

Institution: University of Nottingham
Unit of Assessment: 10
<p>1. Unit context and structure, research and impact strategy</p> <p>1.1 Context and structure</p> <p>The unit maps onto the School of Mathematical Sciences (SMS) at the University of Nottingham (UoN), whose research over the REF period has been structured across seven Research Groups (RGs) to which all academic staff, postdoctoral researchers and PhD students are affiliated, with secondary membership of others as appropriate:</p> <ul style="list-style-type: none"> • Algebra and Analysis (AA) • Industrial and Applied Mathematics (IAM) • Mathematical Medicine and Biology (MMB) • Mathematical Physics (MP) • Number Theory and Geometry (NTG) • Scientific Computation (SC) • Statistics and Probability (SP) <p>The Category A staff submitted (64.5 FTE, bolded throughout, with new appointments noted in <i>italics</i>), comprise 24 Professors (P), 25 Associate Professors (AP), 13 Assistant Professors/ Lecturers (L) and five Research Fellows (two at AP level; three at L level). This represents a net expansion by three since 2014.</p> <p>Our research activity has grown substantially in scope and value in the REF period. Key figures include: 12% increase in research income to £3M p.a.; 50% increase in the value of active research awards in the School to £18M, including major awards from the EPSRC, ERC, Leverhulme Trust, Royal Society and Wellcome Trust; 20% increase in PhD student numbers to 96 FTE.</p> <p>Overall School strategy is developed by the School Executive Board (SEB), chaired by the Head of School (Houston; Dryden prior to 2018). Research and Impact strategies are developed by the Research Board, chaired by the Director of Research (DoR, Sotiriou; Houston prior to 2018), who is also a member of the SEB. Research Board further comprises the REF Coordinator (Adesso), Impact Champion (King), Research and Business Development Manager (RBDM, Hawker), Heads of each RG, representatives from our early career researchers (ECRs) and an EDI representative.</p> <p>1.2 Research strategy</p> <p>The School makes internationally leading contributions in fundamental mathematics and statistics and, in tandem, develops and implements novel mathematical tools needed to advance science, solve major societal problems, and support economic growth. Extending our national and international reach, promoting the use of mathematics by other disciplines, consolidating our key strengths and pursuing new complementary research directions are central to our vision. We foster a supportive, inclusive and collaborative research environment that encourages creative thinking and scientific independence, while offering high-quality training and mentorship at all career stages, from graduate students to established researchers.</p> <p>1.2.1 Research strategic achievements since REF2014</p> <p>The School has successfully met the strategic aims outlined in 2014. UoN funding and outstanding achievements in both teaching and research have supported the creation of six new permanent academic posts (three starting after the census date) and an expansion of our</p>

Research Support Team from one to four individuals - this team supports the grant application process, administers funded projects and helps develop our impact strategy.

- **Enhancing collaboration between RGs**, facilitated by strategic appointments: in NTG, **Hofscheier** and **Kasprzyk** work at the intersection with AA and bring in strong computational elements linking to SC, whilst **Laugwitz** reinforces links between AA and MP; **Cangiani** and **Hubbard** provide new links between SC and MMB and **Neal** between SP and MMB. Large awards such as the Leverhulme Trust DTP 'MASS: Mathematics for a Sustainable Society' (£1M, **Owen**) have underpinned further growth in collaboration.
- **Expanding the scope of multidisciplinary research programmes.** The Leverhulme Trust DTP has supported 15 students working across multiple disciplines on projects related to the sustainability of resources. An EPSRC Bridging the Gaps award in antimicrobial resistance (**King**) involved more than 10 different disciplines and industry representatives (Section 4.1). **King** is also heavily involved in the multidisciplinary Synthetic Biology Research Centre, and other staff are engaged with the UoN 'Beacons of Excellence' (Institutional Statement Section 2.1a). Joint appointments between Engineering and IAM/SC (**Gradoni, Icardi**) and Psychology and MMB (**van Rossum**) have opened new doors, while Band continues her fruitful joint appointment between Biosciences and MMB. **Icardi** is employed within the GeoEnergy Research Centre, a joint enterprise between UoN and the British Geological Survey (BGS). **van Rossum** directs the Nottingham Neural Computation Research Group (created through a UoN strategic development fund award to SMS, Psychology and Physics and Astronomy), which is currently training its first cohort of PhD students and second cohort of MSc students in 'Computational Neuroscience, Cognition and AI'.
- **Establishing a Centre of Excellence in Uncertainty Quantification (UQ).** New appointments **Brown, Icardi, Iglesias, Kalise, Mirams** and Chairs **Neal** plus Leisen and Wilkinson in Q3 2020 have established UQ as a Focus Area that brings synergies between several RGs (IAM, MMB, SC, SP). Linked funding includes **Mirams'** Wellcome Fellowship, a Royal Society International Exchange (**Icardi**), projects with the EPSRC composites hub (**Iglesias, Tretyakov**), and diverse collaborations, e.g. with Architecture at Sheffield (**Iglesias**) and Environmental Systems at Lancaster and Stuttgart (**Iglesias**). We lead (**Kypraios, Preston**) the 'Data, Modelling and Uncertainty' UoN Interdisciplinary Research Cluster (IRC), as well as the EPSRC Thematic Doctoral Training Programme 'MaP: Mathematics and Statistics for Modelling and Prediction' (**Tretyakov**) which includes UQ training for PhD and MSc students.
- **Exploiting opportunities afforded by internationalisation.** We have significantly expanded our reach, exploiting opportunities through both funding calls and community leadership and engagement. For example, a GCRF multidisciplinary project led by **Dryden** includes partners in Tanzania, whilst the £2M EPSRC Programme Grant on 'Symmetries and correspondences' led by **Fesenko** has developed strong links with China, Japan and South Korea. Examples of our growing number of community leadership activities and roles include leadership positions in EU COST Action networks, organisation of around 200 national and international meetings and Visiting Professorships in Austria, Canada, China and elsewhere (Section 4). We have active collaborations with researchers in over 30 countries. Over half of our publications in the REF period were co-authored by international researchers.
- **Pursuing innovative fundamental research.** We have successfully recruited four staff (**Dufresne, Hofscheier, Laugwitz, Tufarelli**) into fundamental areas via UoN Anne McLaren Fellowships (AMF) and Nottingham Research Fellowships (NRF) and two (**Gielen, Schenkel**, plus extension for **Weinfurtnner**) on Royal Society University Research Fellowships (URF). The Programme Grant, EPSRC Fellowship (**Kasprzyk**), several other EPSRC grants, and one new and two continuing European Research Council (ERC) grants, have allowed SMS to expand significantly its activity and outputs,

and attract exceptionally talented ECRs (such as three 1851 Fellows, Section 2.2) and PhD students (Section 2.3).

1.2.2 Future research strategy

RGs served the School well in developing its research priorities, but had hybrid roles as administrative structures. From August 2020, we are decoupling RGs into administrative Sections (Applied Mathematics, Mathematical Physics, Pure Mathematics, Statistics and Probability) and new Research Themes (RTs):

Algebra, Arithmetic and their Geometries	Multiscale Modelling and Heterogeneous Media
Computational Statistics and Machine Learning	Numerical and Applied Analysis
Data-Driven Modelling and Computation	Quantum Information and Metrology
Epidemic Modelling	Quantum Mathematics
Fluid Mechanics	Real, Complex and Functional Analysis
Geometry and Symmetry	Symbolic Computational Mathematics
Gravity	Teaching and Learning in Mathematics Higher Education
Mathematical Neuroscience	Wave Modelling

The RTs were selected after thorough consultation with staff and an EOI process. They reflect our research strengths and priorities, encourage further collaboration across traditional discipline divides, serve as cohesive research communities for staff and PhD students, and allow for flexible updating through regular review in a rapidly evolving research landscape. Together with our world-leading Centre for Mathematical Medicine and Biology (CMMB), RTs will both inform and reflect our future strategy:

- **Recruit exceptional talent that bridges our research.** Early career Fellowships will be a key instrument. We will intensify our effort to identify outstanding potential candidates that fit our strategic needs (annual call for EOIs, proactively approaching candidates, etc.) and support applications to external schemes (e.g. UKRI Future Leaders Fellowships, Royal Society URF, EPSRC Fellowships, etc.) and to UoN Fellowships linked to permanent posts.
- **Strategically invest in innovative research directions.** Alongside strengthening our international leadership in established priority areas, we will build on recent funding successes to pursue new avenues in fundamental research and tackle emerging challenges in applications of mathematics to other disciplines. Facilitated by the flexibility of the RT structure, maintaining a healthy balance between consolidation and innovation is central to our strategy. Current foci are:
 - **Modelling and Data Driven Discovery (M3D).** The interface between Mathematical Modelling and Data Analysis is currently catalysing discovery in disciplines from natural sciences and engineering to medicine and the social sciences. M3D is an exciting major initiative that involves 10 RTs across all four Sections and CMMB. It builds on our UQ development, our 'Data, Modelling and Uncertainty' IRC, and collaborative projects with 15 other Schools and numerous external partners from the public and private sectors. We aim to create a UoN hub to develop new mathematics in tandem with applications, enhance cross-Faculty collaboration, provide tailored training programmes, and act as a one-stop shop for external partners. M3D will also help us align to emerging priorities and showcase the impact of our research.

