Unit-level environment template (REF5b)

Institution: University of York

Unit of Assessment: 10 - Mathematical Sciences

1. Unit context and structure, research and impact strategy

Our submission to UOA10 represents the Department of Mathematics at York, comprising around 50 academic staff, 10 postdoctoral researchers, 50 PhD students, and 12 support staff. Our research covers the full spectrum of mathematical sciences: **Pure Mathematics**, covering a wide range of topics in algebra, geometry, analysis and number theory; **Statistics and Probability**; and a diverse variety of disciplines in **Applied Mathematics**, including mathematical physics, quantum information, mathematical biology and chemistry, and mathematical finance. **Thirteen new academic appointments** have strengthened these areas and the links between them. The Department has doubled in size over the last 20 years, including strong **growth in PDRFs, PDRAs and PhDs** in the current REF period.

Research income has more than doubled compared to the previous REF period, to over £7M, driven by strategic commitments to **diversify funding** (now from over 30 different sources), and to secure more fellowships. Fellowship successes include **Royal Society University Research Fellows** in 2018 and 2019, an **EPSRC Established Career Fellowship** in 2018, and many others. We have also run major research programmes including an **EPSRC programme grant**, the **EPSRC Quantum Communications Hub**, and a **Wellcome Trust Senior Investigator** award. Compared to the previous REF period, our total postdoctoral population has increased by 50%, as has the size of our PhD student body. We are proud of our record of nurturing mathematicians at an early stage of their career, and those returning to academia after a career break: over 90% of our postdocs in this period have gone on to a further position in academia, including international fellowships (e.g., at the ETH in Zurich) and permanent positions in the UK (e.g. Durham, Warwick) and overseas.

There is a strong **interdisciplinary** aspect to much of our work; in our output portfolio 30% of papers have an interdisciplinary flag. The structure of the Department encourages work between mathematical disciplines locally, and we have **active collaborations with 13 other centres** across all three faculties — Sciences, Social Sciences, and Arts and Humanities — of the University [IES8]. This interdisciplinarity is reflected in and supported by our joint appointments with other units, notably Biology, and our financial contributions to multidisciplinary University centres, such as the York Cross-disciplinary Centre for Systems Analysis. Externally, York is a node in **10 LMS Scheme 3 networks**; on the international stage examples include the trans-national MINOUW consortium and support from Collaborative Research Centres in Germany and the Anglo-Franco-German network in Representation Theory.

We have instituted a responsive system of **Departmental funding for research and impact** (e.g., totalling £65K in 2019/20), including dedicated budgets to support our ECR and PhD student community and the development of fellowship applications. Interdisciplinarity is supported through our **External Engagement and Impact** and **Collaborative Research Exchanges** schemes (described in detail below). We have a comprehensive research leave scheme, and successfully encourage staff to use their entitlement to further research ambitions. Workload modelling, allied to a drive for efficient teaching programmes, has enabled us to preserve a minimum of 40% of staff time for research. All research groups have **dedicated seminar series** supported by Department funds totalling £20K per annum, consistently running over 140 seminars per year. We have a Departmentally funded **ECR Forum** to support the development of academics at the start of their careers.

The **physical environment** of the Department has been transformed — during this REF period we have invested in the redevelopment of 5000ft^2 of space. Significant enhancements include our new collaborative space “The Topos”, new accommodation for our PhD students in the “Paul Busch Room” and a dedicated space for our 150 Masters students in the “Dusa McDuff Room”.

The creation of the Topos has given us a **custom-made seminar and interaction space** at the lakeside, transforming the day-to-day working life of the Department.

Strategy and Future Goals

Our current and future plans coalesce under three broad headings, reflected and evidenced through the rest of this document, and aligning with the wider University strategy [IES9].

- **Enhancing Excellence:** We will support the world-leading research of our internationally respected groups, and recruit to strengthen and broaden our expertise across the spectrum of mathematics and statistics. Building in particular on our successes with fellowships in this REF period, we will continue to expand and diversify our funding portfolio to enhance the research environment at York.

- **Capitalizing on Interdisciplinarity:** We will build on our wide experience of interdisciplinary work and collaborations to stimulate new connections, knowledge transfer and impact. Mathematics at York has successfully developed a multi-disciplinary web of connections – locally, nationally and worldwide – and a focus will be to encourage and support colleagues to engage with industry by providing responsive and flexible support for such activities.

- **Training Future Generations:** We will mould the future of the discipline through our excellent support and nurturing of Early Career Researchers and PhD students. Our commitment to this strand will be reaffirmed through our suite of professional development and training activities, the Early Careers Forum, and strong investment in our PhD programme, including the funding of Departmental studentships. We are fully committed to the principles laid out in the Concordat to Support the Career Development of Researchers [IES27-28].

Reflection on REF2014

In the REF2014 submission we planned specifically to:

1. "Selectively strengthen [our] world-leading groups, drive the development of smaller groups towards success … win substantial research funding."
2. "Further strengthen interdepartmental and external collaboration … enhance interdisciplinary collaboration, impact and knowledge transfer."
3. "Maintain and develop our strong MSc/MRes portfolio … to provide income, supply PhD students and support external links."

Success in 1 is shown by the appointment of world-class mathematicians to all groups (details below), and our success in securing prestigious fellowships across the Department. For 2, as evidenced throughout this document, interdisciplinarity is a key strength of much of our work. Highlights include the **UK Quantum Technology Hub for Quantum Communications Technologies** [IES11b], a major national project in partnership with nine other universities and the public and private sector. We continue to support vibrant interdisciplinary links through other University-wide initiatives such as the **York Cross-disciplinary Centre for Systems Analysis**, the **York Environmental Sustainability Institute** [IES42] and the **Biological Physical Sciences Interdisciplinary Network**. Point 3 proved to be highly prescient -- we have recently expanded our portfolio to include a broad **MSc in Mathematical Sciences**, starting in 2018/19, which has grown rapidly and generated several strong internal PhD applicants.

Research Structure of the Department

We are submitting 48 staff (47.08 FTE) for this UOA, an increase of over 50% on the last REF period: 16 Professors, 6 Readers, 13 Senior Lecturers, 11 Lecturers (all permanent contracts) and 2 independent Research Fellows. The interdisciplinary nature of much of our work is reflected in several joint appointments, whose contribution to our research environment is invaluable.

Unit-level environment template (REF5b)

The research strengths of the Department are structured through seven research groups. By nurturing the groups, each of which provides an organising centre for **grant applications** and **training**, we cultivate a world-class research culture for the whole Department. Each group runs a **weekly seminar series** with external speakers**,** supplemented by multiple **research lecture mini-series** (over 20, on topics as diverse as *Wetting Phenomena* and *Gaudin Models and Vertex Algebras*) **and study groups** (developing common understanding of a vast array of topics, from *p-adic numbers* to *buildings*, with many cutting across groups in areas such as *random matrix theory in ecology* and *cluster algebras*). These develop connections and integrate younger talent to create in each group a whole greater than the sum of its parts.

(At first mention, staff who left York in this period are marked *, new appointments in *italics.*)

Algebra:
This group has made major contributions to the department's strategy on income and training. It has been boosted by the Royal Society URF for *Geranios*, built on the success of his collaboration with Donkin – see their complete characterization of the first cohomology groups for Specht modules in odd characteristics (*Adv. Maths 2019*). Geranios was previously a PDRA on the EPSRC project of M Bate in Algebraic Groups, Buildings and GIT. Nazarov has received two EPSRC grants with PDRAs around Cherednik Algebras and Affine Lie Algebras, and Gould has had a grant with a PDRA in Representations of Semigroups. Gould has also supervised three fellowships (two Schlumberger Stichting Fund, one Marie Curie), and supplements the main algebra seminar with a regular Semigroup series. The group was supported with the appointment of *Dufresne* when Donkin retired; as well as complementing the group's work in invariant theory, Dufresne's work on the geometry of sloppiness (*J. Alg. Stats. 2018)* brings an exciting new programme of applied algebraic research to the department.

