We also ensure that we provide support for research students with specific learning needs to ensure success. This includes bespoke support for one child prodigy. Staff have undertaken safeguarding and child protection training and the School has established a tailored approach to monitoring their progress, wellbeing, and mental health.

Around 11% of staff have formal flexible working arrangement, though we fully support flexible and remote working on a more informal basis to facilitate a healthy work/life balance and accommodate those with caring responsibilities.

**EDI and REF.** We are submitting all eligible staff in our REF return. UoL's REF Code of Practice specifies how our REF return has been compiled with due regard to EDI. In advance of this, we ensured a diverse mix of staff were involved in output quality review. We have a supportive process in place for declaring staff individual circumstances in relation to our REF submission, guided by our EDI Champion (**Tyukin**) and University's EDI team. We have robust support structures in place so that even staff facing substantial challenges have been able to produce outputs for REF.

### 3. Income, infrastructure and facilities

#### RESEARCH INCOME

During the REF period, our research income totalled ~£3.5M, with a total spend per FTE of £187k—a 260% increase on REF2014 (£52K/FTE). Our principal sources of external research funding were awarded by the EPSRC (£1.1M), UK-based charities (£559k), UK governmental bodies and health authorities (£526k), industry (£430k), and EU governmental bodies (£321k).

**Strategy for generating research income.** Following REF2014, the School committed to increasing its outward-facing activities, including interdisciplinary and knowledge exchange projects, the success of which is reflected in both a significant increase in the volume and diversity of our funding portfolio. We have made notable gains in several areas, including a 1225% increase in industry funding, a 648% increase in UK government funding, a 288% increase in EU government, and a 165% increase in UK-based charity funding. In addition, we have secured funding from Research Councils outside our discipline, such as the AHRC and MRC.

We have created roles specifically to support grant applications for UKRI, UKSA, and charities. The School further capitalises on College- and institutional-level support for the preparation and costing of research grant applications, provided by our Head of Department, Director of Research, Research and Enterprise Division, Research Institutes, and Key Funder Working Groups. This support package includes raising awareness of funding opportunities, internal peer review of early-stage to fully-developed research proposals, mentoring, progress reviews, and workshops to ensure a good understanding of funder requirements.

*Major grants:* We are Co-Investigators in interdisciplinary research funded by AHRC (**Gorban**, Mirkes, **Tyukin**) & MRC (**Tyukin**), together totalling £1.1M. **Gorban**, Mirkes, **Tyukin** are Co-Is on the Health Foundation's 'Insights Research Programme' (£350k) and the UKRI 'Trustworthy Autonomous Systems: Verifiability Node' (£2.9M), where they lead on development of new AI and Data Analytics methods in relevant application areas. Both **Schroll** and **Petrovskii** are Co-Is on the Coordination Team for the 'Strategic Priority Fund Landscape Decisions Programme' (£725k). The School hosts Fellowships including an EPSRC Early Career Fellowship of £1.2M (**Schroll**), a £1.4M EPSRC Turing AI Acceleration Fellowship (**Tyukin**), a Royal Society Newton International Fellowship £95k, Heilbronn Research Fellowship £214k (**Semeraro**), and a Horizon 2020 MSCA Fellowship, £200k. In addition, the School has obtained funding from the Leverhulme Trust in the form of research project and research network funding totalling £299k (**Georgoulis**, **Leschke**).

*Industry partnership support:* The School has led more than a third of the UoL Innovate UK KTP portfolio. Members of MMNA and DAAI lead 7 UKRI Space Research and Innovation Networks for Technology projects (Levesley, **Paganini**, **Tyukin**). DAAI are PIs on six Innovate UK projects, total more than £1M (Mirkes, **Tyukin**), and AG leads another Innovate UK project (£245k, **Mudrov**). Members of DAAI are support academics for a further two KTPs. Furthermore, through our expertise in data analytics and AI, we provide consultancy services and direct contract research with multinationals such as Alstom, ARM, Weatherford Int., Rolls-Royce, and General Electric to a total of circa £230k. This is a key part of our strategy for conducting research to solve real-world problems and has generated £754k in consultancy and contract income.

**Future strategy to generate income.** We recognise that an over-reliance on a small number of sponsors creates vulnerability. Our strategy led to a balanced research income profile between charities, industry, Government, and Research Councils, ensuring future research income streams are more sustainable and robust to external economic and political changes. We hope this diversity will provide a degree of insulation against fluctuations in the funding landscape, supported by a strengthening of our industrial links and challenge-led research opportunities in areas of AI, data analytics, and modelling.