- **Novel directions in Pure Mathematics (PM).** Our pioneering programmes in Hilbert modular surfaces and in classifying Fano varieties share a distinctive core strength: the interplay between theoretical advances and computational algebra. We will build on this, developing the links between Tropical Geometry and Machine Learning (also linking to M3D). At the interface of Geometry and Number Theory we have world-leading programmes in motives, A^1 -homotopy theory, and the statistics of modular symbols. As high-profile developing areas, they provide a natural route for expansion.
- **Nottingham Centre of Gravity (CoG).** Led by SMS with Physics and Astronomy, CoG is planned for launch in 2021. The discovery of gravitational waves in 2016 highlighted major challenges in mathematical modeling, numerics and data analysis. CoG will expand in these directions, linking our world-leading research in mathematics and fundamental physics to observations. It will tap into new funding opportunities (e.g. STFC Gravitational Wave consolidated grants) and expand our reach globally (e.g. gravitational wave detector consortia).
- **Quantum Technologies (QT).** Building on our award-winning research in quantum science and technology, we will pursue new directions in this national and international priority area. One focus will be on quantum simulations for fundamental physics, boosted by coordination of a new £4M UKRI Programme (**Weinfurter, Louko**) with seven UK Universities and numerous international partners.
- **Continue to foster multi-disciplinarity.** M3D and CoG are central to our pledge to develop fundamental mathematics in constant dialogue with other disciplines. The former will catalyse our expansion into Machine Learning and AI and strengthen links with Computer Science. UoN 'Beacons of Excellence' (Institutional Statement Section 2.1a), will further support multi-disciplinarity, e.g. we plan to expand our expertise in computational biology and interfaces with imaging and 'omics data, to support the Future Foods and Precision Imaging Beacons, in which we have a key role. Our Engineering links will be strengthened through, e.g. the Wave Modelling RT. Energy and water have become new foci, driven by sustainability challenges spearheaded through the Leverhulme DTP. Opportunities for further development include the new EPSRC CDT in Sustainable Hydrogen and the UoN initiative in 'Water Research'.
- **Expand national and international networks.** This is intrinsic to our focus on interdisciplinarity, our recruitment strategy, and the new challenges we are likely to face as a result of Brexit and Covid-19. M3D, CoG, and QT are critical steps in this direction. Other examples include an MRC-funded UK-Malaysia project (**Cangiani, Houston**), the UKCCSRC council (**Graham**) and our extensive involvement and leadership in numerous networks (Section 4).

Contingency plans (e.g. more flexible timelines, alternative funding channels) for the implementation of major initiatives are in place in view of the Covid-19 pandemic. The breadth, dynamism and foci of our research activities gives us confidence in their robustness.

1.3 Impact strategy

This REF period has seen some outstanding achievements in impact, both in terms of supporting its development and in realising outcomes. Highlights include an expansion of our Research Support Team, including a dedicated Impact and Engagement Officer, the development of our Women in Maths initiative (Section 2.4) and a significant range of other public engagement activities (Section 4.2). RGs proved effective in aiding external engagement and extending the reach and significance of our impact. Future strategy will continue this positive trend in supporting the RTs and providing oversight in developing future impact.

The submitted impact case studies are:

- CS1: Enabling the rollout of 5G in Italy and optimising vibration and noise control in vehicles using wave modelling
- CS2: New product development leading to international business expansion for a refrigerant gas sensor manufacturer
- CS3: Industrial use of mathematical models for drug safety testing
- CS4: Informing international regulatory policy for drug safety using cardiac electrophysiology modelling
- CS5: Transforming operational planning and asset management within the UK rail network

1.3.1 Impact strategic achievements since REF2014

This can be summarised via four impact achieving mechanisms:

Enabling: A key part of our strategy has been to ensure impact is nurtured from the earliest stage, with support for development provided at every opportunity. **King** was appointed Impact Champion in 2014 and meets with academics to discuss their research and potential impact. These and other surveys generate new areas of impact that then receive a tailored package of administrative and financial support. For example: UoN's KTP team were instrumental in securing CS5; Faculty and UoN financial support enabled collaborative visits (e.g. **Gradoni, Weinfurter**), and software development (e.g. **Graham, Mirams**). Within SMS, our RBDM and expanded Research Support Team support development. The UoN network of Impact Officers and academic Impact Champions facilitates the sharing of best practice and the development of cross-disciplinary impact.

The staff workload model and study leave scheme are used to support those undertaking impact-related activity. Examples include study leave for **Graham** in 2018 facilitating growing work with industry partners, and for **Creagh** in 2017 and Hodge in 2018 to aid work on CS1 and CS5, respectively. The School Research Board meets 3-4 times a year and advises on priority areas, e.g. through a refresh of our School Research Strategy in 2019 and targeted discussion at Away Days. Board discussions led to appointments in SC and SP, where further personnel were needed to develop our ambitions in linking work to Engineering and our UQ initiative.

Engaging: Maintaining relationships with other disciplines and end-users is critical for impact to be realised. In 2016 we launched a series of industry talks from alumni and other partners (e.g. Bloomberg, Capital One, GSK) to provide routes to collaboration for our staff and careers advice for our students. These have expanded to a Faculty-wide programme to encourage cross-disciplinary working. Engagement events such as Study Groups (e.g. in Clean & Sustainable Growth, 2019, led by **Owen** with Innovate UK) have continued (Section 4). Expanded links with Engineering (e.g. through joint appointments **Gradoni, Icardi**) led to a wealth of new activity, such as the partnerships with Telecom Italia and British Telecom (CS1) and grants with RAEng and H2020 (led by BGS). Alongside our longstanding Engineering connections, we have developed many others, e.g. with Biology, English, Medicine, Physics and Psychology; 2018 saw the 20-year anniversaries of the establishment of both the Rolls-Royce University Technology Centre in Gas Turbine Transmission Systems and our CMMB.

Widening participation activities are another key long-term route to impact, encouraging uptake of degrees and careers in mathematics while disseminating research interests to a wider audience. Aside from our dedicated School liaison team, examples include: **Feinstein** has over 30,000 downloads of materials on mathematical and functional analysis on Open Educational Resources at UoN; numerous staff contribute to summer schools (e.g. Sutton Trust) for promising pupils, taster days, careers events and activity classes; **Wuthrich** took part in a panel at mathscon 2019; a UoN Widening Participation grant in 2017 enabled Knott, Cianciaruso, Coutant (postdocs) to demonstrate a bubble chamber experiment to local schools; numerous interactive talks with local schools and abroad such as **Gradoni** 2018 in Italy with our partner Telecom Italia.

Delivering: Our case studies provide a representative sample of the breadth of impact types and application areas: they span multiple groups (IAM CS1,3; MMB CS3,4; SC CS3,4; SP CS2,5) and impact multiple sectors including communications (CS1), health (CS3,4) and transport (CS1,2,5). The immediate beneficiaries are industry or policymakers, with impact achieved via the delivery of efficiency savings, or new diagnostic or prognostic tools. In the longer term, patients stand to benefit through improvements in drug development and therapeutics (CS3,4), customers through more effective communication and transport infrastructures (CS1,5), and the environment through reductions in pollutants (CS2).

Relationships with clients have been nurtured by **Strömberg** through Winchester Consulting; this is resulting in transformative impact to companies dealing with redundancies, particularly through the Covid-19 pandemic, with support being provided to grow the client relationships. Other successes include knowledge exchange schemes such as CASE PhD studentships (Section 2.3) and KTP (CS5). Public engagement activity has attracted a wide range of audiences, with some particularly high-profile (notably our Women in Maths initiative – see Section 2.4) and interesting approaches including an opera, poetry show, and BBC Radio 4 interview, in addition to multiple outreach videos on YouTube and elsewhere which have collectively attracted well over 6M views (Section 4.2).

Reaching Globally: Our international reach has expanded significantly this period. Examples of success include H2020 programmes (**Billingham, Icardi, Tanner**) and NIH and NSF (**Bharath, O'Neill**) – see also Section 3.1. One focus has involved work with Asia, including via our international campuses such as through the visit of Toussaint (Ningbo) to **Louko** in 2019 and joint mentoring of a researcher based at Ningbo on **Mirams'** Fellowship in 2020. New links have been established through an MRC grant with Malaysia (SC), and developing collaborations in China, Japan and Korea (MP, NTG). New projects with Africa (SP, GCRF grant with Tanzania) and South America (MP, FAPESP grants with Brazil; IAM, RAEng grants with Colombia; SC, networks with Chile) have further expanded our reach.

1.3.2 Future impact strategy

Our future strategy revolves around new key objectives for our impact-achieving mechanisms.