Geometry & Analysis:
Investment to bring this group to critical mass has been a key theme of this REF period. The appointments of *Wilkin* and the Royal Society URF *Simmons* have bolstered the group and provided key connections with other groups. For example, Simmons' work at the interface of Number Theory and Analysis includes landmark work on random walks on homogeneous spaces and Diophantine approximation on fractals (*Invent. Math. 2019*), his far-reaching framework using Gromov hyperbolic metric spaces to approach problems in Diophantine approximation (*Mem. Amer. Math. Soc. 2018*), and an answer to one of the most important open problems in dynamical systems (*Invent. Math. 2017*). New appointment *Wilkin* has been supported to form a Geometry, Analysis and Mathematical Physics seminar to explore mutual interests with other groups in Yang-Mills-Higgs theory, integrable systems, the geometric Langlands programme and Morse Theory. Eveson (*J. Comput. Phys. 2017*) studied models of wave propagation in groundwater systems in the aftermath of the tragic earthquakes in New Zealand, exemplifying our strategic aim to develop impact across all groups.

Number Theory:
This group has flourished throughout this REF period, supported by £2M funding which includes an EPSRC Programme Grant (Beresnevich, Velani) bringing 11 postdocs to York over a 6-year period. The group also attracted a Career Acceleration Fellowship (Haynes*), two standard EPSRC grants (Haynes/Velani) and an EPSRC first grant (Zorin). The appointment of Simmons (previously a Programme Grant PDRA) connects Number Theory and Analysis. Research highlights include Velani's solution to Davenport's problem (*Math. Ann. 2014*) and Beresnevich's breakthrough on badly approximable points on manifolds (*Invent. Math. 2015*). The group has expanded its reach and collaborations via three international workshops held at York (2014, 2016 and 2017) and an Arbeitsgemeinschaft in Oberwolfach (2016). The group has been a major contributor to interdisciplinary research: the 2014 and 2016 workshops targeted collaborations with electronic engineers, resulting in outputs motivated by wireless networks — Beresnevich, Levesley, Velani, Zorin (*Adv. Math. 2016*) and Zorin (*J. Math. Pures Appl. 2018*) — and a *Springer Nature book* (2020) edited jointly with researchers in electronics engineering. Other directions include Zorin's exploration of applications of automatic numbers with computer scientists at Oxford and Haynes' strong contributions to mathematical quasicrystals.

Mathematical Finance & Stochastic Analysis:
This group has been supported with new appointments to consolidate its strength — a new position bringing *Litterer* to York, *Rodrigues* to replace Kang* — and the forging of new connections. *Thijssen*, joint with the York Management School, brings exciting new research directions and interdisciplinarity, with concomitant impact opportunities (e.g., his current involvement with a NERC project on Coastal Ecosystem Recovery). The group has made major contributions to the research strategy of the department: Brzezniak has supported fellowships (Newton Fund and Marie Curie), and the work of Kang with Lacima has great potential for future impact. Research highlights include Litterer's work with Hairer and others on rough paths, linking with the work of the Geometry & Analysis and Statistics & Probability groups.

Mathematical Physics & Quantum Information:
The group has had notable success supporting our research funding vision, in particular with Colbeck's involvement in Phases 1 and 2 of the multimillion-pound EPSRC Quantum Communication Hub (QCH) and two Marie Curie Fellows. Colbeck was part of a collaboration that gave the first experimental proof-of-principle for "device independent" quantum random number generators, and is working towards commercial implementation. The group has been strengthened by strategic appointments. In Quantum Information, *Pusey* (appointed following the sad loss in service of Busch) brings further potential for interdisciplinary applications as well as theoretical work; for example, the development of far-reaching techniques for analysing causation in quantum theory (*New J. Phys 2015*). In Mathematical Physics *Vicedo* was appointed in competition across the University under its "Inspirational Research Leaders" Scheme [IES20]. He brings a ground-breaking programme of research in affine Gaudin models (*Adv. Math. 2019*), and also enhances links with Algebra (exemplified by the partnership of Sklyanin with Nazarov) and Analysis & Geometry.

Mathematical Biology & Chemistry:
This group epitomises our strategic commitment to supporting interdisciplinarity and impact. This is evident in the breadth and depth of interests in the group, with work across Biological Fluid Dynamics and Soft Matter (Bees, Gadelha*, Pushkin), Ecology and Evolution (*Constable*, Delius, joint appointment Pitchford), Systems Biology (joint appointment AJ Wood), Mathematical Virology (*Dykeman*, joint appointment Twarock), and Chemical Statistics (Wilson), with many overlaps. Reflecting the diversity of research conducted by the group, three of its members – Dykeman, Pitchford and AJ Wood – are submitted to UOA5 Biological Sciences; their significant contributions to the research environment in UOA10 are also recognised in this document. The group maintains close working relationships with industry (Wilson: AstraZeneca, Croda, Fera, Paraytec; Bees: Unilever), and government and international advisory bodies (Delius: through MINOUW; Pitchford: CEFAS), and is responsible for all our impact cases. There have been several major funding successes, including Twarock's Established Career EPSRC Fellowship and Wellcome Trust Senior Investigator Awards supporting her ground-breaking work in virus structure and assembly. Investment in the group includes the appointment of Constable, and Departmental support for impact and engagement activities to complement external funding (see Impact Strategy below). The group helps us forge strong links across the University, for example via Departmental financial support for the York Cross-disciplinary Centre for Systems Analysis (YCCSA), which houses Dykeman and Twarock, a thriving joint seminar series with Biology (extended virtually to include Leeds and Sheffield in 2020), and symposia within the Biological Physical Sciences Interdisciplinary Network (BPSInet).

Statistics & Probability:
The group has continued to grow strategically, and has been encouraged to explore applications in various fields including biology, economics and finance. The appointment of *Zhao* reaffirms the Department's commitment to support the group's world-leading theoretical work — notable examples include the work of Li on long-range dependent functional time series (*J. Amer. Statist. Assoc. 2020*) and Zhang on panel data structural identification (*Ann. Statist. 2016*). Building on interdisciplinary networks around Knight (e.g., with development of wavelet techniques for biological data), the group expanded to appoint *Powell.* His work focuses on how

to make inferences to influence real-world decisions, creating interdisciplinary links and potential for impact – for example, with mathematical biologist Pitchford studying the tropical disease Leishmaniasis (a major theme for the York Biomedical Research Institute [IES44]), and for the Office for National Statistics, supported by Departmental funding.

Impact Strategy

The Department's impact strategy embraces all research-active members, recognizing that the impact agenda is important across the full spectrum of our research activity, including outreach work. Joint appointments with other centres help to forge and exploit **industrial connections**, transferring knowledge across disciplines and into industrial and commercial settings. We support **impact-related travel and pilot projects** on the same basis as primary research, with credit in the workload model (see below). We have a dedicated funding stream for external engagement, and all our funding mechanisms encourage applicants to consider potential for impact and engagement.

Broadly, our approach has three interwoven strands:

- **to create potential** for impact, by facilitating connections and exchanges of ideas;
- **to enable** impact, by supporting and shaping the progression from research to application;
- **to build** impact, by strengthening existing links with external partners and continuing to invest in existing impact activity.