## INFRASTRUCTURE AND FACILITIES

**Physical infrastructure.** The AG Group has a dedicated building with a new Common Room, serving as research lab space for group meetings and ad hoc seminars. The DAAI and MMNA Groups are located in the Michael Atiyah complex, a shared space with Engineering, Physics, and Astronomy and Space researchers, comprising both offices, research and seminar space, and laboratories. This building houses the Leicester Space Research Centre, which provides engineering capability in space, building the next generation of instrumentation and tools for space exploration, and facilitating a number of interdisciplinary collaborations, including our work packages associated with the new Space Park Leicester. Additionally, the School has

acquired a cluster of short-term and long-term visitor offices within the two buildings, underpinning the extensive visitor programmes connected to the EPSRC fellowship and the Innovate UK partnerships.

### Specialist infrastructure and facilities

**Centre on Artificial Intelligence and Data Modelling (AIDAM).** The University has supported the School in the set-up and launch of the newly founded AIDAM (£100k, 2020). AIDAM carries out, consolidates, and integrates research on AI, data science, and machine learning to develop data-driven AI systems that are resilient, robust, trustworthy, and adaptable to changing operational conditions. A major objective of the centre is to facilitate AIDAM-driven fundamental and challenge-led research, in particular, supporting collaborations with the Life Sciences and industry. Current projects include the development of AI technology for learning and recognition of tactile gestures (**Gorban**, Levesley, Mirkes, **Tyukin**) with Tangi0's smart touch sensitive material (£380k, Innovate UK KTP). In the short time since its launch, AIDAM has supported interdisciplinary projects and industrial partnerships totalling over £5.5M.

**Leicester Visual Intelligence Lab (VisLab).** Launched in 2015, the VisLab supports research and teaching in data mining and data visualisation, geometry and visualisation, and intelligent image processing. The VisLab is funded by the University Research Equipment and Infrastructure Fund (£60k) and external funding from Apical Ltd. (£100k). It provides working space and high-tech equipment, including GPU servers, a 3D projector, a high-performance desktop, and bespoke hardware for infrared computer vision analysis. VisLab has supported impactful research in developing efficient visual intelligence technologies, including efficient real-time object detection, recognition, and false positives suppression in live video streams. Through the VisLab we have secured three Innovate UK KTP partnerships with ARM and Visual Management Systems Ltd, improving the performance of existing AI systems through methods based on the fundamental property of measure concentration in high dimensional spaces (**Gorban**, **Tyukin**: *Information Sciences* 2019).

**High Performance Computing.** UoL is renowned for its provision of nationally-significant HPC facilities (IES, 4.3). All staff and students have access to two large HPC clusters, ALICE and SPECTRE, providing maximum performance for the most demanding data processing, data analysis, and simulation tasks. These facilities have supported the development of new fully adaptive discontinuous Galerkin methods accepting meshes with arbitrarily-shaped elements (Cangiani, EPSRC £99k; **Georgoulis**, Leverhulme Trust Grant £200k), leading to high-quality articles such as one on hp-Version discontinuous Galerkin methods on polygonal and polyhedral meshes (*SpringerBriefs in Mathematics* 2017). These HPC clusters have further facilitated 3 completed PhD projects with considerable HPC components, including the development of parallelised large-scale long-timescale whole-mantle simulation software, with discontinuous mixed FEM and a-posteriori error estimation for mesh adaptivity, with implementation in an open source code, ASPECT (Cox).

**Leicester Institute for Advanced Studies (LIAS).** LIAS facilitates new ways of modelling and translating interdisciplinary research (IES, 2.2). Our unit has secured and capitalised on LIAS-driven funding schemes designed to facilitate interdisciplinary networks and collaborations, amounting to £30k project funding, plus £120k fellowship funding over the REF period. Our School has received pump-priming funding for interdisciplinary projects relating to Arts and Mathematics (**Leschke**) and Decision Making and Risk (**Tyukina**, **Tyukin**), and Cardiac Scar Quantification (**Tyukin**).