Enabling: Our focus is to exploit the RT structure to identify and pursue opportunities to maximise impact from emerging and developing activity. UQ has broadened to our M3D priority and this, in conjunction with the UoN Machine Learning initiative, provides ample opportunity for impact through, e.g. software development with Computer Science. Our alignment to UoN Beacons puts us in a very strong position to create impact pathways in food security, medical imaging and synthetic biology. We will continue to use our workload model and study leave scheme (Section 2.2) which, with support from the Impact Champion and Impact Officer, have proved highly effective. Specific objectives:

- Ensure impact activity is recognised alongside research and teaching duties, thereby encouraging staff to engage with impact and develop new ideas.
- Maintain development of impact cases, supporting them from the earliest stage.

Engaging: The expansion of the Research Support Team provides an excellent foundation for the next REF period. We have already started to explore new approaches to end-user and public engagement over the last few years (Section 4), and our intention is to enhance significantly both the range and scale of activities in the years ahead. We aim to:

- Coordinate more School-led events involving both staff and students, alongside continued engagement with University-wide activities, and make broader use of social media to promote and report on these.
- Explore a wider variety of industry engagement activities such as breakfast meetings with local SMEs and focused workshops.

Delivering: Our intention is to significantly increase end-user engagement, with support from the Research Support Team and UoN's Digital Research Service (Institutional Statement Section

4.1d). A particular target is student placements (UG and PG). This will be aided by our new degree programme with industry (commencing 2020) and degree apprenticeship in Data Science (commencing 2021). Students undertaking such programmes in the past have been motivated to pursue further studies and to maintain links with the School; this represents a valuable route to nurturing relationships with alumni who pursue careers in industry. These and other exploratory activities (e.g. Study Groups) will expand our industry funding portfolio. In summary, we will:

- Expand our programmes of internships for undergraduate and postgraduate students funded by external partners.
- Expand our business-led activities such as CASE and KTP.

Reaching Globally: We have been successful in developing new global links and funding (noted earlier and in Section 4). Many of these involve end-users such as clinicians, and offer direct routes to impact. Large awards such as our EPSRC Programme Grant, Leverhulme DTP and ERC grants have helped to expand the scope of visitor programmes, as well as our international reputation. Key objectives:

- Exploit interdisciplinary connections to further expand international reach to end users.
- Explore more funding opportunities with an international and impact aspect, e.g. Newton Fund, GCRF.

1.4. Open research environment and research integrity

Open Science

Staff and students have been routinely developing open-source software for many years, primarily in R, C++, or Python, which are made available through repositories such as GitHub, the Comprehensive R Archive Network (CRAN) or UoN's own data repository. SMS also hosts long-term developers in Magma (**Kasprzyk**) and SAGE (**Strömberg, Wuthrich**). Examples of good practice include:

- **Mirams** developed cardiac electrophysiology mathematical models to predict clinical pro-arrhythmic risk. The free simulator (<https://cardiac.nottingham.ac.uk>) has performed over 7,000 simulations for over 350 users (CS3,4). UoN's Digital Research Team have been working on making the code more portable, and UoN covered the costs of MS Azure to allow a Research Software Engineer to optimise the simulations for time-limited queries.
- **Dryden's** R package on CRAN 'shapes' provides shape analysis tools and supports his 2016 book with Mardia 'Statistical Shape Analysis, with Applications in R'. <https://cran.r-project.org/web/packages/shapes/index.html>. This has over 3,000 downloads per month on R studio and a total of >100k (>90th percentile of R packages). The package has 182 Google Scholar citations, primarily by researchers in biological sciences.

Reproducibility and validation of results is an important aspect, which is realised both through public deposition of data and by collaboration with industry partners. Examples of the former include the R package epiABC on GitHub which supports "A tutorial introduction to Bayesian inference for stochastic epidemic models using Approximate Bayesian Computation" by **Kypraios, Neal** and Prangle, and Python code in Bitbucket which supports "Automatic Symbolic Computation for Discontinuous Galerkin Finite Element Methods" by **Houston** and Sime. Examples of validation include performance analysis of **Gradoni's** electromagnetic wave model (CS1) which was undertaken by IMST GmbH to validate the model's theoretical predictions, and a workshop in 2020 organised by **Graham** with companies interested in the rheology software he was developing – with subsequent validation work taking place alongside fitting the code to their needs.

More broadly, industry is regularly engaged through seminars, study groups and other tailored events to promote open dialogue and knowledge exchange. Research articles are deposited in the UoN Repository once accepted, in line with UoN's Publication Framework, and often also in public repositories as preprints, allowing wider access.

Research Integrity

UoN holds the European Commission's 'HR Excellence in Research' badge, signs up to and implements the Concordats to Support Research Integrity and to Support the Career Development of Researchers, and annually reviews and updates its own Code of Research Conduct and Research Ethics (Institutional Statement, Sections 2.4 and 3.1). SMS implements these through the annual review process, guidance in staff and student handbooks, and review of projects and grant applications through our two School Ethics and Integrity Officers (DoR and RBDM) who also oversee compliance with legislation and procedures in the School and report annually to UoN board. Grant applications receive internal peer review; assistance is also provided for data management plans and the writing process in general, including an annual training course for ECRs. Active awards are supported to ensure responsible project management, assessment of risk and accuracy of reporting to funding bodies.

Beyond the formal requirements, SMS employs a range of measures to ensure a positive and healthy working environment for staff and students. All staff undertake training in bribery awareness, data protection, EDI at work, GDPR, modern slavery, staff and student equality, unconscious bias, and responsible use of social media. These are supplemented by other courses, e.g. training for staff involved in interview panels to eliminate bias and ensure fairness throughout the recruitment process. SMS has developed policies above and beyond the University requirements, embodied from 2020 in the SMS Behavioural Charter, which fosters an environment of mutual understanding and respect and is intrinsically linked with our EDI procedures (Section 2.4).

2. People**2.1 Overview and staffing strategy**

Our staffing strategy closely follows the research and impact strategies. Over the REF period, efforts have been made to increase personnel in our smaller groups (NTG, SC and SP) and recruit individuals who work at group intersections (**Hofscheier**, **Kasprzyk** at AA-NTG, **Laugwitz** at AA-MP, **Icardi** at IAM-SC and others) to encourage synergies. The REF period has seen small overall growth from 64 to 67 Category A staff.

Over this period, we have recruited 21 new academic staff, listed below (three further staff will be starting later in 2020/21) and seen six retirements, one voluntary redundancy, one death in service and ten staff moving to new appointments elsewhere, including Wilkinson who is re-joining SMS as a Professor in September 2020. **Iglesias**, **Sotiriou** and **Weinfurtner** joined the School in October 2013 and were included in REF2014 as new appointees.

- AA: **Laugwitz** (2019, joined as NRF).
- IAM: **Gradoni** (2016, previous research assistant since 2013, joint with Engineering), **Icardi** (2017, joint with Engineering), **Kalogirou** (2019, joined as Leverhulme Early Career Fellow), **Scase** (2014, joined from Engineering)
- MMB: **Fadai** (2020), **Mirams** (2016, joined as Wellcome Sir Henry Dale Fellow and NRF; now on a Wellcome Fellowship and a Professor), **R Nicks** (2016)
- MP: **Schenkel** (2016, joined as Royal Society URF), **Tufarelli** (2016, joined as NRF)
- NTG: **Kasprzyk** (2015), **Strömberg** (2014), **Hofscheier** (2019, joined as NRF).
- SC: **Cangiani** (2019), **Hubbard** (2014), **Kalise** (2019)
- SP: **Bharath** (2014), **Neal** (2020), **Severn** (2019), **Silverman*** (2018), **Sirl** (2014)

***Silverman** has a part-time contract with UoN as a Professor of Modern Slavery Statistics in the Rights Lab, one of the six UoN Beacons. He is affiliated to SMS and a member of the SP group (see also substantive connection statement in Staff return).

Promotions have been secured by (2020 promotions come into effect from August 2020):

- AA: **Vishik** (P, 2020)
- IAM: **Gradoni** (AP, 2020), **Graham** (P, 2018), **Scase** (AP, 2019), **Tanner** (P, 2016)
- MMB: Band[#] (AP, 2019), **Brook** (AP, 2017), **Mirams** (P, 2019), **O'Dea** (AP, 2019), **Thul** (AP, 2018), **Wattis** (P, 2017)
- MP: **Adesso** (AP, 2014 and P, 2016), **Fuentes** (P, 2015), **Gnutzmann** (AP, 2015), **Guta** (AP, 2014), **Schenkel** (AP, 2019), **Sotiriou** (P, 2017), **Weinfurtner** (Principal Research Fellow, 2017 and P, 2020)
- NTG: **Diamantis** (P, 2020), **Wuthrich** (AP, 2017)
- SC: **Hubbard** (P, 2020), **Iglesias** (AP, 2020), **van der Zee** (AP, 2020)
- SP: **Bharath** (AP, 2019), Bolton[#] (L, 2021), Brignell (AP, 2019), **Kypraios** (AP, 2015 and P, 2020), **Le** (P, 2016), **Preston** (AP, 2018)

[#]Band and Bolton are being returned to UoA6 and UoA2, respectively. Both represent excellent examples of interdisciplinary collaboration, emphasising the extent of our innovative mathematical approaches to biomedicine. Band completed a PhD in SMS and then joined the Centre for Plant Integrative Biology; she is now AP on a joint appointment with Biosciences, with significant funding successes (£1M from BBSRC, HFSP). Bolton is an AMF who is progressing to an academic post from March 2021; her expertise in the spread of pandemics has been very much in demand in the last year, including via an MRC project led by Life Sciences.

