Institution: University of Southampton

Unit of Assessment: 10 Mathematical Sciences

1. Unit context and structure, research and impact strategy

1.1 Overview: structure and context

UoA10 within the University of Southampton (UoS) brings together colleagues from the School of Mathematical Sciences and the Department of Social Statistics and Demography. Our research covers a wide range of pure and applied mathematics, statistics, and applications, and its major strength is its distinctively collaborative, interdisciplinary, and impact-oriented ethos. We are committed to the ideals of equality, diversity, and inclusion in our efforts to create a supportive community of scholars (§2.2). The submission comprises 69 staff, **64.3 FTE** (compared to 54.8 FTEs in REF2014), which provides a significant critical mass to support research across all represented fields. The increase in FTE is in a large part due to the success of our drive to attract strong early career researchers (ECRs) supported by the Royal Society, STFC, and EPSRC Fellowships (§2.1).

Research within UoA10 is structured around the following research divisions: *Applied Mathematics and Theoretical Physics* (led by **Skenderis**), *Operational Research* (**Fliege**), *Pure Mathematics* (**Theriault**), and *Statistics* (**Woods**) which are located within the School of Mathematical Sciences, with **Taylor** as Head of School. *Social Statistics and Demography* (**Tzavidis**) is part of the School of Economic, Social, and Political Sciences (ESPS). Its inclusion within UoA10 follows from and exemplifies strong interdisciplinary links forged by our staff.

To showcase the research across UoA10, and to promote and facilitate *interdisciplinary collaborations* within the University, nationally, and internationally, we support four international centres of scholarship and excellence. These are: CORMSIS (Centre for Operational Research, Management Sciences, and Information Systems, led by **Currie**), S3RI (Southampton Statistical Sciences Research Institute, **Böhning**), STAG (Southampton Theory, Astrophysics, and Gravity Research Centre, **Skenderis**), and CGTA (Centre for Geometry, Topology, and Applications, **Brodzki**).

CORMSIS is one of the largest research centres of its kind in Europe, with around 50 academics from Mathematical Sciences and SBS. CORMSIS is a world leader in optimisation and stochastic simulation, with a strong focus on mission-oriented research, particularly in health, aerospace and transport. It partners with more than 100 organisations from the public sector and commerce to implement Operational Research (OR) techniques in practical situations, which is a key part of the UoA10 impact strategy. CORMSIS's high-profile long-term collaborators include NHS Trusts, Boeing, Airbus, Babcock, Virgin Atlantic, Carnival Cruises, Royal Mail, Tesco and Ford.

S3RI brings together statistical scientists from UoA10 and from Health Sciences and Medicine to collaborate on the development of core statistical methodology at the centre of a host of substantive applications. Southampton is recognised internationally as the UK's leading centre for statistically-designed data collection via experiments and surveys, and more recently, in administrative data. We achieve impact of our research through strong strategic partnerships with external organisations, such as the Office for National Statistics (ONS).

STAG was launched in 2013 to create new opportunities for interdisciplinary research through the affinities between research groups within Mathematical Sciences and the School of Physics



and Astronomy (UoA9). This strategy was vindicated as STAG is now a thriving, internationallyleading centre of excellence with a network of major international collaborations. These include the Laser Interferometer Gravitational-Wave Observatory (LIGO), whose founders won the 2017 Nobel Prize in Physics. Among STAG's many activities is an innovative and intellectually diverse programme of outreach activities. A highlight of this programme is the STAG annual lecture series for the general public given by distinguished lecturers which included Nobel Physics Laureates: Gerard 't Hooft (2014), Brian Schmidt (2015), David Gross (2016), Rainer Weiss (2018), as well as Baron (Martin) Rees OM (2013), Jocelyn Bell-Burnell (2017), and Nathan Seiberg (2019). The lectures attract sell-out audiences, including a very strong participation of secondary schools.

CGTA was founded in 2018 to connect the substantial core strengths in Pure Mathematics in geometry, geometric group theory, and topology with significant applications through applied topology. A CGTA Distinguished Lecture Series was inaugurated in 2019 with a lecture by Gunnar Carlsson, the founder of Topological Data Analysis. Early successes in this direction include the study of the topology of the lungs in Chronic Obstructive Pulmonary Disease (**Brodzki**), a spin-out company *TopMD* (**Sanchez-Garcia**) applying topology to improve the accuracy of disease diagnostics and a Knowledge Transfer Partnership (KTP) award (**Brodzki**); Southampton is now a recognised centre in the theory and practice of topological data analysis.

Our staff make a significant contribution to the UK and international scientific community through active involvement with major funding councils and learned societies, editorships of international journals, and external peer review (§4.3). Service of this kind is encouraged and valued within the University career pathways.

1.2 Research strategy

Our mission is to cultivate a *dynamic, collaborative, inclusive, and interdisciplinary research environment* to create world-class fundamental research of significant impact, and to train young scientists to become leaders in their chosen fields.

Our ambitions and plans for the assessment period were founded on the specific goals stated in the REF2014 submission which included:

- Enhancing the collaborative and interdisciplinary research environment;
- Building on our core strengths to diversify our research portfolio;
- Developing impact of our research;
- Consolidating our position as a leading centre for postdoctoral research and training.