Our chosen cases demonstrate the success of our strategy over the period. For example, the case study **Marine-Ecosystem Dynamics and Balanced Harvesting: the mathematical underpinnings of a sustainable fisheries policy** was developed over this REF period with Department funding and research leave for Delius to visit collaborators in Chile, Australia and New Zealand, augmenting a £4K University EPSRC IAA Strategic Partnership award with a further £2K. To initiate and support new connections, the Department funds travel, colloquia, research away days, and the hosting at York of workshops and meetings. A data-sharing workshop with Fapas, Fera and Thompsons of York to discuss food proficiency testing, resilient crops, food fraud (Manuka honey) and commodity procurement in the animal feed sector supported the case study **Chemometric methods for food and environmental studies,** and departmental funding allowed case study lead Wilson to visit conferences such as the Annual Conference of the Metabolomics Society (Dublin, 2016). The case study **Statistical pattern recognition applied to protein crystallisation images in the pharmaceutical industry** was supported with funding for Wilson's visit to AstraZeneca; this has also resulted in a CASE PhD studentship.

We have an Impact Lead, an academic member of staff whose remit is to nurture future impact, to build awareness of the impact agenda, and to link our work with wider University themes. For example, marine protection and biodiversity, an important research priority for the wider University [IES12b], is reflected in the Fisheries case study above. Tapping into University support [IES49-50] also led to the award of EPSRC IAA funding for Twarock, the lead on our mathematical virology case study, **Discovery of a virus assembly mechanism using models of viral geometry: new opportunities for anti-viral therapy**, to explore the therapeutic potential for her work on virus packaging signals. Twarock has also been supported in the Department with extensive grant buyout and teaching relief over the period. Section 4 gives further examples of our support for impact during the period.

Open Research, Research Integrity

We publish our research outputs in line with funder and REF requirements, and in line with the University's Policy on the Publication of Research [IES16], ensuring Open Access. Typically, outputs are also deposited on the ArXiv in preprint form, reflecting the fact that the **Open Research culture** has been prevalent in Mathematics for many years now. Many colleagues also produce **open source code** and **software packages**. For example, Powell, Knight and Delius have packages on the Comprehensive R Archive Network (CRAN); usage statistics report over 130K downloads for Knight's packages, 20K for Powell's, and almost 30K for

Delius's Mizer packages (see Marine-Ecosystems Dynamics Impact Case). Colbeck has two Mathematica packages available on GitHub, partly developed by summer research students supported with Departmental funding. Our Research Support Team drives our local approach to Open Research (working with institutional teams).

We have robust mechanisms in place to ensure we adhere to the University Policy on Research Data Management and Codes of Practice on Research Integrity and Principles for Good Ethical Governance [IES14,17]. The Departmental member of the University Physical Sciences Ethics Committee works to raise awareness of ethical considerations, which we have also committed to embed in our undergraduate curricula during the next few years. Concerning wider ethical behaviour, especially in publishing and editorial work, Gould is a member of the **Ethics Committee** of the European Mathematical Society.

2. People

Staffing strategy and appointments

The main goal of our recruitment strategy is to seek colleagues of the highest research excellence, who will have natural exchanges of ideas and potential collaborations with current staff. Appointments support our strategy to:

- **Reinforce existing strength**: for example, the proleptic appointment of Royal Society URF Geranios (Algebra);
- **Expand groups to critical mass**: for example, Geometry & Analysis boosted with two new members, Wilkin and Royal Society URF Simmons;
- **Reinvigorate groups with ECRs**: for example, Dufresne (Algebra) on the retirement of Donkin; Pusey (Mathematical Physics & Quantum Information) upon the sad loss of Busch;
- **Develop new streams of interdisciplinarity and impact**: for example, the appointments of Constable (Mathematical Biology & Chemistry) and Powell (Statistics & Probability).

In total, in this period we have appointed 13 new members of staff. This includes new positions, as part of our long-term strategic plan — e.g., Wilkin — and in response to specific opportunities — e.g., the appointment of Vicedo under the University's "Inspirational Research Leaders" scheme [IES20], and the joint appointment of Thijssen to strengthen ties with the Management School. Six appointments have been made to fill vacancies created by the departure of other staff. We are committed to long-term sustainable appointments for staff [IES26] – Category A submitted staff are almost exclusively on permanent ART contracts; independent research fellows are offered proleptic appointments.

Staff Development

Our goal is to support and enable all staff to do their best work, at all career stages and across all facets of academic life. A comprehensive system of **mentoring for new staff** runs alongside the University's arrangements for probation and for early career staff [IES29]. Personal and career development for all staff is embedded in our **annual performance and development reviews** [IES22]. These are two-way conversations, with a senior staff member trained in the process, usually conducted by the Head of Department or the Head of Section. The reviews are intended above all to **support career development and promotion** aspirations, and underpin the aspirations set out in our Research and Impact Strategies. The emphasis is on support to: submit applications for internal and external funds; attend conferences; apply for research leave and training; build CVs for promotion applications [IES21]. Such activity is also monitored by the Departmental Research Committee across various dimensions including age, ethnicity, gender, and research group. We have a strong record of helping staff to develop into senior research leaders. For example, across the Department, there have been 14 promotions of one or more grades during this REF period (approximately 25% of staff).

Primary research time is enhanced with **research leave** (see below), and a generous **suite of funding** (detail discussed in Section 3 below) for attending conferences and research visits. New staff have an extra £2.5K allowance for the first two years after appointment. Of particular relevance to staff development are the Collaborative Research Exchange initiative and the Fellowship Development Bursary. The former is specifically designed to enable staff to maintain or initiate collaborations through incoming and outgoing visits; this scheme is particularly beneficial for staff with care commitments who are unable to leave York. The latter has allowed us to invite more than 20 potential fellowship applicants to York, helping to initiate new collaborations with ECRs.

A key part of our strategic aim to train future generations is developing our **community of ECRs**, postdoctoral research fellows, PDRAs and research students. In this REF period we have supported the careers of more than 50 postdoctoral colleagues across all our groups, and in return they have enhanced the environment of the department in many ways. This includes many impressive sole-authored publications by PDRAs and PhD students, for example Chow, *Bohr sets and multiplicative Diophantine approximation*, *Duke Math. J.* (2018). By supporting postdocs to undertake key roles in our groups — e.g., organisation of seminar series — we develop CVs and give essential opportunities to expand networks of contacts. Mentored engagement with the teaching activities of the Department helps develop a rounded profile for job applications.

During this REF cycle we have established an **ECR Forum** which has brought together much existing activity for ECRs, postdoctoral research fellows, PDRAs and research students, and also promoted new opportunities. This forum is supported by Departmental research funds – e.g., providing a refreshment budget to support weekly social seminars for ECRs. The activity of the forum is led by its members and supported by our research administration team, for example with help finding appropriate experts from around the university. Alongside this, we are developing a Departmental programme that covers career development and professional training, tying in with courses provided by the university [IES32], covering Self-Management, Research Responsibilities, Governance, Professional Conduct and Communication Skills. Outside York, Gadelha sat on the EPSRC Mathematical Sciences Early Career Forum during the REF period.

Equality and Diversity

We are a department made up of individuals from a range of backgrounds and cultures; for example, we have 22 nationalities represented amongst our staff. We are proud of our record of recognising and celebrating diversity, and in this period have formalised and structured much of what we do through our **Equalities and Good Practice Committee (EGPC)**. The Chair of EGPC sits on the Department Management Team, and has a remit built on the Athena SWAN framework to ensure that consideration of equality, diversity and good practice is embedded in all that we do. We have held an Athena SWAN Bronze award since 2014. The work of the EGPC has positively influenced much of the activity in the Department, including the **support of staff at all career stages**, and is reflected in the Department's strong and inclusive sense of community. One strong indicator of the effectiveness of the combined work of EGPC and the Departmental Management Team to support wellbeing was the 2017 (five-yearly) University Staff Survey. On almost all measures the Department was the best (of 11) in the Faculty, and among the best in the University.