Our strategy has ensured that we have maintained an excellent balance of age and experience. We are working towards addressing the gender imbalance prevalent in the subject (new appointments *Dufresne*, **Kalogirou**, **R Nicks**, **Severn** and promotions for Band, Bolton, **Brook**, **Fuentes**, **Le** and **Weinfurtner**), see also Section 2.4.

The School continues to recruit internationally and has attracted staff from, e.g., the US (**Bharath**, **Laugwitz**), Canada (*Gielen*, **Hofscheier**) and Australia (**Fadaï**). UoN and SMS provide tailored advice for overseas applicants, covering visas, finance, accommodation, registering with local facilities, the university system and UK culture. The School also has a dedicated visitor room and regularly hosts international visitors (Section 4.1).

2.2 Staff development

SMS has a dedicated staff development programme that seeks to identify beneficial changes in School practice, to promote effective use of new technology and to encourage research collaboration, as well as supporting individual staff in their careers. The programme is led by the Staff Development Officer, with input from the Head of School, DoR, Director of Teaching and Learning, and SMS Boards. Individual needs and opportunities are identified through the staff appraisal scheme (Institutional Statement Section 3.1), through which advice on training and career development, including promotion and objective feedback on progress are provided. This is supplemented by our peer-mentoring system which has recently been enhanced following consultation, and by regular group and individual meetings.

UoN's Researcher Academy (on which **Graham** serves as Faculty of Science Lead) and Professional Development Unit run a wide range of courses designed in collaboration with the School to foster and enhance skills needed for career development; SMS also runs tailored training, e.g. in grant-writing and working with the media, as well as an annual exercise allowing draft promotion cases to be considered by senior colleagues and feedback provided.

For academic staff, a workload model is used to ensure that the demands of teaching, research and administration roles are distributed fairly. Several staff work part-time and loads for these staff are balanced appropriately in the model. Study leave is offered on a 'one for six' basis (i.e., after six teaching semesters staff can apply for a semester of leave); cases are assessed on the proposed activity and benefits for the individual and the School. In this REF period, 28 academic

staff have been granted study leave, with outcomes including the production of high-quality research papers, successful grant applications, development of impact case studies and impact activity (Section 1.3.1), and engagement such as Newton Institute programmes (Section 4). Pressures on staff time are also alleviated by the work of our seven dedicated teaching staff, as well as assistance from our in-house Research Support and wider School Support teams.

Early and mid-career researchers

Postdoctoral ECRs benefit from our staff development programme and are offered optional teaching, mentoring and supervision experience to further aid their development. They are encouraged to take the lead in organising seminars, events and other group activities in the School. Members of academic staff new to lecturing are given reduced administrative and teaching duties under the School's workload model. All new staff are assigned an established-staff mentor and are encouraged to disseminate their research within the School's extensive seminar programmes. New lecturers have preferential access to School travel and equipment budgets to enhance their opportunities to participate in international conferences and collaborations and to ensure that they have appropriate computational resources. ECRs have representation on the School's Research Board where they can raise issues and provide fresh outlooks on existing activities. Grant applicants are supported through the School's formal mentoring and review systems and training, as mentioned above.

UoN's Research Leadership programme provides mid-career support to successful applicants; in this period **Graham, Kypraios, Sotiriou, Tanner, Vishik** and **Weinfurtnner** participated in one of these programmes. Promotions to Professorial level were subsequently achieved by all six.

Fellowships

During this REF period, the School has made concerted efforts to encourage fellowship applications (internal and external). These include:

- 1851 Commission Fellowship (Knott 2017, McIlroy 2017, Saravani 2016)
- Daphne Jackson Fellowship (Franks 2015)
- EPSRC Early Career Fellowship (**Kasprzyk** 2016)
- Marie Curie Individual Fellowship (Coutant 2014, Iannella 2015)
- Royal Society Industry Fellowship with BT (**Gradoni**, 2020)
- Royal Society URF (**Gielen** 2018, **Schenkel** 2016, **Weinfurtnner** extension 2018)
- Wellcome Senior Biomedical Research Fellowship (**Mirams** 2018)

Outgoing Fellowships for our PhD students are noted under Section 2.3. In addition to the above, **Dufresne, Hofscheier, Laugwitz, Mirams** and **Tufarelli** won internal AMF/NRFs.

All Fellows receive the same career development support as academic staff. AMF/NRF holders and other longer-term Fellows such as EPSRC, Royal Society or Wellcome Fellows, are supported in progression to a permanent academic position through the appraisal scheme and regular reviews of goals. The double promotion of **Weinfurtnner** during her Royal Society Fellowship illustrates the effectiveness of such support.

2.3 Research students

The School currently hosts 96 PhD students. The gender balance at PhD level has remained stable across the REF period, at around 30% female. Since 2014 we have awarded on average 24 PhDs per annum, a slight increase on REF2014's 22. The School recruits highly qualified candidates from across the world through advertising and personal contact, and from our nine MSc programmes (whose intake tripled over the REF period) and strong UG population. The latter is aided by our well-supported summer research bursary programme (15-20 UG students in a typical year) which also helps (particularly ECR) staff with preliminary results to aid grant

applications, e.g. Band's successful HFSP application in 2020. Our annual PhD open day is widely promoted, and staff and PhD students frequently represent us at external recruitment events.

Studentships are assigned largely on quality, with other factors including supporting new, particularly ECR, staff, alignment to external grant applications and balance amongst the RGs. Many studentships are multidisciplinary, e.g. through the Leverhulme DTP, UoN BBSRC and MRC DTPs, Synthetic Biology DTProg and themed 'mini-CDTs': 'MAML' (Modelling and Analytics for Life Sciences) and 'MaP'. Funding has also been secured through the EPSRC DTG and School-funded studentships, CASE awards (**Houston, Icardi, Stupfler** and van Gennip, **Tanner**), and a fully industry funded studentship from BAST Inc Limited (*Stupfler, Brignell*).

Training and support mechanisms

The School holds two annual Welcome Events for new PhD students. Students have access to a continuously updated online School handbook, which provides guidance on all aspects of student life. Every student is assigned a principal supervisor, responsible for research guidance and administrative matters, and at least one secondary supervisor, whose involvement may range from additional mentorship to effective research co-supervision (where relevant, from a different UoA or by external collaborators, e.g. BAST Inc Limited, Crick Institute). In addition, a 'buddy' is assigned, typically a PhD student in the year above, and since 2020 also a postdoctoral mentor. There is a dedicated Support Team that PhD students communicate with on a regular basis. This team holds regular meetings to discuss everyday issues involving PhD students, and members offer confidential help and advice. Moreover, the School has a PhD Student Mental Health Representative, who holds monthly mental-health meetings. Important issues related to PhD students (and postdocs) are discussed in a dedicated Forum which meets quarterly.

Training of supervisors is provided via the PGCHE and Professional Development short courses. Our supervision quality has been recognised, e.g. through **Adesso** being shortlisted for Outstanding Supervisor of the Year at the 2017 THE Awards. Excellence in enhancing the student learning environment has been recognised by UoN's Dearing Awards where SMS won best overall School (in 2017) and three individual awards.

Formal assessed PhD training requirements (which includes required broadening training) depends on the length of the programme (3, 3.5 or 4 years), which in turn reflects the incoming student's experience, as well as any multidisciplinary elements of the project. In general, the School encourages 3.5-year programmes to allow consistency and better cohort building. Assessed training is provided through modules delivered by SMS and other Schools, as well as the MAGIC (Mathematics Access Grid: Instruction and Collaboration) and APTS (Academy for PhD Training in Statistics) UK Taught Course Centres. Since 2019, PhD students are required to take a Research Integrity Course, as part of the UoN-wide initiative. PhD students have access to an array of free training courses from the Researcher Academy, e.g. CV writing and interview training, and SMS sessions, e.g. annual review peer practice. Many PhD students also receive joint training, for example, through our joint PhD partnerships with Birmingham and Adelaide or through co-supervision with other Schools.