We have realised all of these strategic aims:

- Of over 1200 outputs created during the REF period, more than 90% are the results of collaborative work, and over 60% included international co-authors (§4.1).
- We have expanded and diversified our interdisciplinary portfolio and research capability through new research directions (e.g., applied topology), new appointments (§2.1), as well as activities of our research centres (see below) supported by a diverse group of research councils (§3.1).
- We have a thriving programme of impact creation (§1.4) which goes significantly beyond the submitted REF Impact Case Studies (ICSs), and we have a number of projects in development for the next REF.

- Our grant success (§3.1) enabled us to support more than 75 Postdoctoral Research Assistants (PDRAs) and eight Fellowships from the Royal Society, the STFC and the EPSRC.
- We have developed a rich portfolio of innovative outreach initiatives (§4.2) which form an important part of our impact strategy.
- We attract excellent candidates to our PhD programme and we graduated more than 130 alumni (§2.4).

Evidence of our international reputation includes the election to prestigious Fellowships of **PWF Smith** (British Academy) and **Woods** (American Statistical Association), and the award of the Royal Statistical Society West medal for official statistics to **Pfeffermann**. We are very proud that OR and Statistics were placed 37th in the 2020 QS World University Rankings. **Andersson** was elected President of the International Society for General Relativity and Gravitation. **Jones**, a member of LIGO and the Gravity group, shared the *Special Breakthrough Prize in Fundamental Physics* awarded for the discovery. **Hoyle** shared the 2020 Institute of Physics Rosalind Franklin Prize. Many more examples are provided in §4.3.

Further evidence of the success of our research strategy is provided through the excellence, breadth and depth of the work of research groups and centres, which rest on the achievements of our staff. The following overview contains many examples of *significant results* obtained through *collaborative* and *interdisciplinary* work.

The research of the **Applied Mathematics and Theoretical Physics** division is structured around the following main themes: *Gravity, Strings and Holography, Continuum Modelling and Mathematical Biology.* The Gravity and Strings groups are *founding members* of STAG.

The *Gravity group* (Andersson, Barack, Gundlach, Hawke, Jones, Schmitt (who held an STFC Rutherford Fellowship until 2020), Vickers, and Pound (supported by a Royal Society University Research Fellowship from 2017)) made substantial contributions to the detection and analysis of gravitational waves and provided a firm theoretical foundation for gravitational-wave astronomy. It hosted 13 PDRAs, funded by grants from the ERC, STFC, EU Marie Skłodowska-Curie, and NWO.

Andersson published (OUP 2019) a first comprehensive graduate text to outline breakthrough detection of gravitational waves from binary black holes in 2015 and merging neutron stars in 2017. **Barack** helped develop a rigorous new method for calculating the gravitational self-force in Kerr spacetime needed for the ESA-funded space based LISA detector planned for the 2030s; **Gundlach** obtained important results on critical phenomena and gravitational collapse; **Hawke** developed a new efficient multiscale formulation for large scale simulations of relativistic resistive MHD in neutron star mergers; **Jones** made significant contributions to the LIGO project and the *discovery of the gravitational waves* (playing a central role in the search for continuous-wave sources); **Pound** pioneered new methodology for high-precision gravitational-wave science; **Schmitt** created a new way to describe real-world nuclear and quark matter in the interior of neutron stars; **Vickers**' results extended the celebrated singularity theorems of Penrose and Hawking.

The String theory and Holography group (Aniceto, Dias, Kennedy, Lobo, Mafra, O'Bannon (returned within UoA9), Skenderis, Taylor, Turton, and Withers) carried out internationally leading research in theoretical high energy physics with emphasis on string theory and holographic dualities. The work covered foundational issues of holography and their applications



to black holes, cosmology and out-of-equilibrium systems. It includes studies of string theory amplitudes, and renormalisation and anomalies in Quantum Field Theory (QFT). This work overlaps with other groups within UoA10 (*Relativity, Modelling,* and *Pure Mathematics*), as well as with Theoretical Physics in UoA9.

Aniceto's results on integrability in AdS/CFT and on non-perturbative methods in QFT overlap with the work of Howls. Working on gravitational aspects of AdS/CFT, Dias obtained new localised black hole solutions in AdS₅ x S⁵ and significant results on the strong censorship conjecture. Kennedy studied Casimir forces in inhomogeneous media. Lobo explored the behaviour of impurities in Fermi gases, and showed how topological invariants can be measured in certain two-dimensional lattice systems (Hofstadter strips). Mafra uncovered remarkable new structures in superstring scattering amplitudes. Skenderis pioneered applications of holography to cosmology and obtained the first observational evidence for a holographic description of the very Early Universe. Skenderis and Taylor discovered a new anomaly in supersymmetry, the first such result since the creation of supersymmetry. Taylor defined renormalised entanglement entropy in quantum field theory and holography and she elucidated the relation between generalised conformal structure of the SYK model and black holes. Turton obtained the first ever family of black hole microstate supergravity solutions that have large near-horizon throats, arbitrary angular momentum, and identified holographically dual conformal field theory states. Withers developed holographic methods for condensed matter applications and out-ofequilibrium phenomena, including the introduction of a simple model for momentum dissipation.