Considerations of **equality and diversity in recruitment** and all other principles from the Concordat to Support the Career Development of Researchers [IES27, 35-37] are now embedded in all stages of our recruitment process. Policies and processes and the writing of job adverts are overseen by the EGPC, with special emphasis on increasing diversity on shortlists and reducing bias in appointments. All adverts include the Athena SWAN logo, express our commitment to equality and diversity, and highlight the options to work flexibly and share jobs whenever feasible (many academic staff have childcare or other constraints factored into annual timetables; eight in 2019/20). Velani has been a key figure in the University's drive for better BAME representation within the promotions process [IES21].

These policies are affecting practice: for example, over this period we have interviewed and appointed a higher proportion of female applicants to academic posts than male. Interview panel chairs all undertake University recruitment and selection training, and we ran training on unconscious bias for all staff in 2014. Candidates with commitments preventing them from attending in person are interviewed online. All staff with direct responsibility for constructing the REF submission have attended REF-specific **Equality, Diversity and Inclusion training,** and at all stages we have considered relevant data in our preparations. For example, we have analysed our output portfolio against protected characteristics including age, disability, ethnicity and gender to ensure that we do all we can to avoid any bias. This is supported by the University's processes [IES35, University Code of Practice].

Recognising the specific need to support the career progression of women [IES21], in this REF period we have given support to a regular "Women's Research Lunch" for all female staff, postdocs and PhD students, providing mentoring on career development and research. Our three women professors (Gould, Head of Pure for much of the period, Twarock, Wilson) are all group-builders and developers of new talent, and provide role models and leadership; Twarock in particular has an international profile as an inspirational woman in mathematics (see our Virology Impact Case). The percentage of female staff at grade 8 or above has increased from 30% to 50% over the REF period. We have hosted two Daphne Jackson Fellows in this REF period — Dickinson with Wilson and F Bate with Bees/Pushkin. Dickinson subsequently secured EPSRC IAA Researcher Mobility funding and then a Research Associate position on a Knowledge Transfer Partnership with Croda (Wilson's work with Croda was also supported by Research Leave in 2018). Another highlight in this period was the EMS exhibition of "Women of Mathematics Throughout Europe", which visited the Department in 2017 and featured our own Rejzner as one of the 13 women chosen for a portrait and interview. We have supported two Schlumberger Stichting Fund "Faculty for the Future" Fellowships, supporting female citizens of developing or emerging economies.

Research Students

Regardless of background or funding source, every student is treated equally. This fosters collegiality and an engaged student community, bringing enduring positive social and academic outcomes. For example, in 2020 we matched UKRI COVID-related funding extensions for our Departmental studentships. Simultaneously, we purchased "gaming" microphones/cameras for our PhD students to seamlessly mix in-person and video seminars; our students immediately extended this facility to all departmental research seminars.

We have made significant **investment in PhD training**, combining increased EPSRC studentship allocation with **strategic Departmental studentships**, a **Doctoral Prize Studentship** (from 2019; benefactor-funded) and an EPSRC NPIF studentship for Wilson. We maintain our excellent record of supporting almost all PhD students to completion within four years, whilst increasing student numbers by 50%. PhD recruitment processes have been revised to acknowledge protected characteristics e.g. by reducing the weight of the interview, thought to unduly disadvantage some students.

Every student has **equal access to funding** for travel, training and conferences; web-based applications are typically approved rapidly by chair's action. Funding is protected in the Department's research budget. We follow the monitoring and progression rules from York Graduate Research School [IES31]. Additionally, our students receive **weekly supervision** meetings, supplemented with regular informal contact (research group seminars, study groups). Six-monthly Thesis Advisory Panel meetings provide regular independent encouragement and feedback. Over 40% of students are co-supervised; this increases their exposure to different ideas and backgrounds, supports ECR staff in supervision, and encourages interdisciplinary interactions.

We encourage engagement with the **extensive skills training** on offer inside and outside the University [IES32]. We actively engage with EPSRC MAGIC (https://maths-magic.ac.uk/) and

APTS (apts.ac.uk) consortia, providing graduate-level taught training and encouraging long-term networking. Students attend research seminars, and we subsidise collaborative lunches with speakers. Research students run their own weekly research seminar series via our ECR Forum. Our annual **Graduate Symposium** is embedded as a PhD progression requirement; the **KM Stott Memorial Prize** rewards the best talk. Our recently instituted Departmental **Doctoral Prize Fellowship**, awarded on the basis of research excellence, provides an extra year of funding to the best student, supporting their transition into a mathematical research career. The annual **Anand Ramachandran Prize** rewards the best thesis; winners since its 2017 inception reflect healthy diversity (40% female recipients, different disciplines, 4 nationalities).

Management of Workload

The Department recognizes that effective management of workload is essential when it comes to giving colleagues enough time and space for research. For example, a key focus of a substantial teaching restructure during this REF period was to consolidate activities to free up more time for research. Our **workload model** underpins many of our values, aiming to equalize work over a 3-5-year period. Transparency is key: the full spreadsheet is accessible to all. Primary research time accounts for a minimum of 40% for all research-contracted academic staff, and this is enhanced by grant buy-outs and supervision of PDRA/Fs. Research leave is incorporated as 10 weeks (375 hours) of research time, and the model gives credit for time spent on grant applications. There is additional weighting for teaching newly taken on and for the creation of new teaching materials.

Research Leave

The Department operates a research leave scheme available to permanent staff which provides a period of time free from teaching and administrative duties [IES23]. Managed by the Departmental Research Committee, the scheme supports all types of **research and impact** activities, including: the production of research outputs; developing collaborations; research visits; seeding research grant applications; deriving impact from research. Staff are entitled to leave at the rate of one term in any nine teaching terms with the possibility to accumulate up to a **full year of research leave**. In the current period 45 terms have been awarded across 29 staff, with others choosing to accumulate a longer leave entitlement. The call for applications aligns with the Annual Performance and Development Review process so that staff can be supported and encouraged to use the scheme; equality and diversity aspects are also given due consideration by the Research Committee. Applications include a coherent research plan for the periods before, during and after the leave, and indicate how these plans mesh with Department research and impact strategies. A “light touch” report is required at the end of each research leave to reflect on the original plan and its development over the intervening time. The scheme has proved to be a great success. For example, we were able to support the Erskine Fellowship of Eveson at Canterbury (NZ) by freeing him from teaching in the academic year 2017/18; his work on how waves propagate through a saturated porous medium has generated interest around the world, for example from scientists predicting the severity of earthquakes (NZ) or the location of sweet water in island aquifers (Tonga).

Working Arrangements for Staff

The Department encourages **flexible working arrangements** [IES24], both through formal registration of constraints and widespread recognition of issues of **work-life balance** across the Department. Policy has been developed through our EGPC, with direct reference to the experience of colleagues in the Department, as well as institutional guidelines [IES24-26] and national best practice (e.g., through the Athena SWAN framework). Our **core hours policy** ensures that research seminars and other important activities are scheduled during the middle of the day, avoiding pinch-points for those with caring and other responsibilities. **Remote working** is facilitated via a simple spreadsheet used by all staff to record home working, trips away from York, annual leave, etc.

In the Department, we have several members of permanent staff on part-time contracts, and they are supported to further their careers in exactly the same way as other colleagues [IES26].

Fixed-term staff have access to mentoring and training to help them develop a well-rounded academic profile to make them competitive in the job market.

Estates work has been optimized for **disabled access**. For example, the main research discussion and seminar facility (the Topos) is on the ground floor in the centre of the Department, is fully disabled-accessible, and is set up to accommodate seminar speakers who wish to remain seated. Occupational health advice and support is readily available (and has resulted, for example, in standing desks). When the need arises, **compassionate support and leave** are provided in full for colleagues. The Department's **parental leave policy** has successfully supported flexible working and staged return, including the option of a part-time contract with a guaranteed return to full-time working at a later date. Similar options have been offered to those returning to work from a period of illness. The University has a carer's fund [IES24] to support research travel, and staff have also made use of external funds such as the LMS Caring Supplementary Grants.