SMS houses dedicated PhD student offices. Students share common room facilities with staff and can access further work and social space in the nearby Engineering and Sciences Learning Centre and George Green Library. Financial support of £1,000p.a. per student is provided for conference attendance and the RBDM advises on further funding opportunities and provides annual training in grant-writing, working with the media and pursuing a career in academia. Students take the course 'Facilitating UG learning as a Postgraduate Student Teacher in Mathematical Sciences' as a requirement for UG demonstrating, teaching or assessment marking. All students benefit from extensive seminar programmes (each RG runs one or more series, supplemented by coordination of regional activities such as the East Midlands Seminar in Geometry), Study Groups and workshops.

PhD students are proactive, with staff encouragement, in event organisation, e.g. the 2014 and 2020 National Research Students' Conferences in Probability and Statistics and the 'Quantum Roundabout' workshops in 2014, 2016 and 2018. They also co-organise events led by staff, such as the 2016 ECMTB/SMB conference. Students are passionate about outreach, e.g. Akele visited a UK desalination plant and as a result co-led an event there in 2019 with the Institute of Chemical Engineers, and Radjen appeared on local radio in 2019 (more in Section 4). The School's SIAM-IMA Student Chapter was established in November 2017; this is run by PhD students and is very active in event organisation.

Prizes and awards

The effectiveness of our PhD training is evidenced by the many prizes and Fellowships awarded to our students. We have supported several competitively awarded EPSRC Doctoral Prize winners (Seymour 2019, Le 2020, Morris 2020) and UoN provided six equivalent prizes for students on the 'MASS'. Others include first prizes at TakeAIM (Holden, 2017; Brown, 2020), an EPSRC Fellowship (Girolami, 2014 – who subsequently won a JR Oppenheimer Fellowship at Los Alamos in 2017), a JSPS-Royal Society Fellowship (Oliver, 2014), LMS Early Career Fellowships (Morris, 2020 and Pybus, 2020), an MRC New Investigator Award (Chernyavsky, 2015) and an honourable mention in the 2018 Giulio Rampa Thesis Prize (Juarez-Aubry, 2018). Many students secure competitive funding from UoN schemes (e.g. Researcher Academy Travel Prize) and externally (e.g. MRC-funded visit to Harvard for Brown, 2018), as well as winning prizes at events (e.g. Braun, 2015; Mills and Schäfer, 2017). Prizes to top postgraduate students include e.g. the UoN Dean Moore Research Scholarship (Baker, 2014; Roggendorf, 2018). Every year our students have been selected to attend the SET/STEM for Britain competition at the Houses of Parliament; Irons won the national Silver Prize for mathematics in 2018. Birkar, recipient of the 2018 Fields Medal, was a UoN PhD graduate in 2004 and visited SMS in 2019 to inspire our students.

Many of our PhDs go on to postdoctoral research positions; they have also proved highly employable in industry. Several who graduated in the REF period have already secured permanent academic appointments, including at Bath, Brasilia and Crete or fellowships, as noted above.

Progress monitoring

A student's status as a PhD candidate is probationary during the first year of registration: each is subject to a Confirmation Review by the end of that year, followed by Progression Reviews in subsequent years. These involve a written report and research plan that are assessed in an oral exam by two independent assessors, who also monitor successful completion of training requirements. Further reviews can be held at any time should concerns be raised, for example, through the regular supervision meeting reports (at least 10 p.a.) completed by the supervisors and student. Progress monitoring seeks to ensure thesis submission within the period of registered study, with extra time granted for cross-disciplinary studentships (who are often based in other Schools), CASE, etc, as well as for students affected by Covid-19 and personal circumstances.

2.4 Equality, Diversity and Inclusion (EDI)

In the REF period SMS established an EDI Committee (formerly the Athena SWAN group and since 2020 the broader People and Culture Committee) to ensure that all matters affecting staff and students are considered fully. The committee includes staff and student representatives. The first Chair of the EDI Committee (**Pumpluen**, who now sits on the Faculty EDI Committee) was appointed to the LMS Women in Maths Committee in 2016 in recognition of her work towards the EDI agenda. The School hosts the Faculty BAME Champion (Augustus) who supports positive change across UoN and works closely with Faculty and UoN EDI staff

including the PVC for EDI (Sharples) who sits on UoN Executive Board. UoN EDI policies (Institutional Statement Section 3.5) are followed, with additional key School-level actions taken by our EDI Committee including:

- Pushing for, and achieving, greater equality in event participation, particularly seminar and conference speakers, e.g. half of the ECMTB/SMB conference speakers were women (from 2014).
- Initiating surveys and follow-up support activities for disabled, LGBT+ and BAME people, including actions to reduce the attainment gap and encourage more diverse internal PhD candidates (from 2015).
- Providing staff and student training on unconscious bias (from 2016), including explicitly linking training to the School's behavioural standards, which have been formalised into the SMS Behavioural Charter (2020).
- Enacting (University-wide) supportive parental leave and flexible working policies that allow people of all genders and role types to access support, including a consistent policy for all PhD students irrespective of the funding policies (from 2017).
- Creating specific 'safe-space' offices where students and staff can feel at ease to discuss issues without fear of discrimination, aimed particularly at supporting LGBT+ staff and students (from 2017).
- Changing role requirements and the tone of job adverts explicitly to encourage a more diverse applicant pool (from 2019).

Our Behavioural Charter and other measures above have been well received. Evidence of appreciation of our proactive approach to reducing discrimination and providing a supportive environment include the award of a Vice Chancellor's Medal to Moriarty (Impact Officer 2016-2018) for exceptional contributions to developing UoN EDI procedures, and to **Pumpluen** and Nichols (PhD student) for their efforts as ambassadors for women in STEM.

The committee actions contributed heavily to the successful renewal of the School's Athena SWAN Bronze Award in 2016 and 2019. SMS also supports the LMS Good Practice Scheme. Over the period the School has championed nationally and internationally its 'Women in Maths' initiative. This has included a 2018 conference, with speaker Maria D'Orsogna who discussed ethical uses of mathematics and showcased the science and careers of female researchers in computation. A Facebook community (over 8,200 followers at Aug 2020) was established in 2014 by **Pumpluen**, and two groups are coordinated: "Women in Maths" (over 1,500 members at Aug 2020) and "Alice: Women in Quantum Information" (over 300 members at Aug 2020). The initiative has been lauded by the LMS, European Mathematical Society, European Women in Mathematics and others, and has been extended to widen the diversity net beyond gender considerations. **Pumpluen** was featured in an article in Womanthology, an online magazine that champions positive female role models (124k readers and 21.4k Twitter followers), where over 85% of surveyed viewers said their interest in mathematics had increased and many women found it 'empowering', noting that they were more inclined to study or resume studying mathematics afterwards. Supplementing this online activity, a PhD-instituted group for women, trans and non-binary people in mathematics meets for lunch weekly in term time. Students have further contributed to EDI through, e.g. participation in the Nottingham civic showcase for international women's day demonstrating the uses of mathematics, outreach to schools (Section 4.2), Accenture girls in STEM day, and creation of the Women and Pride in Maths bimonthly newsletter that now has around 200 global subscribers. The School continues to have a dedicated Tutor for Women Students.

Ten staff are trained as mental health first aiders (in addition to our regular first aiders) to help understand and respond to student and staff concerns. Students have mental health meetups to reduce isolation and general stress. The Health and Wellbeing Officer coordinates activities to encourage social and professional wellbeing, e.g. social exercise during lunch breaks, provision of fruit in our common room and a School table tennis tournament. Students are encouraged to contribute ideas, which have included a mathematical poetry club, film club and board game competitions. After the outbreak of Covid-19 and move to online working, numerous training and

discussion events were held to develop best practice in the new environment. Covid-19 has accentuated the importance of mental health and wellbeing, particularly for those with caring responsibilities and other factors that can aggravate the situation; online fora such as a School virtual cafeteria have helped retain a sense of community.