Since 2013, the *String theory and Holography* group have obtained one STFC Ernest Rutherford Fellowship (**Dias**), three Royal Society University Research Fellowships (**Mafra, Turton**, **Withers**) and one EPSRC five-year Fellowship (**Aniceto**). It has also hosted two Marie Skłodowska-Curie Fellows (**Caldarelli**, **Pang**), and a Leverhulme Visiting Professor (**Coriano**), as well as 14 Postdoctoral Fellows funded by STFC, the Royal Society, Templeton Foundation, Leverhulme Trust and the Turing Institute. The group have also attracted international doctoral students funded by grants from CONACYT (Chile, Mexico) and the Chinese Scholarship Council, as well long-term visitors funded by INFN (Italy), CNRS (France) and EU COST networks.

The research of the Continuum modelling and Mathematical Biology group (D'Alessandro, Greulich, Hoyle, Howls, MacArthur (joint appointment with Medicine, returned in UoA1), Richardson, Sanchez-Garcia (also Pure Mathematics) and Sluckin) is highly interdisciplinary, connecting with the physical, life and social sciences. Greulich demonstrated that oesophageal tumours grow due to a subtle imbalance in stem cell replication. Hoyle's influential work in evolutionary biology showed how maternal effects evolve under environmental change. Richardson's pioneering work on charge transport elucidated previously unexplained phenomena in perovskite solar cells. His work on lithium-ion batteries with General Motors and McMaster University is an important part of UoA10's wider impact portfolio. Howls discovered a major new source of aircraft jet engine noise not captured by statutory noise control, and his novel exponential asymptotic results were subsequently found to arise in a variety of physical situations including black holes, nonlinear water waves, and continuum physics. D'Alessandro's deep understanding of liquid crystals was used in the development of a new integrated device for characterisation of liquid crystals which is now being commercialised. The group also bridges intradisciplinary divisions: Sanchez-Garcia (with Brodzki, Niblo, and Wright) applied spectral graph theory to solve the challenging problem of blackouts in power grids, and with Greulich and *MacArthur* derived a criterion for stability of complex cooperative systems.

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A unique strength of the OR division (Ahipasaoglu, Avramidis, Coniglio, Currie, Fliege, Nguyen, Phan, Potts, Qi, Zemkoho) is its substantial network of collaborations with more than 100 industrial, business, and governmental partners. The high quality of our staff is recognised externally, most notably through an EPSRC Early Career Fellowship to Nguyen. Coniglio's and Potts' work with the RNLI highlighted potential efficiency savings of 50% in RNLI's maintenance operations. Currie's EPSRC-funded project optimised the pricing for vehicle tickets as well as packing on ferry services and the methods were implemented by Red Funnel. Fliege, in collaboration with the European Space Agency and Airbus, developed global and multi-objective optimisation tools for mission planning in the lunar environment as well for manned missions to Mars. Qi's convex interpolation algorithm has been incorporated into NAG's Financial Mathematics toolbox. Phan is the co-creator of COBRA, a software toolbox for the analysis of experimental molecular systems and quantitative prediction of biochemically stable molecular systems. The group hosted eight PDRAs.

The main strengths of the **Pure Mathematics** division (**Anderson**, **Brodzki**, **Grbic**, **Koeck**, **Kropholler**, **Leary**, **Martino**, **Minasyan**, **Niblo**, **Petrosyan**, **Renshaw**, **Sanchez-Garcia** (joint appointment with Applied Mathematics), **Spakula**, **Theriault**, and **Wright**) in noncommutative geometry, geometric group theory and algebraic topology were augmented by applied topology and new opportunities for applications. The ambition of the group to build on its strengths and to create new expertise in applications motivated the creation of the new Centre for Geometry, Topology and Applications (CGTA, §1.1).

Southampton is a recognised leader in *Geometric Group Theory*. **Leary**'s construction of uncountably many groups of type FP represents a major breakthrough; **Kropholler** (with Bridson) solved a 50-year-old question on the homological dimension of elementary amenable groups; **Minasyan** created a new research direction by proving (with Osin) that most groups acting on trees are acylindrically hyperbolic. **Anderson** found bounds on the Hausdorff distance within the moduli space of Riemann surfaces. **Petrosyan**, with **Leary**, discovered surprising bounds on the Bredon dimension of various groups that disproved a question of Ken Brown. **Martino** developed new metric techniques for the study of the outer space of a free product.

In *Noncommutative Geometry*, **Niblo** and **Wright** (with Plymen) found an unexpected link between the Baum-Connes Conjecture and Langlands duality, and **Brodzki** (with Guentner, Higson and Nishikawa) gave the first constructive proof of the Baum-Connes Conjecture for groups acting on CAT(0)-cube spaces. **Spakula** answered a question of Roe for Property A spaces.

In *Algebraic Topology*, **Grbic** (with Beben) introduced configuration space methods into the study of toric topology and polyhedral products, while **Theriault** solved a 50-year-old conjecture relating nilpotence and cocategory in homotopy theory. **Koeck** obtained significant generalisations of deep results in geometric Galois module theory.