3. Income, infrastructure and facilities

Strategies and Research Income

The Department has **more than doubled research income** compared to the previous REF, to over £7M in total over the period, illustrating the success of our research strategies and support mechanisms. Reflecting our wider strategy, our approach to funding has had three interlinked strands, to:

- diversify our portfolio, whilst continuing to build EPSRC funding;
- target fellowships;
- encourage interdisciplinarity and impact.

Highlights include our increased **European funding** — for example, since October 2016 we have always had at least one Marie Skłodowska Curie fellow in post, and in 2017 we secured 2 of just 22 such fellowships awarded to mathematics across all participating nations — and our success in attracting major **independent early-career research fellows** (we have two Royal Society University Research Fellows, for example). We have maintained an excellent level of **Research Council grants**, including a **Programme Grant in Number Theory**, but also significantly increased funding from other sources. Through the forging of strategic ties, we have managed to make significant **industrial contacts** which are crucial to our **impact plans**.

Evidence of increased diversity in our portfolio includes European funding streams, which have also been part of our focus on fellowships:

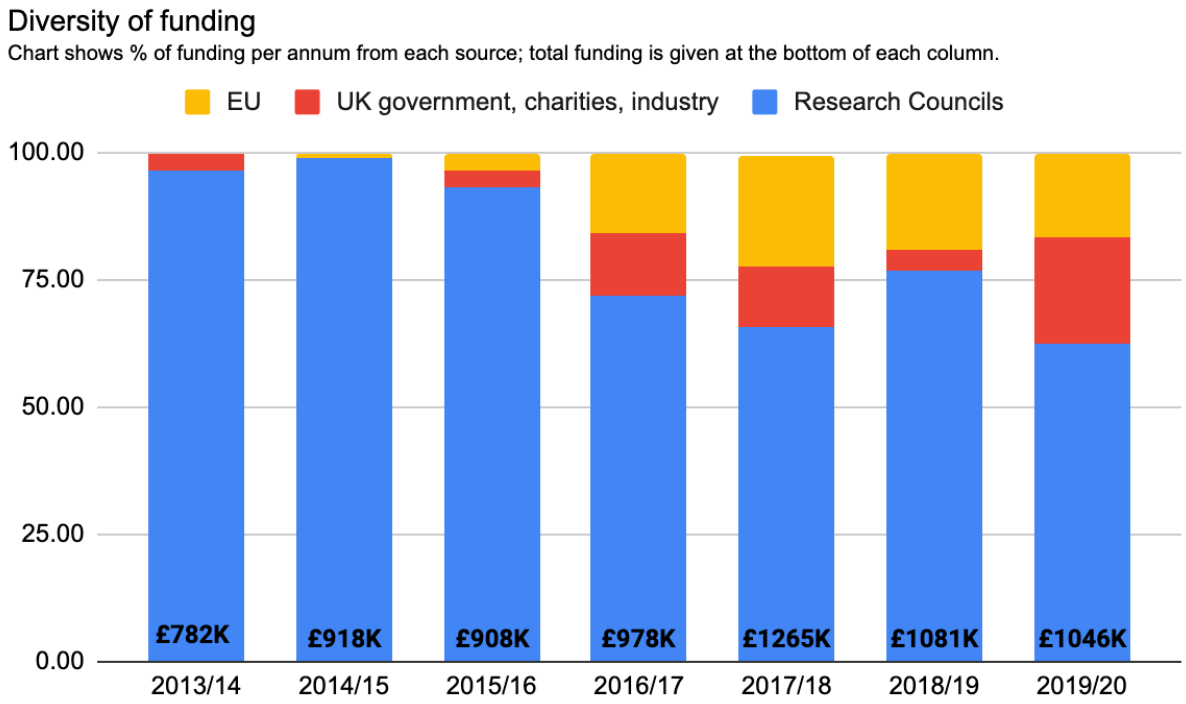
- Delius, with the **MINOUW Project**, which is made up of over 15 different maritime science institutes and bodies from across Europe, including scientists, the fishing industry, NGOs and policy makers (his funding £224K as part of €6m project, 2015-19; see also our Fisheries Impact Case).
- **Marie Curie** research fellows:
    - Higuchi & Fröb (£114K, 2016-18);
    - Fewster & Kontou (£176K, 2017-19);
    - Gould & Szakács (£165K, 2019-2020);
    - Brzezniak & Razafimandimby (£176K, 2019-20).

The focus on **interdisciplinarity and impact** naturally also helps to diversify funding. We now have a variety of partners outside the traditional funding streams for mathematics, showing our increased engagement with applications of mathematics across science and industry.

- Twarock's **Wellcome Trust Senior Investigator Award**, "New perspectives for antiviral therapy: the regulatory roles of genomic RNA in virus assembly, infection and evolution" (£621K, 2016-21). This grant develops new therapeutic antiviral strategies based on Twarock's hugely influential work on virus structure and assembly.
- Colbeck's funding from **Innovate UK** as part of the **Industrial Strategy Challenge Fund (ISCF)**, "Assurance of quantum random number generators", (£322K, 2020-23).

- **NC3RS** for Pitchford (£222K+£20K, 2013-16 and 2017-18, the latter in partnership with SimOmics)
- AJ Wood, Co-I on **Newton-Bhabha/BBSRC Industrial Waste** project "Reducing Industrial Waste from Sugarcane Processing in India" (£712K, 2018-21).
- **Innovate UK/BBSRC** for Bees (£48K, 2016-17).
- Industrial research partners:
  - **Unilever** with Bees, modelling of biofilm inhibition (£32K);
  - Wilson, with multiple companies, including **Paraytec, Croda, Phasefocus Ltd, Bettys & Taylors** (over £160K, including Knowledge Transfer Partnerships and EPSRC Innovation Vouchers).

The following chart illustrates the **increased diversity** of our funding. In fact, in this period, we have received funding from: ASEM-DUO, AstraZeneca, Australian Research Council, BBSRC, British Academy, British Council, Croda, Daphne Jackson trust, Douglas Bomford Trust, EMS, EPSRC, European Commission, Fisheries Innovation Scotland, FQXI, Glasgow Mathematical Journal Trust, ICMS, Innovate UK, Institute of Physics, Leverhulme, LMS, MRC, NC3RS, NERC, Paraytec, Royal Commission for the Exhibition of 1851, Royal Society, Santander, Schlumberger Stichting Fund, Unilever, Wellcome Trust, World Universities Network.



We have maintained high levels of **EPSRC** funding, including:

- The **Programme Grant** "New Frameworks in Metric Number Theory" (£1.65M, 2012-18). Held by Beresnevich and Velani, this wide-ranging grant focussed on Diophantine approximation, links with other areas of mathematics including ergodic theory, dynamical systems and fractal geometry, and applications to real world problems arising from the rapidly developing areas of electronic communications, antenna design and signal processing.
- Twarock's **Fellowship** "Geometry as a key to the virosphere" (£1.08M 2018-23), with partners including the London School of Hygiene and Tropical Medicine, the Pasteur Institute and the University of California (UC Riverside).
- Colbeck is a key player in the **Quantum Communications Hub** led by York (Phase 1, 2014-19; Phase 2, 2019-24), one of four hubs in the UK's £120M quantum technologies programme, with **industrial partners** including Toshiba and BT (Colbeck's funding includes £410K in Phase 1 and £820K in Phase 2). Colbeck's input includes the development of mathematical models for commercial and near-commercial quantum

random number generators, with the aim of quantifying the extractable quantum randomness.
- Haynes' **Career Acceleration Fellowship** "Circle rotations and their generalisations in Diophantine approximation" (£370K, 2013-2017).
- Bees was a part of the **EPSRC TARGeTED project** "Tackling Antimicrobial Resistance through Goal-Orientated Thinking in the EPS Disciplines" £403K, 2015-2017).
- Responsive mode grants for:
  - M Bate (£298K, 2014-2017);
  - Colbeck (£101K, 2017-19);
  - Gould (£249K, 2012-2015);
  - Haynes (£228K, 2013-2015);
  - Haynes & Velani (£322K, 2015-2018);
  - Nazarov (£194K, 2016-2019, and £306K, 2011-2014);
  - Rejzner (£79K, 2017-19);
  - Twarock (£278K, 2013-16);
  - Zorin (£93K, 2015-2017).