**Other infrastructure.** The unit has access to Leicester's award-winning library (IES, 4.2). In addition to our Research Group seminars, we run a further three seminar series which include external speakers: Pure Mathematics, Applied Mathematics, and AIDAM seminars. Videos of these seminars are posted on the dedicated seminar webpages, accessible to all staff and students. The UoA is also the grant holder for 2 LMS network grants (BLOC, Yamcats), and is a node in a further three (Artin, EMSG, TTT). Since May 2020 in response to the COVID situation, the AG group has launched a new international online seminar series, 'Leicester Algebra and Geometry Open ONLINE Seminar', in collaboration with the ICMS in Edinburgh.

#### Future investments

Members of staff from the UoA have been fully engaged in the development of the case for the various activities of Space Park Leicester (IES, 2.4, 4.4), including industrial engagement (**Tyukin**) and training (Levesley). The first phase for SPL will be open in spring 2021. Following on from the initial phase, a further investment of £13.75M through the UK Research Partnership Investment Fund (**Gorban**, Levesley, **Tyukin**) has leveraged an additional £50M from the University and business to support the Manufacturing, Engineering, Technology and Earth Observation Research Centre (METEOR). METEOR will be a key part of SPL, bringing together academic research (including researchers from this UoA) and industrial space and Earth observation R&D. The centre represents an internationally unique approach to understanding and delivering space capabilities, revolutionising how satellites are conceived, designed, operated and produced, as well as how data derived from them is interpreted and used to solve real world problems. The UoA contributes to SPL and METEOR, in particular, through expertise in mathematical modelling, numerical analysis, data analytics, and machine learning (**Georgoulis**, **Gorban**, Levesley, **Paganini**, **Tyukin**).

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

##### COLLABORATION WITH AND CONTRIBUTION TO THE RESEARCH BASE

Our staff have led and contributed to multiple research collaborations resulting in high-quality outputs and notable advancements in mathematical science. These include collaborations with colleagues from ~20 different UK HEIs and ~40 universities, including Oxford, Cambridge, Ecole Polytechnique, Institut Curie, Orsay, Harvard, MIT, Yale.

**Leschke** leads the 'Minimal Surfaces: Integrable Systems and Visualisation' network (Leverhulme Trust (£105k). Partnering with researchers from the Universities of Tsukuba, Granada, College Cork, and the Technical University Munich, **Leschke** has created an international network dedicated to the study of minimal surfaces, with the aim to develop new methods by exploiting the link of minimal surfaces to integrable systems and, by using computer-based experiments, provide new tools to approach the classical Finite Topology Conjecture. The network has facilitated a rich programme of research, workshops, seminars, and research visits, including applications of Quaternionic Holomorphic Geometry to minimal surfaces (**Leschke**, *Complex Manifolds* 2016).

**Morozov's** collaboration with colleagues (**Petrovskii**, **Gorban**) and researchers from Arizona State, University of California, Yale University, University of Waterloo, Case Western Reserve University, and others made significant advancements in understandings of transient dynamics in ecology. By utilising **Morozov's** expertise in non-linear systems of ordinary, partial, and integro-differential equations, the group were able to organise a systematic study of transient dynamics in ecological systems. This made it possible to understand when transients are likely to occur and the various properties of these transients, with implications for ecosystem



management and basic ecological theory (*Science* 2018, *Physics of Life Reviews* 2020). The development of such a framework for organising the study of transients in ecological systems opens up a number of avenues for future research and application, and raises important questions for further development in dynamical systems.

**Neumann** is currently the chair of the 'Mentoring African Research in Mathematics' (MARM) scheme of the London Mathematical Society. MARM links African academics with their UK and European counterparts via professional mentoring partnerships. In doing so, MARM provides the means and opportunities for African mathematicians to develop international working relationships while also improving the quality of academic provision within their home institution. **Neumann** is involved in research mentoring PGRs and ECRs at universities in Ghana, Tanzania, and Malawi. In addition, he has co-supervised research students at the African Institute for Mathematical Sciences in Senegal and Tanzania.

### **COLLABORATION AND CONTRIBUTION, BEYOND ACADEMIA**

Our School has made significant contributions to the economy and society through collaboration and partnerships with industry, end users, and beneficiaries. We have bettered healthcare standards and diagnostics, devised more efficient methods for monitoring greenhouse gases, developed new capabilities in satellite imagery analysis, increased productivity of resource extraction, and increased public safety and security.