Members of Pure Mathematics organised activities around the world, including a six-month thematic programme at the Fields Institute (**Theriault**) and a one-month programme at the ICM in Singapore (**Grbic**). Pure Mathematics established two new research relationships: Southampton-Bielefeld in geometric group theory and Southampton-Kyoto in algebraic topology, both of which hosted reciprocal workshops. Pure Mathematics hosted thirteen PDRAs supported by the EPSRC, Leverhulme, Turing Institute, JSPS, and the Newton Fund of the Royal Society.

The work of the **Statistics** division (**Berger**, **Biedermann**, **Böhning**, **Dawber**, **Dodd**, **Durrant**, **Liu**, **Lu**, **Luna Hernandez**, **Ogden**, **Overstall**, **Pfeffermann**, **Sahu**, **PA Smith**, **PWF Smith**,



Tzavidis, **van der Heijden**, **Woods**, **Wu**, **Zhang**, **Zheng**) is facilitated by S3RI, and its members made major contributions to three ESRC Research Centres awarded to Southampton: the Administrative Data Research Centre for England (**PWF Smith**, **Durrant**, **Zhang**), the National Centre for Research Methods (**Durrant**, **PWF Smith**) and the Centre for Population Change (**Dodd**, **PWF Smith**). Statistics research is organised within six research themes: Survey Theory and Official Statistics, Survey Modelling, Design of Experiments, Statistical Modelling, Biostatistics and Actuarial Modelling. There is substantial collaboration and overlap between these themes, and their highlights are as follows.

Design of Experiments: **Overstall** and **Woods** developed the first computational tools for practical Bayesian design of multifactor experiments for nonlinear models, which have become the gold standard comparator method in the field. **Biedermann**, with Mitra, pioneered a new strand of optimal design with incomplete or missing data, important in clinical and social experimentation. The group has been strengthened by the recent appointment of **Ahipasaoglu** with expertise in optimisation problems for the construction of efficient experimental designs.

Survey Theory and Official Statistics: **Tzavidis**, **Zhang**, **Pfeffermann**, **Luna Hernandez** and **Dawber** created novel methods for small area estimation which resulted in new benchmarking and protocols for official statistics. The group also developed novel methodology for: analysing data collected via complex survey designs (**Berger**), estimation and inference under data linkage and linkage errors and methods for the analysis of social network data (**Zhang**), analysis of business survey data, the estimation of consumer price indices, and Census coverage (**PA Smith**).

Survey Modelling: **Durrant** and **PWF Smith** have developed new methods for assessing the representativeness of surveys, which allowed the ONS to substantially reduce the number of response attempts for their Labour Force Survey.

Actuarial Modelling: **Dodd** and **PWF Smith** developed Bayesian methodology for estimating mortality, which was used by the ONS in the production of the English Life Tables: Number 17.

Biostatistics: **Wu** made substantial contributions to modelling the effects of interventions in the early phase of the COVID-19 pandemic in China and epidemic evolution in Brazil. Her work has informed WHO policies. The work of **Böhning**, **Ogden** and **van der Heijden** on meta-analysis of rare event studies was used for population estimation to estimate hidden infections of COVID-19.

Statistical Modelling and Computation: Sahu's improved predictions of air pollution in England and Wales created estimates at local authority level that have become a standard reference. Lu obtained new theoretical results for non- and semi-parametric spatial density estimation, including bandwidth choice and methods for dynamic models. Ogden created new methods and theory for inference for intractable likelihood models, Liu developed new methods for constructing exact confidence sets for univariate polynomial functions, and Zheng used variable selection confidence sets to rank genetic factors to model age-related macular degeneration.

Since 2013, Statistics has consolidated and expanded its network of academic, industrial, government and third-party collaborations, including long-standing strategic partnerships with ONS, the Defence Science and Technology Laboratory and GlaxoSmithKline, a new partnership with Statistics Netherlands (University-level MoU signed 2019), and new collaborations with, among others, the Welsh government, Public Health England and Wales, QinetiQ, and the World Anti-Doping Authority. New academic collaborations have emerged from a strategic focus on core areas of Statistical Data Science, spurred by Southampton's membership of the Alan



Turing Institute, including EPSRC-funded projects on active learning (**Woods**) with chemists and chemical engineers from Cambridge and Glasgow. We used diverse funding from EPSRC, ESRC, Horizon2020, MRC, industry and the Government to support 15 PDRAs.

1.3 Interdisciplinary research

The core of our interdisciplinary research is facilitated by our Centres and Institutes (§1.1) through a vast network of collaborations (§1.2, §3.1, §4.1). Furthermore, nine of our colleagues (**Böhning**, **Brodzki**, **D'Alessandro**, **Greulich**, **Hoyle**, *MacArthur*, **Richardson**, **Sanchez-Garcia**, **Zemkoho**) are members of the Institute for Life Sciences (IfLS) within UoS whose mission is to '*catalyse interdisciplinary collaborative research*, *education*, *and enterprise'*. UoA10 also engages with the Alan Turing Institute through the UoS membership, and **Brodzki**, **Greulich**, *MacArthur*, **Ogden**, **Qi**, **Sanchez Garcia**, **Smith**, **Taylor**, **Woods**, and **Zemkoho** have been accepted as Turing Fellows from 2019, while *MacArthur* is ATI's Deputy Programme Director for Health and Medical Science. We continue to make permanent appointments to support interdisciplinarity, e.g., *O'Bannon* will be appointed jointly with Physics at the end of his Fellowship to add to our existing appointment with Medicine (*MacArthur*) and an intradisciplinary post connecting Pure and Applied Mathematics (**Sanchez-Garcia**).