3. Income, infrastructure and facilities

3.1 Research income and funding portfolio

Research income increased steadily over the period, aside from a dip in 2017-18 due to some larger grants closing the year before. Our current portfolio (grant value to the School) is worth £18M, representing a 50% increase from the last REF. This comprises over 70 active awards comprising (by value) 42% EPSRC, 15% Wellcome Trust, 12% Leverhulme Trust, 8% Royal Society and a variety of other UK and international sources. Notable examples include:

<i>Award</i>	<i>SMS staff</i>	<i>Value</i>
EPSRC Bridging the Gaps in Antimicrobial Resistance	King	£0.5M
EPSRC Design by Science Grant	Graham	£1M
EPSRC Fellowship	Kasprzyk	£0.5M
EPSRC Nexus with Southampton	Owen	£1.5M
EPSRC Programme Grant with Oxford	Fesenko	£2M
ERC Starting Grant	Adesso	£1M
GCRF award with Tanzania	Dryden, Le, Preston, Silverman, Sirl	£0.5M
H2020 RIA with BGS	Icardi	£9M
Horizon Digital Economy Hub renewal	Dryden	£4M
Leverhulme DTP	Owen	£1M
Marie Curie IAPP with Engineering	Tanner	£2M
Marie Curie ITN with Engineering	Billingham	£4M
Royal Society/Wellcome Sir Henry Dale Fellowship	Mirams	£0.5M
Royal Society URFs	Gielen, Schenkel, extension for Weinfurtner	£1.5M collectively
STFC Consolidated Grants with Physics	Barrett, Krasnov, Louko, Sotiriou, Weinfurtner	£1.5M collectively
Wellcome Collaborative Award with Imperial	Brook	£2M
Wellcome Senior Biomedical Fellowship	Mirams	£2M

King directed the modelling work on BBSRC/EPSRC industrial technology and synthetic biology grants held within Life Sciences exceeding £18M in total value, serving on the Core Management team of UoN's Synthetic Biology Research Centre. Around a dozen further BBSRC grants and studentships with Biosciences with a collective value of over £4M have involved **Band, Farcot, King, Owen** and **Preston**. Other awards of lesser face value but equal strategic importance have included a Leverhulme project grant with Physics (**Scase**), two UK Regenerative Medicine Platform awards (**King, O'Dea**), NERC grants with Biology (**Brignell**) and work funded through the EPSRC Composites Hub (**Tretyakov, Iglesias**). Charity and international funding increased substantially, e.g. via FQXi (**Adesso, Fuentes, Tufarelli**), NIH (**Bharath, O'Neill**), NSF (**Bharath**), ONR (**Tanner**) and the major Leverhulme and Wellcome awards mentioned above. Industry funded research was also a key feature of this period, e.g. with Bloomberg by **Preston, Bharath**, van Gennip and Mahlberg (English, Birmingham) and

£100k from BAST Inc Limited supported a four-year PhD studentship. Substantial investment (over £650k) from predominantly US philanthropists enabled the establishment of the Physics branch of the Penrose Institute (**Fuentes**) which supported two postdocs and multiple visits by Penrose to SMS (Section 4). The School was also aided by the provision of two internally funded doctoral training grants: 'MAML', centred around MMB, that supported five students and 'MaP', spanning multiple groups (IAM, SC, SP), that supported four (with 11 other students aligned).

Research margin (combined with income from teaching) contributes towards supporting pump-priming activity for research, as well as a significant investment into PhD studentships (Section 2.3).

3.2 Consultancy and professional services

Formal consultancies have included Element Six (Cliffe, **Houston**, 2012-date), Mars Petcare (**Owen**, 2019-date), Chalice Medical (**Houston, O'Dea**, 2016-17), Cranswick (**Icardi**, 2019-date), Heilbronn (**Kasprzyk**, 2017-date), Rambus (**Farcot**, 2015-16), Winchester Consulting (**Strömberg**, 2016-date). Our impact case studies highlight further examples such as Dynament (CS2). In 2017, **Preston, Kypraios** and Brignell established their own company, DAMSL Ltd, alongside Goulding (Business School) and Wilkinson (Sheffield, now UoN), consulting for over a dozen private and public sector clients on projects from rail-safety standards to optimising a multinational retailer's website.

Cliffe (Rolls-Royce) and **Tanner** (inuTech) have been part-funded by industry and extensive interactions also occur through other mechanisms, including internships, CASE awards (Section 4) and patents developed by staff (**Fuentes, Weinfurter, Zhang**). Many of these are supported by UoN's 'Nottingham University Consultants', who assist with the legal and financial aspects of the relationships.

3.3 Infrastructure and facilities

The School is housed in a dedicated facility built in 2011, which contains offices for all academic staff, postdocs and PhD students, research and admin support and our in-house IT team. The building includes dedicated study space and computing facilities for UG and MSc students, eight 'break-out' rooms to encourage small group discussion, and a shared staff-PhD student common room. An AccessGrid room provides space for delivery of advanced courses through the UK 'MAGIC' consortium (Section 2.3). SMS has eight in-house dedicated Linux multi-core servers and access to the University's High-Performance Computing Facility (with 15 SMS registered users in 2018-20); UoN is a partner in the EPSRC-funded MidPlus regional HPC centre. The IT team maintain the hardware, as well as providing support for software and liaising with the central Information Services team.

Weinfurter has dedicated laboratory space in an adjacent building due to her developing both theoretical and experimental aspects of her work. A further laboratory is being refurbished for her new Leverhulme Research Leadership Award (£1M) and UKRI Programme (£4M) in 2020.

Reflecting our funding successes, the School's Research Support team has expanded since 2014 to four: the mathematically-trained RBDM assists staff with applications, provides training and aids with strategic planning; a Research Support Officer and Research Support Administrator together provide day-to-day assistance with event support, budgeting, project management and administration; and an Impact and Engagement Officer helps to develop and realise research impact, and supports outreach and business engagement activity in the School. This team also advises on ethics and integrity matters (Section 1.4), alongside the DoR, as well as assisting in meeting requirements for the open data agenda such as production of Data Management Plans, accessing funds for open access publication, and matters of data storage, retention and security.

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

4.1 Research collaborations, networks and partnerships

The School is engaged in many hundreds of research collaborations, most of which are interdisciplinary. These occur through funded grants (Section 3.1), joint events, networks and research papers. Below, we present an indicative selection to highlight the disciplinary and global reach of our work.

Selected international collaborations, networks and partnerships

We have represented the UK on EC COST networks: **Barrett** “Quantum Structure of Spacetime” 2015-19; **Gradoni** “Advanced characterisation and classification of radiated emissions in densely integrated technologies” 2015-19; **Sotiriou** “Gravitational Waves, Black Holes and Fundamental Physics” (also Working Group leader) 2017-21 and “Quantum gravity phenomenology in the multi-messenger approach” 2019-23. **Kalise** leads “TIDAL: Taming the Curse of Dimensionality in Dynamic Programming Equations” 2019-22, funded by the French Gaspard Monge Program on Optimisation, Operations Research and Data Science with partners in Boston, Imperial, Graz and Sorbonne.

The continuing partnership with the Mathematical Biology Institute in Ohio supported a joint workshop ‘Generalized Network Structures and Dynamics’ in 2016 (**Coombes**). **Mirams** has led on the CiPA initiative with the US Food and Drug Administration and was part of the Health and Environmental Sciences Initiative Cardiac Safety Technical Committee (CS4).

Other funded collaborations include: **Creagh**, **Gradoni**, **Tanner** with electrical engineering at University of Maryland and UoN, supported by multiple EC, EPSRC and other grants; **Icardi** with Porta (Politecnico di Milano) funded by Royal Society; **Kurzke** with Cabre (UPC Barcelona) funded by IRCEA and with Ignat (Toulouse-Paul Sabatier) funded by ANR; **Oblezin** with Lebedev (Moscow) funded by the Russian Science Foundation. Collaborations such as **Diamantis** with Hoffstein (Brown), Kiral (Keio) and Lee (Bristol), **Strömberg** with Skoruppa (Siegen) and **Vishik** with Smirnov (St Petersburg) have helped secure external funding; the latter also led to a 2017 lecture series. Other international programmes include a year-long programme on IUT in Kyoto, Japan (**Fesenko**, 2020/21), and a six-week programme on Probing Effective Theories of Gravity in Strong Fields and Cosmology at Kavli Institute for Theoretical Physics, Santa Barbara, USA (**Sotiriou**, 2020).

Selected national and regional collaborations

The BBSRC Multiscale Biology Network led by **Owen** included a summer school at UoN in 2017 that sparked several new collaborations including with Schupper and Krishnan (Aachen, Germany). This led to a mini-symposium (by postdoc Kalogiros) at the SIAM Conference on Computational Science and Engineering in Washington, USA in 2019.

One highly successful collaborative award is EPSRC ‘Bridging the Gaps: Systems-level approaches to antimicrobial resistance’ (**King**, 2015-17) which fostered relationships with Biology, Veterinary Medicine, the Medical Faculty, Chemistry, Physics and Engineering. The programme supported 23 pump prime projects, 40 researchers (largely ECRs) and around 40 activities that engaged end users including via changes to the education of healthcare professionals, input into NHS improvement projects, informing governmental organisations such as the Animal and Plant Health Agency and DEFRA, and impact on competitive business decisions such as for Severn Trent Water.

Our multi-disciplinary collaborations are often supported and/or initiated through UoN investment such as the Beacons and IRCs that include the ‘Data, Modelling and Uncertainty’ cluster we lead (**Kypraios**, **Preston**), and Impact Acceleration Accounts such as work by **Stupfler** with Derclaye

(Law, UoN) on EU case law. Beacons involve staff from around 20 different disciplines across UoN and provide excellent opportunities to develop exciting new directions.

SMS staff are involved in various regional groups, including through coordination of the: East Midlands RSS Group (Brignell, **Kypraios**, **Sirl**); LMS East Midlands Seminar in Geometry (**Kasprzyk**); Northern Number Theory Seminar Series (**Wuthrich**). Staff also organise activities or speak at the Newton Institute: Uncertainty Quantification for Cardiac Models (**Mirams**, 2019); Flows, mappings and shapes (**Zhang**, 2017); Gravity, twistors and amplitudes (**Krasnov**, 2016); Free Boundary Problems (**King**, 2014; with a six-month resurgence programme planned in 2021/22); speakers: **King** 2015 (Simons Fellow), **Wattis** 2016, **Zhang** 2017, **Houston** and **King** 2019, **Ball** 2020 (Covid-19 related).