By strategically **targeting fellowships** from non-EPSRC funders, we have been able to massively increase funding from **Royal Society**, **Leverhulme Trust** and the **Newton Fund**. Again, this also helps to diversify the portfolio:
- Royal Society University Research Fellowships:
  - Geranios, "Problems In Modular Representation Theory Of General Linear Groups" (£424K + £101K supplement 2017-22);
  - Simmons, "Nonstandard Applications Of Schmidt's Game To Diophantine Approximation" (£450K, 2019-24).
- **Leverhulme Early Career Fellowship** for Dykeman, "Physical Virology: A novel approach to virus assembly and evolution" (£153K, 2014-16).
- **Newton International Fellowship** for Maurelli, "Stochastic Euler Equations And The Kraichnan Model" (£99K, 2018-20).
- **Wolfson Fellowship** for Twarock (£90k, 2018-23);
- Leverhulme/Royal Society Senior Research Fellowships
  - Busch (£53K, 2017-18);
  - Sklyanin (£47K, 2016-17);
  - Twarock (£48K, 2014-15);
- Leverhulme standard grants
  - Brzezniak (£93K, 2012-14);
  - Higuchi (£133K, 2019-21).

On top of this, we received further **fellowship funding:**
- £120K through the Schlumberger Stichting Fund
  - Gould & Naz (2016-2018);
  - Gould & Zenab (2016-2018).
- Daphne Jackson Fellowships
  - Wilson & Dickinson (sponsors: **Royal Society of Chemistry, BBSRC**, 2016-18);
  - Bees/Pushkin & F Bate (sponsors: **BBSRC**, University of York, 2019-21).

Much of the funding above demonstrates the success of our **tailored support** for ECRs and the pipeline to a successful academic career. For example, Geranios, Simmons and Dykeman were previously employed as PDRAs on grants of M Bate, Beresnevich & Velani, and Twarock, during which they were supported in their applications for fellowships. Dykeman now has a permanent appointment in the Department, and Geranios and Simmons have proleptic positions.

Other external funding: We have received substantial funding through small grants from bodies such as the **LMS**, **EMS**, **ICMS**, **British Council**, **Heilbronn Institute** and **Institute of Physics** to support a variety of activities, from conferences and workshops to research trips and collaborations. For example, in this period we have received over £13K through the LMS Scheme 4: Research in Pairs scheme.

Infrastructure Supporting Research

Internal Funding for Research and Impact
The Department recognizes the potential for relatively small amounts of research funding to facilitate excellent mathematics, and we have striven over the REF period to ensure such funds are available to all. The result is that over this period our research committee has never had to turn down a request due to lack of funds.

Our workload model gives credit for preparing a research grant, translating to an investment of £4K in average staff costs for a typical application; this is increased for more substantial projects. In order to facilitate applications, encourage new collaborations and impact-related activity and support the dissemination of research, the Department has instituted several **tailored internal funding streams**. Many of these are specifically designed to match external sources of funds and to seed potential large-scale grant applications and other activity.

- **Fellowship Development Bursaries** support young researchers who wish to visit the Department with a view to applying for a postdoctoral fellowship. Since its inception in Summer 2016, we have hosted **over 20 academics** through this scheme, with most visits generating new collaborations as well as fellowship applications. Successes include the Newton International Fellowship for Maurelli and the Marie Curie Fellowship for Szakacs mentioned above, plus an LMS Early Career Fellowship for Fregoli.
- **Collaborative Research Exchanges** support new and existing collaborations by funding visits (incoming and outgoing, over 30 since 2017), leading to larger-scale projects. Recipients' reports (6 months after the visit) indicate that almost all visits result in joint publications and several in substantial funding applications.
- The **Pump Priming Fund** helps colleagues to scope and write substantial grant applications. For example, Nazarov utilized a combination of Department and University funds [IES10] to invite Koroshkin (ITEP, Moscow) to York, leading directly to an EPSRC grant (2016-19).
- Our **External Engagement and Impact Fund** supports engagement with industry, government and other organisations external to academia, for the purpose of enabling or developing the impact of our research. For example, MacKay's relationship with the **US Naval Postgraduate School** in Monterey, California (which trains mid-career professionals in the military service of the USA and its NATO allies), has been sustained by departmental funding for visits. One instance of this is his talk on "Concentration and Asymmetry in Air Combat" at their primary OR colloquium in 2016.

The total annual budget allocated to these funding opportunities is over £65K. Additionally, all staff have their own research account, used to fund research activity such as conference visits, or travel to and from York for collaboration. These accounts can receive fees from consultancy, summer schools and other activity, and new appointments are given an initial allowance of £2.5K over and above their entitlement to general funds. There is a specific **fund for PhD students** — over the period all reasonable funding requests for travel by PhD students have been met.

Each of the seven research groups has a **dedicated budget for seminars**, amounting to a total of £20K in 2019/20, which has allowed for each group to pay for travel, accommodation and subsistence for **20-30 national and international external speakers per year** without requiring any extra funding. Our long-standing Departmental Research Away Day is held annually (virtually in 2020), mixing research talks and academic discussions with interactive sessions based around Departmental research strategies and broader developments in UK research and funding.

Organisational Infrastructure
University support, now focussed through the three faculties [IES8], has helped us enhance our presence across many **multidisciplinary centres** — we have key players in:

- York Cross-disciplinary Centre for Systems Analysis (YCCSA, which we also support financially);
- Quantum Communications Hub (QCH, [IES11b]);
- York Centre for Quantum Technologies (YCQT);
- Biological Physical Sciences Interdisciplinary Network (BPSInet);
- York Environmental Sustainability Institute (YESI, [IES42]).

This organisational support for research at an institutional level matches key aspects of the Department strategy and organisation. This not only helps to facilitate primary research, but also to leverage applications of that research across science and society, and to translate research outcomes into impact.

Operational Infrastructure

We have appointed a **Research Support Team**, comprising a research facilitator and research administrator to enhance our administrative support for research [IES38e]. This new team has provided the support necessary to allow new initiatives to be realized (e.g., the internal funding streams described above). They also give regular updates on funding opportunities, provide tailored research-focussed events (for example on grant opportunities for ECRs), and give individual support for those developing proposals. Our administrative team also provides operational support for the organisation of workshops and a dedicated system for visitors and collaborators, including visitor offices.

Estate and Facilities

Supported by the University, we have seen **extensive investment** (approx. £300K over usual estates funding) in Departmental research facilities. A major triumph has been the development of "The Topos", a large area on the ground floor of the Department, designed specifically as a mathematics lab. Hosting almost all our research seminars, it is situated to increase the visibility and impact of the research activity of the Department, with a lakeside view and three generous spaces separated by glass walls, so that research activity is visible to the wider community thereby encouraging participation. It is not an exaggeration to say that the Topos has revolutionized the day-to-day research life and interactive culture of the Department.