In addition to the many examples of interdisciplinary projects (§1.2, §3.1, §4.1), we can name **Hoyle**'s work, who partnered with biophysicists to further our understanding of the mechanisms of DNA unwinding. **Wu**, in a collaboration involving the Max Planck Institute, ANU, Oxford, Auckland, Uppsala, and Radboud University, performed a large-scale study of Pacific languages which overturned a long-held assumption in linguistics.

1.4 Impact strategy

The drive to achieve impact is supported by the vibrant interdisciplinary and collaborative research environment described above. Creating impact is facilitated by the following mechanisms:

- Disseminating our research results of potential interest to industry partners through our substantial network of industrial collaborations;
- Exploiting a variety of funding including from non-research organisations (e.g., ONS, WADA, Ford, National Grid, Boeing);
- Using Impact Acceleration Accounts (IAAs) from EPSRC, STFC, and ESRC, pumppriming funds (UoS, IfLS), and KTP awards to bring our research closer to potential endusers;
- Engaging with interdisciplinary applications-oriented calls from research councils and building applications into appropriate grant proposals; and
- Developing a portfolio of innovative and varied outreach activities.

Our strategy has brought significant success, as evidenced by our Impact Case Studies. We developed eight ICSs to an advanced stage, from which the final five were selected:

• Optimisation of Baggage Processing at London Heathrow Airport (**Potts**) brought substantial savings to Heathrow operations (£10M pa since 2016 in operational costs as well as over £20M reduction in capital costs);



- **van der Heijden** and **Böhning** created new methods for national-level estimates of the extent of human trafficking that were adopted by the United Nations Office on Drugs and Crime to provide estimates for the Netherlands, Ireland, Romania, Serbia, and led to a significant policy change in the Netherlands;
- Novel statistical methodologies (**Böhning**, **Liu**) improved the detection of growth hormone misuse through their refinement of a biomarker test, approved by the World Anti-Doping Agency for use at all events governed by the International Athletics Organisation, from the Olympics to the World Athletics Championships;
- The work of **PA Smith**, **van der Heijden**, and **Zhang** informed the design of population censuses in the UK, the Netherlands, Ireland and New Zealand bringing significant quality improvements, process simplification, policy changes, as well as significant savings (£750K in UK alone).

Our enduring collaboration with the ONS was expanded thanks to ONS funding to appoint **Dawber** and to support ongoing work by **PWF Smith** and **PA Smith**. **Currie** and **Nguyen**, with support from the EPSRC, improved the pricing optimisation in the transport sector, increasing by millions of pounds the revenues of partner companies Carnival, Red Funnel, and Virgin Atlantic. **Fliege**'s work with Boeing has brought substantial savings to MoD (£3.4M pa since 2018).

Results on discontinuities in major government surveys (**PA Smith**, **Tzavidis**) were incorporated by the ONS, as well as by the Welsh government in its National Survey 2016-17 and evaluations of changes in the UK labour force. **Tzavidis** and **Luna Hernandez** are funded by the Foreign, Commonwealth, and Development Office as part of a large academic and non-academic consortium (Southampton awarded £300K) to work on developing methods for high spatial resolution estimates of extreme poverty, which is based on an earlier work supported by a £810K grant from the ESRC (**Tzavidis**, **Luna Hernandez**, **Zhang**, **Berger**). **Richardson** secured over £980K from the Faraday Institution, a key part of the UK Government's Industrial Challenge Fund, for work on modelling battery performance and manufacture. **D'Alessandro** is part of a team that created a new device for testing the physical properties of liquid crystals which was purchased and is currently implemented by a major corporation (whose name is confidential). **Sanchez-Garcia** is a co-founder of a spin-out company *TopMD* which offers services and a software platform based on topological data analysis to the medical community. **Kennedy** is a member of the technical and income protection committees of the Continuous Mortality Investigation group at the Institute and Faculty of Actuaries.

Brodzki, **Currie**, and **Zemkoho** received EPSRC IAAs, while **Taylor** and **Vickers** held IAAs from STFC, and **Currie** from ESRC. **Potts** holds a KTP award for coach and driver scheduling with Lucketts. **Brodzki** received the first KTP award (with AI Corporation for detection of fraudulent credit card transactions) at Southampton involving Pure Mathematics.

We regard *outreach* as a very important pathway to impact creation, and we have developed a broad, varied portfolio of inventive activities which represent a significant contribution to the wider society and are described in detail in §4.2.

Southampton has expanded its support for impact and engagement (REF5a§2.9) guided through the Public Engagement in Research Unit, and PublicPolicy|Southampton. UoA10 is



supported by Industrial Liaison Officers, jointly appointed with SBS. Opportunities for impact creation in the healthcare sector will be strengthened by the appointment of the Head of the Healthcare Analytics group within SBS which will expand the range of collaborations between the OR division and SBS.