**Health.** DAAI has worked closely with the Trauma Audit Research Network on improving accuracy of mortality estimates. Mirkes's and **Gorban**'s research (*Nature Communications* 2014, *Information Sciences* 2018, *Computers in Biology and Medicine* 2016) validated the feasibility of implementation of the Paediatric Observation Priority Score (POPS), a method of quantifying patient acuity. The POPS score is used in 12 hospitals and 4 ambulance services in the UK, supporting clinical decision making by helping to 'identify a range of severity of childhood illness, to support staff in taking the decision to redirect the child to primary care or discharge to self-care, and to help them in expediting senior/specialist assistance for deteriorating children' (letter of acknowledgement from POPs, ICS1). The group further works with the University Hospitals Leicester and National Institute for Health Research on externally- and internally-funded research projects on better healthcare standards and diagnostics in the context of quantification of damage in heart tissue after infarction (**Tyukin, Wang**; LD3, BHF, NIHR, ~£100k).

**Environment and sustainability.** DAAI collaborates with the NERC National Centre for Earth Observation (NCEO) on developing next generation systems for efficient monitoring of greenhouse gases using satellite-derived data (Fenwick, **Tyukin**). Our research produced novel, scalable, data-driven AI algorithms capable of accurate inference of greenhouse gas concentrations without using HPCs. Jointly with NCEO, 2Excel geo, Satellite Applications Catapult, DAAI develops novel AI methods for automated ground validation of the intelligence derived from airborne and orbital assets, including rapid assessment of roadside trees' health using dash cameras (SPRINT £18k, **Tyukin, Tyukina**). Additionally, our partnership with Bluesky International, an aerial mapping company, has enabled new capabilities in satellite imagery analysis (SPRINT £32k). Together, we are developing a new portfolio of geospatial data products for the UK insurance sector. Using machine learning and AI, combined with satellite imagery and aerial survey data, the project will improve the analysis of key urban environmental data to automatically recognise building classifications and structure detail (**Tyukin**).

Another major collaboration includes Weatherford International plc, a multinational company which provides technologies and services to the oil and gas industry. This resulted in the development of a new software tool for visualising the structure of the Earth. Pseudo-outcrop visualization of borehole images (Levesley, Mirkes, **Gorban**: *Mathematical Geosciences* 2017) created by the software transforms data into a solid 3D volume, which can be sliced to simulate how rocks might look in a natural outcrop setting. Data acquired along the length of the borehole provides information about the physical and chemical properties of the rocks, allowing materials of interest to be identified, as well as nearby geological structures that may be targeted for future drilling. Leicester research not only transformed knowledge about mathematical modelling and AI capabilities in resource extraction but was directly responsible for assisting Weatherford in retaining a \$15M contract.

**Safety and security.** Partnership with Apical/ARM on the development of new chips for advanced image processing led to the ingenic t01 chip for advanced image processing analytics. The development of this chip is underpinned by more than 10 outputs in high-impact journals, an Innovate UK KTP project and a PhD studentship from Apical/ARM, and formed one of our impact case studies (**Tyukin** ICS2). Our KTP with Visual Management Systems Ltd (VMS) was awarded 'outstanding' by Innovate UK for its achievement of developing leading edge convergent low-cost, power-efficient security systems capable of realtime facial recognition. This research resulted in a spin-out company increasing public safety and security using patented AI technology, Titan AI. Drawing on Leicester research (**Gorban**, Mirkes, **Tyukin**), Titan AI provides unique Advanced Imaging Module (AIM) architecture, algorithms, and machine learning capability, operating at the forefront of cutting-edge high-speed video, behaviour analytics, and image processing technology. One of its flagship products, Titan Detect, offers unique advanced face recognition and detection software products, utilising the latest AI, neural network, and analytical techniques developed at Leicester to provide high-speed high-accuracy facial detection and recognition. It provides state-of-the-art image analysis for applications in, for example, law enforcement, airports, hospitality, retail, transportation, and smart cities. Furthermore, we collaborated with Synoptix Ltd to develop, for the first time, a provably certifiable AI system to help Network Rail in gathering accurate census data from rail level crossings across the UK (£197k Innovate UK KTP, **Gorban**, **Tyukin**, Tyukina).