As the Department has grown, we have also made creative use of our other facilities, and procured new areas. A case in point is the new Paul Busch room for PhD students: a moribund University computer lab has been creatively reimagined as the centre of our PhD community. Since this facility opened in 2018, there has been a noticeable increase in the integration of our students into the research life of the Department, and in their interaction and coherence as a group.

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

Collaboration and networks

Our research has an international reach. Over the REF period we have given hundreds of conference and seminar talks in institutions across all the continents of the world. We have hosted visitors from more than 200 institutions, and have active collaborations (for example, involving research outputs or grant activity in this REF period) with over **400 external organisations**. Notable visitors in the period include Fields Medallists Sir Michael Atiyah, Sir Martin Hairer (a collaborator of Litterer in this REF period and 2020 Breakthrough Prize winner), Sir Vaughan Jones (who spoke at a conference organised in York) and Grigory Margulis (a collaborator of Beresnevich in this REF period, he also won the Abel prize in 2020). We have awarded honorary degrees to Wolfgang Schmidt, winner of the Cole Prize in Number Theory, and Dame Frances Kirwan FRS. Our marquee series of **Lewis Fry Richardson Lectures**, inaugurated in 2015 by Richardson's great-nephew Julian Hunt FRS, Baron Hunt of Chesterton, has attracted a stellar list of speakers including multi-prize-winning statistician Richard Samworth and seven Fellows of the Royal Society: https://www.york.ac.uk/maths/events/lfr/

Over **two-thirds of staff have received external funding** to support collaborations, and this is supplemented by the internal funding streams described in Section 3 above. The Collaborative

Research Exchanges scheme was specifically set up to help us widen our collaborative networks, and has supported more than 30 exchanges since 2017, with countries including Australia, Cameroon, China, Germany, India, Israel, Italy, NZ, Poland, Portugal, Russia, Serbia, Singapore, Ukraine, and USA. On top of this, over 100 applications for general Departmental research funding mention collaboration as a key goal of the request.

Many of our colleagues are supported to play active roles in national and international collaborative networks. We have outlined above Colbeck's key role in the EPSRC Quantum Communications Hub, and the work of Delius through the MINOUW consortium, with significant and long-term influence on European fisheries policy, is detailed in one of our Impact Case Studies. Colleagues have benefited from support by German Collaborative Research Centres (Beresnevich, Daletskii), and networks such as the Anglo-Franco-German Network in Representation Theory and its Applications (Bate).

York contributes widely to the health of the discipline nationally. The vibrant **seminar series** organized by our research groups have attracted **over 700 speakers** since the start of 2015, and in addition York is an active node in **ten LMS Scheme 3** networks (many co-sponsored by other key research funders):

1. Algebra and Representation Theory In the North (ARTIN)
2. Algebraic Quantum Field Theory in the UK (AQFTUK)
3. Applied Algebra and Geometry Research Network
4. Mathematical Modelling of Random Multicomponent Systems (MMRMS)
5. North British Geometric Group Theory Seminar (NBGGT)
6. North British Mathematical Physics Seminar (NBMPS)
7. North British Semigroups and Applications Network (NBSAN)
8. Northern Number Theory Seminars (Northern NuTS)
9. Probability in the North-East (PiNE)
10. Yorkshire Durham Geometry Days

The pandemic prompted most of our weekly research seminars to explore online options, resulting in a significant widening of their international reach. Particular successes include: the Semigroup Seminar, which in Summer 2020 regularly reached an international audience from over 15 countries, including Australia, Brazil, China, Canada, India, and the USA; the international "Diophantine approximation and Homogeneous dynamics" seminar organised jointly with researchers from Israel and China, and with well over 100 people enrolled; the Mathematical Biologists' joint seminars with Leeds and Sheffield.

Locally, the Department is also highly outward-looking, with links across all three faculties at York. We have particularly close links with **Biology**, which are fostered and maintained partly through joint appointments, including Twarock, whose ground-breaking and highly funded work in virus structure and assembly is conducted in **YCCSA**, and J. Wood, who in addition to his systems biology work has created with MacKay a pioneering collaboration with historians at York St John University. Bees maintains a lab in Biology to support the work of his group, and has industrial partners including Unilever. The Mathematical Biology & Chemistry group runs a joint weekly seminar with colleagues in Biology, and are active participants in the **BPSInet**. Research themes which naturally arise in mathematics are also reflected in priorities of other units and institutes — for example, the collaboration of Pitchford and Powell on the tropical disease Leishmaniasis, speaks to a major theme for the **York Biomedical Research Institute** [IES44], and the work of Constable in Evolution and Ecology matches a research priority for Biology. Many colleagues, including Delius, Knight, Pitchford, Powell and Pushkin, are members of the **York Environmental Sustainability Institute** [IES42], a multidisciplinary centre facilitating and delivering research to address environmental challenges at local, regional and global scales. Gould has joint research interests with **Computer Science** exploring the applications of Semigroups in Cryptography, recently supported by an LMS Undergraduate Research Bursary. Striking applications of Diophantine approximation in wireless communication technologies have been exploited by the number theory group to establish links with the **Electronic Engineering** Department at York and industrial users such as British Telecom.

Wilson collaborates across many Departments, including **Biology**, **Chemistry**, **Environment and Geography**, and **Archaeology**. Connor has collaborated with the **York Management School**, with whom we now also have a joint appointment Thijssen. Members of the Department have also collaborated with the Centres for **Health Economics**, **Immunology and Infection,** and **Novel Agricultural Products**, as well as the Departments of **Health Sciences**, **Sociology** and **Economics and Related Studies**.

Impact and relationships with key research users

As well as the internal funding streams described above, the Department has utilized **EPSRC and BBSRC Impact Accelerator Award** funding in developing impact and impact opportunities [IES50]. Activities have included funding for such diverse areas as the mathematics and statistics of warfare (MacKay), lignocellulosic biomass data (Wilson), investigations of the hydrodynamics of nascent biofilms (Bees), the conversion of food waste to animal feed (Wilson) and computational models to inform biologics production (AJ Wood). We proactively explore possibilities for impact based on colleagues' research, connections and knowledge, and also via the external links maintained by the University's Research and Enterprise Directorate [IES49]. Our taught provision also helps to build and strengthen industrial links. For example, the first graduate of our new **MMath with Year in Industry** had a placement year with **Fera**, which led to a collaborative final year research project, and permanent employment.

By filling the gap between mechanisms for creating new applicable research and the larger-scale support of existing research with impact, we have been able to seed many **potential impact cases of the future**. The Number Theory group continues to pursue real-world applications of Diophantine approximation to the theory of interference alignment in **wireless communications**: they hosted two international collaborative workshops in York (2014, 2016) with scientists working in network coding and electronics engineering, for which the Department provided financial and full administrative support. A highlight outcome is the book "Number Theory Meets Wireless Communications" (Springer Nature) with Beresnevich and Velani as editors and contributors. Another example is the work of Eveson, who has engaged in projects with huge potential for future impact, supported by internal funding and sabbatical leave (see *Research Leave* above*)*. He has developed sophisticated software to numerically solve PDEs describing how waves travel through the ground and water, which can be implemented on High Performance Computing facilities [IES41], and has applications in **seismology** and **hydrogeology**. Other relationships include the continuing work of Wilson with **Fera Science** and Bees with **Unilever**. Recently, Wilson has had successful **Innovate UK Knowledge Transfer Partnership** applications with **Croda** and **Paraytec.** AJ Wood and collaborators have a spin-out company "Asperchem" holding the IP from their Newton-Bhabha project above.