1.5 Future strategy

Our plans over the next five years include the following:

Research: We aim to consolidate the core strengths and international leadership position of our Centres, Institutes, and research groups across UoA10. We will identify and explore new trends to create opportunities for interdisciplinary, collaborative research and enterprise. We will lead on UK and international data science initiatives, particularly through Southampton's membership of the Alan Turing Institute. We will maintain engagement and leadership within research councils and professional societies, both nationally and internationally.

Staffing: As permitted by the University finances, we plan to make strategic new appointments to support and expand the spectrum of our research while strengthening existing areas of expertise. In parallel, we plan to develop fully the potential of individuals, especially ECRs, through mentoring and support for applications for prestigious Fellowships and grants.

Diversity: We will use new appointments to increase the diversity of our staff, and ensure that the principles of Equality, Diversity, and Inclusion (§2.2) are integrated into all facets of activity of UoA10.

Funding: We aim to increase the numbers of EPSRC bids and awards and identify and exploit a variety of external funding sources, including industrial funding.

Impact and enterprise: We will develop impact from our research via existing and new interand intra-disciplinary collaborations, making use of IAA funding and diversifying the routes to impact of our research portfolio. We will maintain existing external links to non-academic partners, and develop new links, via consultancy and CPD activities in areas directly related to research strengths.

Postgraduate research: We will grow a strong community of postgraduate research students in proportion to staffing numbers using a variety of funding routes including UKRI DTPs, Centres for Doctoral Training (CDTs), and industrial support.

Facilities: We will work with the University to develop modern, flexible, and accessible accommodation for Mathematical Sciences to support our collaborative and interdisciplinary research, impact and enterprise initiatives, e.g., CPD courses, as well as research meetings.

Embedding sustainability: We will work to embed environmental sustainability (REF5a§2.6) throughout our research, impact, and education. Our new facilities will be developed to support hybrid events, remote collaborations and research programmes.

1.6 Open Research

We support open research and open data ideals and policies of the national and international funding councils. UoS is a leader in supporting open research and Open Access publishing and archiving (REF5a§2.4), in particular all outputs are archived in the ePrints repository. In common with the wider community, we make use of the arXiv repository, and where appropriate, we use GitHub and similar to distribute code, data, and supporting information.



1.7 Research Integrity

Members of UoA10 subscribe to the highest standards of academic integrity and research ethics. The Ethics Officer (Lu) is responsible for the implementation of the necessary requirements in the handling of data where appropriate, e.g., in medical statistics. All of our PGRs undergo compulsory ethics and research integrity training. Staff are encouraged to participate in the Faculty-organised ethics training events. Where appropriate, our research is approved by the University's Ethics and Research Governance Online (ERGOII). All staff are required to complete an annual register of interests return in accordance with the *UoS Conflict of Interest Policy*.

2. People

2.1 Staffing strategy and staff development

Our staffing strategy aims to enhance our significant core research strengths, while increasing the diversity of our staff and creating new opportunities for interdisciplinary research with promising impact potential. All of our appointments are made through a rigorous and competitive process, and wherever possible, we make permanent appointments. We are committed to developing and retaining talented staff, and we welcome the opportunity of accommodating excellent scientists who joined us on prestigious Fellowships. The success of our approach is evidenced by growth from 54.8 FTE in 2014 to 64.3 FTE (10.5F, 53.8M) in this submission. UoA10 comprises 69 members (12F, 57M); 45% of our staff are UK nationals, and 55% from the EU/EAA and the rest of the world; 17% of our staff identify as Black, Asian, or Minority Ethnic. Our commitment to the long-term goal of increasing diversity guided all our recent appointments and promotions, and the overall rate of change is proportional to the available appointments. We are dedicated to ensuring equality of opportunity for all staff and fostering inclusion and diversity (§2.2).

The appointments of **Hoyle** (Chair in Applied Mathematics) and **Greulich** strengthened the Continuum Modelling group. The OR division was considerably strengthened by the appointments of **Ahipasaoglu**, **Coniglio**, **Phan** and **Zemkoho** who bring new expertise in theoretical and methodological aspects of OR and provide focus on interdisciplinary, applications-driven research with strong engagement from end users. In Statistics, the appointment of **Overstall** has enhanced our leadership in Bayesian and computational design, while the appointments of **Ogden**, **Zheng** and **Wu** has brought new expertise in inference and estimation in mixed models, change point analysis and bioinformatics, and opened up new collaborative opportunities between the research themes on Design of Experiments and Statistical Modelling. The appointment of **PA Smith** and his subsequent promotion to Chair have strengthened and expanded our research base in Official Statistics and Sample Surveys.

Applied Mathematics and Theoretical Physics received a significant influx of excellent ECRs supported by prestigious Fellowships. **Dias** and **Schmitt** were awarded STFC Ernest Rutherford Fellowships in 2014 and 2015, respectively, and have been appointed to permanent positions on the completion of their Fellowships. **Mafra**, *O'Bannon*, **Pound** and **Turton** joined Southampton supported by Royal Society University Research Fellowships; *O'Bannon* will be appointed jointly with Physics, and **Mafra**, **Pound** and **Turton** are on proleptic contracts, i.e. will be appointed to a permanent position at the end of their Fellowships. **Aniceto** is funded by a five-year EPSRC Fellowship from 2018-2023. **Withers**, a Royal Society University Research Fellow, joined us



(with a postdoc) in 2019. Lkabous was appointed in actuarial science (start delayed by the pandemic to September 2020).