During the Covid-19 pandemic, staff were involved in the Royal Society Rapid Assistance in Modelling the Pandemic (RAMP) initiative (Band, Bolton, **Kypraios**, **Mirams**, **Owen** and **Preston**), as well as in multidisciplinary and multi-institutional Covid-19 UKRI projects (Bolton, led by Life Sciences and **Kalise**, led by Warwick).

Research events (around 200)

In 2016 we hosted the ECMTB/SMB conference, one of the largest mathematical and theoretical biology events in the world (around 850 delegates from 40 countries for a week). This was organised by our MMB staff and PhD students, with support from our admin team. Below is an indicative selection of other events hosted at UoN (around 100 in total):

<i>Event title</i>	<i>Funder</i>	<i>Year</i>	<i>Organiser(s)</i>	<i>Delegates (approx.)</i>
57 th ARTIN Mtg (online)	UoN, LMS	2020	Laugwitz	100
Holomorphic dynamics	LMS	2019	D Nicks	25
LMS Regional Meeting on zeta functions and elliptic curves	LMS	2019	Gnutzmann, Strömberg, Wuthrich	30
Scientific computation using machine learning	UoN, UoB'ham	2019	van der Zee	50
SECURE Workshop	H2020	2019	Icardi	50
Threshold networks	EPSRC	2019	Coombes, Lai, Thul	40
Mathematics of multiscale biology	LMS	2018	Farcot	80
Polaron Day	LMS	2018	Tufarelli	30
Multiscale biology summer school	BBSRC, LMS	2017	MMB group	80
Stochastic epidemic models	LMS	2017	Sirl	40
Bogomolov 70 th birthday	EPSRC	2016	Fesenko	30
BritGrav	UoN, IoP	2016	Louko, Sotiriou	80
Kac-Moody Groups and L-Functions	Heilbronn	2016	Oblezin	12
Manifold-Valued Data	EPSRC	2016	Dryden, Le, Preston, Wood	60
Graviton scattering	ERC	2015	Krasnov	50
Gravity at all scales	ERC	2015	Sotiriou	100
Quantum cybernetics & control	FQXi	2015	Adesso	80
Statistical inference for epidemic models	EPSRC	2015	Kypraios	25
Waves in complex media	H2020	2015	Gradoni, Tanner	40

Selected outgoing visiting appointments (over 20 in total)

- **Ball**, Visiting Professor, Stockholm University, 2017, supported by the Knut and Alice Wallenberg Foundation.
- **Fuentes**, Visiting Professor, University of Vienna, 2015-2018.
- **Sotiriou**, Distinguished Visiting Professor, Instituto Superior Tecnico, Lisbon, 2018.
- **Tretyakov**, Visiting Professor, Chinese Academy of Sciences, Beijing, 2017.
- **Weinfurtner**, Emmy Noether Fellow, Perimeter Institute, Canada, 2015-2016.

Selected incoming visiting researchers (over 100)

Notable visitors include: Antonsen (Maryland), Bogomolov (Courant Inst. NYU), Britton (Stockholm, via an EPSRC Visiting Fellowship for **Ball** and **O'Neill**), du T Mouton (Stellenbosch), Falk (Wurzberg, supported by LMS), Gillibert (Toulouse), Goldfeld (Columbia), Lafforgue (IHES), Marron (N Carolina), Penrose FRS (Oxford), Pickering (Rey Juan Carlos), Prohl (Tubingen, supported by LMS), Smirnov (Steklov Inst.), Unruh FRS (Perimeter Inst. UBC), Zelmanov (UCSD).

4.2 Engaging with end users and contributing to society***Reaching out to industry, clinicians and policymakers***

Work with industry often arises through consultancy (Section 3.2; industry income is also noted in Sections 3.1 and 3.2.). **Tanner** and **Gradoni** continue to develop a wide network of industrial connections, most recently with BT (talk to BT Research Labs 2019, **Gradoni's** Fellowship), Telecom Italia, Airbus and others. **Tanner** supports other staff in his role as the School industrial engagement representative. CASE awards have proven a successful mechanism for engagement for many years in the School, and over the period we have secured four in a competitive environment: with Element Six (**Houston**), Romax (**Tanner**), Russell Group Limited (**Stupfler**, van Gennip), and Total (**Icardi**). The appointment of **Mirams** in 2017 allowed him to enhance his existing wide network of industrial and public sector connections, e.g. with GSK, Roche and the FDA.

The UoN Institute for Policy and Engagement, established in 2017, has helped to encourage policy work, e.g. **Graham** is a committee member of the US-led Additive Manufacturing Benchmark Test Series, which allows modellers to test their simulations against rigorous benchmark data. **Graham** also sits on the UKCCSRC council and ran a workshop in 2014 with participants such as National Grid and the Pipeline Industry Guild.

Fuentes was part of the Strategic Research Agenda Working Group, Quantum Flagship European Commission 2018-19. **Sotiriou** was Topical Team Member in ESA's Voyage 2050 space program and Fundamental Physics subgroup Chair in the 3rd Generation Gravitational Wave Detector Consortium Science Case Team. **Hubbard** and **Scase** collaborate with Johnson (Geography, UoN) on work with the Environment Agency, and **Icardi** with BGS through his joint appointment.

Science communication

Many staff and students are involved in Open Days, the annual UoN community day, and local events such as Light Night, Science in the Park and the Nottingham Festival of Science and Curiosity. One of the highlights has been the 'PubHD' programme: this began in Nottingham in 2014 with the aim of enabling speakers to explain their work to the general public in an informal pub setting. SMS students and staff have contributed to nine talks and the scheme has been so successful that there are now over 20 branches in seven countries. Staff have also made contributions to: Skeptics in the Pub (van Gennip 2018); Scibar (**Coombes** 2016); Pint of Science (**Weinfurtner** 2016, **Sotiriou** 2017, **Adesso** and **Fuentes** 2019). For the 2017 Pint of

Science, SMS submitted mathematics-inspired artwork, including a large art installation; Brewer (PhD student) was an exhibited finalist.

Public talks are organised when the opportunity arises, e.g. Penrose delivered a sold-out (~350 in person, others via livestream) public lecture in 2018 during one of his visits and **Sotiriou** organised events celebrating the centenaries of General Relativity and Black Holes and the first detection of gravitational waves. In 2017, **Wattis** gave a talk to a local Science and Technology Club and **Sotiriou** at a Café Scientifique. **Sotiriou** also gave invited outreach talks in Cambridge (Archimedean, 2018) and Malta (2018). **Fuentes** talked about her work on a BBC programme (2018) and gave a plenary talk at the New Scientist Live Event in London (2019) which had an audience of 20,000. Symonds produced three videos for the YouTube educational channel Numberphile (up to 296k views each), while **Weinfurtnner** made several videos and interviews, e.g. a Sixty Symbols video (2016, over 230k views to date), one in Spiegel online (a renowned German magazine), in NOWTHIS (2017, over 3.1M views to date) and in Techinside UK (2017, over 1.3M views to date). Newspaper coverage of **Weinfurtnner's** work and/or expert opinion includes numerous articles in the German and English press such as The Times (2016) and New Scientist (2014). These and multiple other YouTube videos and interviews have encouraged particularly women to consider careers in mathematics and physics (Section 2.4). **Fesenko** has appeared on BBC Radio 4 and been interviewed by New Scientist and others regarding his work with Mochizuki. The School was also active in the immediate response to the Covid-19 pandemic: for example, **Ball** co-authored a paper in Science (2020) modelling the threshold for reaching herd immunity; this was covered in the news and an interview on Notts TV and by many outlets including the Daily Mail and Hindustan Times.

Knott and **Tufarelli** collaborated with an artist to produce a book about quantum mechanics ('Our quantum reality') using accessible text and illustration. Knott was subsequently interviewed by FQXi who funded the project, and the design for the book appeared on the front cover of Physical Review Letters in 2018. **Adesso** hosted a performance of 'Entanglement: An entropic tale' by Midlands troupe Infinite Opera at Lakeside Theatre in 2018 with a Q&A (leading performer Korda moved onto a PhD at Birmingham City University on 'Librettising Science' co-supervised by **Adesso**), and the public dissemination event 'Science Rhymes' in 2019 within Nottingham Poetry Festival (PhD student Lanyon, who performed at the event, also ran an SMS Mathematics & Poetry club in 2018-20). Links to the arts world have also appeared naturally through **Owen's** cancer modelling work which was featured in a 2018 exhibition 'Where science and art meet' in the Netherlands and in the associated O2 magazine in 2020.

4.3 Academic leadership and services to the research community

SMS staff undertake a wide array of other activities in the mathematical sciences community.