One way we **inform and influence policy** is by engaging with national and international advisory bodies. For example, Powell is involved in various collaborative projects with the **Office for National Statistics**, including work on the fast estimation of biases in new survey methodology. As well as receiving EPSRC funding through York's Impact Acceleration Account, this activity was given funding by the Department, allowing the hosting of a two-day workshop at the **Royal Statistical Society** in 2019, involving participants from across Europe and the US (the follow up in 2020 was delayed by the pandemic). Pitchford's increasing influence in fisheries policy has led to an appointment on the Scientific Advisory Committee for the **Centre for Environment, Fisheries and Aquaculture Science** (CEFAS), who are also using Powell's expertise to explore habitat classification and the detection of rare species (see also [IES12b]). The **National Physical Laboratory** and device manufacturers such as **ID Quantique** and **Toshiba Research Europe Limited** are working with Colbeck towards a UK assurance process for quantum random number generators; such devices will be included as components in many future technologies, across mobile networks and the Internet of Things. A group led by Pitchford and AJ Wood were invited by Prof Michael Cates, Lucasian Professor at Cambridge, to moderate and manage the community review server in support of the **Royal Society RAMP (Rapid Action Modelling Pandemics)** initiative. Number theorist Hughes has been a consultant for the **Heilbronn Institute**, a partnership between **GCHQ** and the UK mathematical community.

Engagement with diverse communities, outreach

In keeping with the University's strategic vision for Civic Responsibility, the Department is committed to **public engagement**, **schools liaison** and **outreach activities**, and supports colleagues in providing these, for example by giving such activities full credit in our workload model. Our records show over 150 one-off sessions provided during the REF period, with several longer-running commitments adding to that. Many of these activities have a research focus. For example, MacKay and AJ Wood have engaged widely with the public on their work on the quantification of historical counterfactuals, including videos, news articles and battle simulations. Highlights include an extended interview with **Dan Snow** in his **HistoryHit** subscriber podcast, with over 100,000 end-to-end listens, and a lecture at the **US Naval War College** (Newport, RI) to a combined public and professional audience (with around 7,500 YouTube views). Many notable activities by our mathematical virologists are detailed in our Virology impact case, including Twarock's appearance in Hannah Fry's **BBC documentary series** "Magic Numbers", and contributions to art exhibitions "The State of Us" at **the Lowry** in Manchester and "Dans le cadre de Mutation/Créations" at the **Centre Pompidou** in Paris, both in 2019-20. Gadelha's work on the dynamics of swimming sperm was featured on the **BBC**: https://www.bbc.co.uk/news/health-39292913.

A particular focus has been to engage women with mathematics; the visit of the **EMS Women in Maths** exhibition was tied to outreach sessions for schools, including an all-girls school. We have given hugely diverse contributions to the annual **York Festival of Ideas** [IES13] and **Pint of Science** events, and delivered sessions in partnership with the **National STEM centre**, which is located on campus. We have delivered **Royal Institution Masterclasses** and **STEP classes** to hundreds of school pupils.

Indicators of wider influence

Journal editorship, refereeing:

Colleagues have acted as **editors** for more than 20 journals, and have performed **peer-review refereeing** jobs for over 200 individual journals during this REF period, many on multiple occasions, and including all of the top general mathematical journals (e.g., *Ann. of Math., Invent. Math.*), many multidisciplinary journals (e.g., *Nature*), and journals of learned societies around the world (e.g., LMS, AMS, EMS).

Grants panels, reviewing:

Members of the Department have been members of **grant panels** for the EPSRC, Royal Society (including Corrigan **chairing** the Royal Society Research Appointments Panel Aiii), NSF (in the USA), DFG (in Germany), OTKA (in Hungary) and the LMS. We have members of peer review colleges for many research councils, and have reviewed numerous grant proposals, for all the major UK funding bodies for mathematics (EPSRC, Royal Society, Leverhulme, LMS), as well as other research councils (BBSRC, MRC) and the major funding bodies of other countries (including the USA, Germany, Austria, Italy, Czech Republic, Poland).

Other committee membership:

Zhang is a member of the Physical Sciences Panel for the **Hong Kong RAE2020**. Gould is on the **Ethics Committee of the EMS**. For the **Royal Society**: Higher Education Steering Group and Advisory Committee on Mathematics Education (Mackay); Royal Society Rosalind Franklin Awards Committee (Wilson). For the **Royal Statistical Society**: Computational statistics and machine learning (CSML) section (Powell); Meetings secretary, Applied Probability Section (Connor). Wilson was an **Athena Swan** awards panel member. MacKay has held roles for the exam boards **MEI** (Critical Maths advisory group), **IOP** (curriculum committee) and **OCR** (Higher Education Consultative Forum).

Prizes and other esteem:

Twarock was awarded the IMA Gold Medal in 2018. Busch was President of the International Quantum Structures Association from 2016. Mackay is Chair of Correspondents for the INI/ICMS. Bees gave a Society of Mathematical Biology Lee Segel Prize seminar, Osaka,

Japan, 2014. Eveson held an Erskine Fellowship at the University of Canterbury in New Zealand, 2018.

Conference organization:
Colleagues have been involved in the organisation and development of almost 100 one-off and recurring conferences across all our areas of expertise, including membership of **Programme and Steering Committees** for international conferences. For example: Busch, *IQSA Workshop on Quantum Structures* (Netherlands 2017); Colbeck, also a founding member (in 2011) for the largest annual international quantum cryptography conference *QCrypt* (France 2014, Japan 2015, UK 2017, China 2018), as well as *Quantum Information Processing* (Australia 2015), *International Conference on Information Theoretic Security* (Switzerland 2015), *Asian Quantum Information Science* (Korea 2015); Fewster, *IV Amazonian Symposium on Physics* (Brazil 2016); Gould, *Semigroups and Groups, Automata and Logics* (Italy 2019); Li, *International Conference on Computational and Financial Econometrics* (UK, Spain, Italy 2015-19) and the *International Conference on Econometrics and Statistics* (Hong Kong 2018, Taiwan 2019); Rejzner, a founding organizer of *Women at the Intersection of Mathematics and High Energy Physics* (Germany 2017, Switzerland 2019); Velani, *Dynamics, measures and dimensions* (Poland 2019); Zhang, *CMStatistics* (online 2020) and *ICSA China Conference* (China 2021).

We have organized workshops at **prestigious international institutes**, including Oberwolfach (Beresnevich, Haynes, Rejzner, Velani) and the Perimeter Institute (Rejzner). In York, we have hosted a multitude of conferences, workshops and network meetings (see, for example, the list of LMS Scheme 3 networks above). Notable large-scale events at York in this period include: *Quantum Field Theory: Concepts, Constructions & Curved Spacetimes* (2017), speakers including Fields medallist Sir Vaughan Jones; *Representations of Algebraic Groups* (2016), in honour of Donkin, with funding from the LMS, Heilbronn Institute and the Royal Commission for the Exhibition 1851; *Workshop on Diophantine Approximation and Related Fields* (2017), as part of the Number Theory Programme Grant; *Mathematical Foundations of Quantum Mechanics* (2019), in memory of Paul Busch.

Invited talks: in this REF period, York mathematicians have given well over 500 invited talks, of which roughly half were conference talks. Examples include: Connor, at the **World Statistics Congress** in 2017; Rejzner, at the **International Congress of Mathematical Physics** in 2018; Haynes (2014), Hughes (2019), Gould (2018), Everitt (2017, 2018), at the **BMC**. Twarock gave the **IMA Lighthill lecture** at the BAMC in 2018. Examples of York mathematicians helping to develop the subject across the globe include: Everitt lecturing Galois Theory at the African Institute for Mathematical Sciences in Ghana (2016); Higuchi's long-standing relationship with the Federal University of Pará in Brazil, where he has given several talks and lectured on Quantum Field Theory (2014-2019); Wilson's five-day training course on Traceability & Authenticity of Edible Bird's Nests in Selangor, Malaysia (2017).