To recognise talent and achievement, fifteen (11M, 4F) colleagues were promoted to Chair, and sixteen (13M, 3F) to Associate Professorships. New appointments and promotions strengthened senior management and research groups following the departures of Ruostekoski and Ho in Applied, and Gilmour, Mylona, Mitra, Forster, Okhrati and the retirement of Kimber in Statistics. Appointments in OR were replacements for Batarra and Xu.

We support the career development of our staff through annual appraisals (REF5a§3.1), and provide development opportunities through events organised within the UoA or through University and Faculty agencies. An example here is a recent series of workshops devoted to grant application and management processes. We operate an internal peer review system for grant applications, advising staff at all stages of the process. To support staff in their research, we operate a successful sabbatical leave system; over 60 periods of sabbatical leave were taken since 2014. For example, after focussing on teaching of actuarial science for many years, **Kennedy** used a sabbatical at Texas A&M University to restart his research in theoretical physics.

2.2 Equality, Diversity, and Inclusion (EDI)

Through our EDI strategy, we aim to create a community in which equality, diversity, and inclusion are inherent to all aspects of our activity. We have made significant progress in the implementation of good practice in EDI, which is realised through visible senior leadership, research-informed policies and customised staff training. When preparing our submission, we ensured that all staff have had the opportunity to input into this document, and we have followed Southampton's REF code of practice (REF5a§3.9). In particular, our outputs portfolio includes 19.3% of papers authored by women in line with our gender profile.

Implementation of EDI in UoA10 is overseen by a dedicated committee, whose membership embeds diversity in its core. The School of Mathematical Sciences and ESPS both hold Athena SWAN Bronze awards, with Mathematical Sciences preparing for a Silver submission in November 2021.

In 2017, we organised an EPSRC IAA-funded international meeting on gender in mathematical physics, which brought together scientists and gender experts to discuss effective EDI interventions. This meeting led to the founding of a permanent working group (GenHET) on gender at CERN theory, led by **Taylor**, which has several hundred members from around the world. We are very active in the work of WiSET (Women in Science and Technology) which is dedicated to promoting the work and achievements of female academics.

EDI practices in supporting research

- We operate core hours policies, where the working patterns of part-time staff are taken into account in the scheduling of research meetings and seminar series.
- We provide support to ensure that postdoctoral researchers can fully benefit from parental leave; e.g. in 2019/20 two female PDRAs could return for a full year after maternity leave. This allowed them to receive the enhanced maternity benefits offered by the University (not just statutory pay) and gave them more time to develop their research.



- Staff returning from leave for physical or mental health issues have a reduced teaching and administrative workload, determined according to individual circumstances, to ensure that they have sufficient research time.
- Staff taking maternity leave or other extended parental leave are automatically awarded a sabbatical in the semester after they return to focus on their research.
- We are a sponsor of Women in OR and Analytics Network (WORAN).
- EDI is embedded into every aspect of our recruitment processes by debiasing the phrasing of advertisements, circulating advertisements via channels that target minority groups, and compulsory EDI training (including implicit bias).
- We worked with external coaches to develop customised training for staff on creating a collegial and supportive environment and on maximising the development of ECRs.

Mental and physical health of staff

- We offer customised training (with Solent Mind) for group leaders on supporting group members with mental health issues.
- We discuss return to work plans with PGRs recovering from mental or physical health issues incorporating structured and scaffolded objectives, and encouraging regular meetings with their supervisory team and support services.
- Post COVID-19, individuals with physical and mental health requirements have priority access to campus facilities as well additional support through more regular COVID-secure in-person meetings.

Support for individuals with caring responsibilities

• Our embedded culture of flexible and part-time working supports those with caring responsibilities, including a number of female and male staff and PhD students with childcare responsibilities.

Research career development and mentoring

- EDI action plans, including those flowing from our Athena SWAN Bronze accreditation and our work towards Silver in 2021, ensure researchers from under-represented groups receive support in developing their research careers and applying for promotion.
- ECRs are offered meetings with senior academics to provide independent advice on their progress and research portfolio, highlighting potential funding opportunities, and developmental leadership roles.

EDI culture

- All staff and PGR students can obtain funding to attend EDI related meetings such as 'Women in Mathematics' meetings and conferences.
- We provide support for the 2021 national Undergraduate Women in Physics conference to encourage more women in physics to pursue PhDs.
- **Howls** is University lead on EPSRC mobility DTP providing funding for those from underrepresented backgrounds, mature students, students on secondment from industry, to study for a PhD on projects related to defence in association with industrial partners. The DTP uses industrial connections established through CORMSIS (§1.1).

 Our use of EPSRC summer vacation bursaries to offer under-represented students a taste of research and encourage them to consider applying for PhDs has been successful in recruiting PhD students from lower socio-economic backgrounds.