Prizes and awards

Our academic leadership and the international reputation of our research were recognised with prestigious awards, including:

- **Weinfurtnner**, Leverhulme Research Leadership Award, 2020
- **Silverman**, Knighthood for Public Service and services to Science, 2018
- **King**, LMS Naylor Prize and Lectureship, 2017
- **Adesso**, World Economic Forum Young Scientist Honour, 2016
- **Gradoni**, Latmiral Prize, Italian Society of Electromagnetics, 2015
- **Tanner**, Best Paper Award of the IEEE EMC, 2015
- **Farcot**, La Recherche Biology Prize, 2014

Steering and advisory committees

In addition to staff involvement in numerous conference steering committees, we highlight:

Brignell (APTS Executive Committee), **Kasprzyk** (Classification, Computation, and Construction, EPSRC Programme Grant), **King** (EPSRC FAST Healthcare NetworkPlus Advisory Board, subpanel 10 member and interdisciplinary advisor for REF2021), **O'Neill** (NIHR 'Real time modelling of a pandemic influenza outbreak' project 2013-15), **Silverman** (UK Research Integrity Office, Chair of Trustees), **van Rossum** (Bernstein Center Munich advisory board).

Funding panels

EPSRC panel members include **Kasprzyk** (2016), **Strömberg** (2018), **Dryden** (2015, 2018), **King** (2016), **Owen** (2017), **Coombes** (2017, 2018, 2019), **Oblezin** (2019), **Fuentes** (2014, Physics Chair), **Billingham** (2017, 2018). We maintained representation in the EPSRC Early Career Forum (**Thul** 2014-2015, van Gennip 2016-2018, McIlroy 2019-2020) and hosted an EPSRC SAT Meeting in 2019.

Other agency roles include: **Brook** (Royal Society Newton Fellowships panel 2018-2021); **Coombes** (Royal Society Research Grants Board 2013-15; MRC Skills Development panels 2017-18; Commonwealth Scholarship Commission); **Fuentes** (EC FET panel member and reviewer); **Graham** (UKCCSRC council since 2017); **Graham, Le, Schenkel** (Royal Society International Exchange Committee); **Kypraios** (Chair of RSS Statistical Computing Section); **Scase** (NERC Highlight Topics panel 2018).

Grant reviews

Demonstrating the breadth of our interdisciplinary activity, staff undertake reviews for almost all the UK Research Councils (AHRC (**Silverman**), BBSRC – **Farcot, O'Dea, van Rossum**; EPSRC – over 20 staff; MRC (**Farcot, Mirams, van Rossum**), STFC (**Sotiriou**), UKRI (**King**)), as well as for Leverhulme Trust (**Kurzke**), LMS (**Bharath**) and Wellcome Trust (**Kypraios, Mirams, Owen**). Internationally, we have reviewed, e.g. for Cariparo Foundation (**Sotiriou**), Chilean FONDECYT (**Houston, Pumpluen, Sotiriou**), Czech Science Foundation (**Sotiriou**), Danish Council for Independent Research (**Graham**), ERC (**King**), German DFG (**Adesso, Barrett**), Hong Kong Research Grants Council (**Diamantis, Houston**), NSERC (**Barrett, Louko, Sotiriou**), NSF (**Barrett, Louko**), NWO (**Farcot**), South African NRF (**Sotiriou**) and the Swiss National Science Foundation (**Houston, Sotiriou**).

Learned society roles

Numerous staff are members of the IMA, LMS, RSS or SIAM. More substantial roles include: **Billingham, Coombes, Icardi, King, Scase** and **Wattis** (Fellows of IMA), **Dryden** (elected Fellow of Institute of Mathematical Statistics, elected member of the International Statistics Institute), **Icardi** (Interpore event committee), **King** (IMA Journals Board of Management, SIAM Prize Committee), **Louko** (International Society on General Relativity and Gravitation committee since 2013), Mitchell (PhD, RSS committee), **Pumpluen** (member of Deutscher Hochschulverband since 2013, elected member of LMS Women in Maths committee since 2016), **Silverman** (Fellow of the Academy of Social Sciences since 2014, FRS), **Sotiriou** (Chair of Gravitational Physics Group at IOP since 2017), **Tanner** (elected member of the Sudendentusche Akademie since 2017), **Weinfurtnner** (Chair of International Society for Relativistic Quantum Information since 2018).

Editorial duties (over 40) and monographs

- *Journal board memberships include:* Acta Applicandae Mathematicae (**King**, joint editor-in-chief), Advances in Computational Mathematics (**Houston**), British Journal of Pharmacology (**Mirams**), Classical and Quantum Gravity (**Louko**), Communications in Mathematical Research (**Zhang**, deputy editor), Computational Methods and Function Theory (**Langley**), European Journal of Applied Mathematics (**King**, joint editor-in-chief), General Relativity and Gravitation (**Sotiriou**), IMA Journal of Numerical Analysis (**Tretyakov**), International Journal of Machine Tools and Manufacture (**Billingham**),

Journal of Engineering Mathematics (**Billingham**), Journal of Mathematical Neuroscience (**Coombes**, joint editor-in-chief and co-creator), Journal of Physics A (**Adesso**), Mathematical Biosciences (**Ball, Kypraios**), Mathematical Medicine and Biology (**King**, joint editor-in-chief), Physica D (**Coombes**), PLOS One (**King, O'Dea**), Proceedings of the Royal Society A (**Barrett, Sotiriou**), PRX Quantum (**Adesso**), QJMAM (**Billingham, King**), Quantum (**Fuentes**), Sankhya Series A (**Bharath**), SIAM Journal on Scientific Computing (**Houston, Tretyakov**), Statistical Science (**Kypraios**), Wave Motion (**Gradoni**).

- *Book editorships include:* Geometry Driven Statistics (**Dryden**, Wiley 2015), Optimal Control: Novel Directions and Applications (**Kalise**, Springer 2017), Thermodynamics in the Quantum Regime (**Adesso**, Springer 2019).
- *Monographs include:* hp-Version Discontinuous Galerkin Methods on Polygonal and Polyhedral Meshes (**Houston**, Springer 2017); Formulations of General Relativity (**Krasnov**, CUP 2020), Modular Forms: A Classical Approach (**Strömberg**, AMS 2017).

Invited talks

Staff have provided many hundreds of invited talks over the period. We highlight here some of the (over 50) special events and notable talks.

Special events:

- **Barrett:** Conference for Alain Connes' 70th Birthday, Fudan, China, 2017
- **Dryden:** 3rd David Finney Lecture, Edinburgh, 2019
- **Edjvet:** Workshop for Arye Juhasz' 70th Birthday, Technion, Israel, 2017
- **D Nicks:** Workshop for Walter Bergweiler's 60th birthday, ICMS, 2018
- **Schenkel:** Workshop for Klaus Fredenhagen's 70th birthday, Hamburg, 2017
- **Sotiriou:** '100 years of gravitational light deflection', Sao Tome and Principe, 2019
- **Vishik:** Voevodsky Memorial Conference, IAS, Princeton, 2018

Keynotes and plenaries include:

Speaker	Event	Venue	Year	Delegates (approx.)
King	International Symposium on Bifurcations and Instabilities in Fluid Dynamics	Ireland	2019	300
King	XI Summer Workshop in Mathematics	Brazil	2019	400
R Nicks	International Conference on Mathematical Neuroscience	Denmark	2019	100
Houston	16 th Conference on the Mathematics of Finite Elements and Applications	Brunel	2019	350
Gradoni	International Symposium on Antennas, Propagation and EM Theory	China	2018	200
King	Mathematics for Complex Microbial Systems	Canada (Fields Institute)	2018	60
Coombes	International Conference on Artificial Neural Networks	Spain	2016	200
Dryden	SIS2017	Italy	2017	300

<i>Speaker</i>	<i>Event</i>	<i>Venue</i>	<i>Year</i>	<i>Delegates (approx.)</i>
Fuentes	The Science of Consciousness	USA	2017	300
Kypraios	52 nd Gregynog Statistical Conference	Wales	2016	50
D Nicks	LMS Postgraduate Conference in Complex Dynamics	London	2015	30
Louko	Hawking Radiation	Sweden	2015	100
Coombes	International Conference on Complex Dynamical Systems and their Applications	Turkey	2014	60

Other notable talks include:

<i>Speaker</i>	<i>Event</i>	<i>Venue</i>	<i>Year</i>	<i>Delegates (approx.)</i>
Weinfurtner	29 th Workshop on General Relativity and Gravitation	Japan	2019	230
Sotiriou	GWADW2019	Italy	2019	200
Barrett	Non-commutative Geometry, Index Theory and Mathematical Physics	Germany (Oberwolfach)	2018	50
Brook	7 th Conference on Systems Biology of Mammalian Cells	Germany	2018	100
Sotiriou	Shapes of Gravity	Netherlands	2016	100
Coombes	International Conference on NeuroInformation	China	2015	100
Graham	British-German Frontiers of Science	Germany	2014	70