**Public Engagement.** The School has a strong public engagement component. **Leschke** initiated the 'Minimal surfaces: artists' views' (Wellcome Trust ISSF £5k) project, wherein artists and mathematicians worked together to explore how modern mathematics can be effectively communicated to non-experts. Outputs included two performance evenings, attended by the public as well as mathematicians. Building on this, LIAS (£5k) and the ISSF Wellcome Trust (£2k) supported an interdisciplinary and international research 'Maths Meets Arts' team, led by **Leschke**, to explore creativity in mathematics and communication of mathematics through creative expression. Work of this group was showcased at the 2020 Bridges Conference short Film Festival, which offered a glimpse into this meeting of art and minimal surface theory. The Maths Meets Arts team organised the first (virtual) Maths Meets Arts Festival in July 2020 with daily themes, including Maths & Games, Maths & Music, Maths & Dance, and Maths & Creativity. In addition to journal articles on creativity in mathematics and informatics (*Manuscripta Mathematica* 2020), a game is being developed which explains representation theory of algebras and exploring mathematical surfaces as a virtual reality adventure.

We also contribute to policy/parliamentary engagement. **Tyukin** is a member of the All-Party Parliamentary Group on Artificial Intelligence (APPG AI), set up in January 2017 to explore the impact and implications of AI. The APPG AI, co-chaired by Stephen Metcalfe MP and Lord Clement-Jones CBE, gather evidence and create reports and Parliamentary briefs on key

aspects and challenges of AI, such as education, AI adoption, Citizen Participation, Data governance, Sustainability, and Health and Wellbeing. **Tyukin** contributes to APPGI by sharing his expertise and knowledge on benefits and challenges of AI related to Sustainability and Health and Wellbeing.

## ESTEEM AND EVIDENCE OF LEADERSHIP

*Editors, Associate Editors and Editorial Board Members:* Staff in this UoA hold editorships for over 20 journals, including: *Bulletin of the LMS* (Q1, **Schroll**); *Communications in Nonlinear Science and Numerical Simulations* (Q1, **Tyukin**); *Compositionality* (new open-access journal, **Paoli**); *Physical Review Letters* (Q1) (**Brilliantov**); *Scientific Reports: Fluids* (Q1) (**Brilliantov**); *SIAM Journal on Numerical Analysis* (**Georgoulis**, Q1); (**Grechuk**); *Information Fusion* (Q1, **Wang**).

*Guest editorships: Conference and Research School Proceedings:* Select examples include: *Special Issue of Advances in Applied Mathematics* (**Schroll**); *Special Issue in Applied Soft Computing* (**Tyukin**); *Special Issues in Mathematical Modelling of Natural Phenomena* (**Gorban**, **Tyukin**); *Special Issue in Neurocomputing* (**Tyukin**); *Special Issue in Measurements* (**Wang**); *Special Issue in IEEE Biomedical and Health Informatics* (**Wang**); *Special Issue of the Royal Society Proceedings A* (**Gorban**).

*Leadership in professional bodies:* Select examples include: Board Member for the LMS-IMU-AMMSI committee on the research initiative Mentoring African Research in Mathematics MARM (**Neumann**); Board Member of the European Mathematical Society (**Neumann**); Committee for the Support of Eastern European Mathematicians, (**Neumann**); LMS Council Member (**Neumann**); Member of the IMA Research Committee (**Schroll**); Member of the LMS International Affairs Committee (**Schroll**); Member of the LMS Prizes Committee (**Schroll**); Member of the Technical Committee on Adaptive and Learning Systems of IFAC (**Tyukin**).

*Organisation of International Conferences.* Select examples include: 31<sup>st</sup> Summer Conference on Topology and its Applications 2016 (Clark); LMS-EPSC Durham Symposium-Building Bridges: Connections and Challenges in Modern Approaches to Numerical PDEs 2014 (Cangiani, **Georgoulis**); 32<sup>nd</sup> British Topology Meeting 2017 (**Tonks**); Modelling Biological Evolution Workshop (biennial) 2015, 2017, 2019 (**Morozov**, **Petrovskii**); Model Reduction Across Disciplines 2014 (**Gorban**); Dynamical Systems for Aperiodicity 2015 (Clark), and; MPDEE'18 2018 (**Petrovskii**, **Morozov**).

*LMS workshops.* Select examples include: Cluster Algebras and Finite Dimensional Algebras 2015 (**Schroll**); Variational Methods in Submanifold Theory 2017 (**Leschke**); Galois covers, Grothendieck-Teichmüller theory and dessins d'enfants 2018 (**Neumann**, **Schroll**); LMS-CMI Research School 2018 (**Neumann**); Interactions between representation theory and homological mirror symmetry 2019 (**Schroll**).

*Keynotes and Plenaries.* Select examples include: World Congress on Computational Intelligence 2020 (**Gorban**); Category Theory CT2019 (**Paoli**); and Latin American Algebra Colloquium 2019 (**Schroll**).