Members of UoA10 lead internationally on EDI issues in science, e.g., **Dias**, *O'Bannon*, **Taylor** and **Skenderis** were organisers of the "Third workshop on gender and string theory" (Southampton 2017), **Taylor** was a member of the organising committee of the "First workshop on high energy theory and gender" CERN 2018, and of the workshop "Promoting gender equality in physics: barriers and opportunities", Weizmann Institute 2019.

2.3 Early Career Researchers (ECRs)

Support for ECRs is governed by the University's compliance with the *Concordat to Support the Career Development of Researchers* (REF5a§3.5). Within UoA10, the interests of ECRs are represented by the Postdoc Network, most of whose activities contribute to the implementation of the Concordat. The Postdoc Network organises regular meetings for ECRs which are designed to allow the exchange of information, providing support to ECRs, and enhancing the research environment of UoA10.

ECRs are made aware of the *Concordat* through announcements as well as presentations and discussion at a dedicated meeting. Similar meetings are organised by the Postdoc Network to inform ECRs of the University's EDI policy.

We have implemented and maintain rigorous, fair, and inclusive selection and appointment practices in the recruitment of ECRs. All ECRs are assigned mentors from the senior staff. They undergo annual appraisal meetings, and are aware that they are eligible to apply for promotion.

ECRs are aware of their rights to and benefit from flexible working, statutory rights, and maternity leave. UoA10 actively supports ECRs in this, and is proactive in resolving any issues, for instance, arising from contract timing which might prevent ECRs from benefiting from their rights.

To ensure access to professional development training for ECRs mandated by the *Concordat*, regular sessions cover various aspects of career development and progression. Examples of recent events (2019/20) include: Applying for Research Fellowships (now annual); Careers outside Academia; Personal Development training workshop. ECRs are encouraged to actively participate in UoA10's research environment, with support from their host research group.

The views of the ECRs are important in shaping our research environment and culture, e.g., the session on Careers Outside Academia was arranged at the request of the ECRs.

To deal with the consequences of the COVID-19 pandemic, we proactively implemented a wide range of solutions to support ECRs in the new working from home regime.

2.4 Postgraduate Research Students (PGRs)

UoA10 has a thriving PGR programme, which attracts excellent candidates. A total of 131 PhD degrees were awarded in the REF period. The gender split of our PGR alumni (41%F, 59%M) compares favourably with the HESA figure of about 30% female PGR students in mathematical sciences.



PhDs awarded (FPE)

2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	Total
11.70	19.00	23.95	20.65	20.90	18.40	16.35	130.95

UoA10 actively shapes PGR provision across the University of Southampton. Our staff are often co-supervisors with other Departments (e.g., 16 joint supervisions with SBS, as well as with Medicine, Chemistry, Physics, Psychology). **Howls** is the Director of UoS Doctoral College, and **Sanchez-Garcia** is the Faculty PGR Senior Tutor.

Recruitment

We are proactive in seeking out excellent candidates from diverse backgrounds. We participate in the national LMS Prospects in Mathematics meetings, we engage with students from leading Masters programmes, and we run Summer Internships supported by EPSRC, Ogden Trust and others. We organise an annual Postgraduate Recruitment Fair and PGR Open Days. We are a partner in a CDT in New Generation Computational Modelling, a £9.9M investment sponsored by EPSRC, industry and the University. We are also a partner in an EPSRC CDT on New and Sustainable Photovoltaics, and an STFC DISCnet data science CDT, and the ESRC South Coast DTP.

All potential candidates are interviewed by at least two academics, who are required to undergo interviewing training which includes EDI issues and unconscious bias.

The main source of funding support for our PGR students is in the form of UKRI DTA studentships (45%). In addition, we use UoA10 funds to provide further investment in our PGRs (25%). These two main streams are augmented by funds from institutional themes, including the Vice-Chancellor's (VC) scholarships (12%), Institute for Life Sciences (5%), and external funders, including The Royal Society (7%), and other sponsors, e.g., Irish Statistical Office.

Co-sponsors of the VC scholarships include Northrup Grumman, the Turing Institute, Scottish Forestry Trust, Urban Forest Research, Boeing, RNLI, ESA, Horizon2020. We also received a number of direct sponsorships for PhD places from Horizon2020, CONACYT (Mexico), Chinese Scholarship Council, and the Turkish and Brazilian governments.

Supervision and progression

In line with the University policy (REF5a§3.7), each student is supported by a supervisory team that includes a supervisor and a co-supervisor, plus additional experts if necessary. This system is designed to ensure that students have unimpeded access to a variety of expertise to shape their studies as their interests evolve. The supervisory teams also allow junior staff members to gain experience.

Within the first three months from commencing, PGRs complete an Academic Needs Analysis (ANA) to identify training and equipment needs; each ANA is reviewed every year. The student's progress is monitored through the online 'PGR tracker' that holds the record of training, courses attended, reports, and progress reviews. There is an annual progression review, with the Confirmation review (typically at the end of the second year) being the main step to the final preparation and submission of the PhD thesis.

Skills and research development

Generic skills training is coordinated by the University Doctoral College (REF5a§3.7) in alignment with the UKRI *Vitae Researcher Development Framework*. Additionally, our PGR programme is enhanced through our association with the national training centres APTS and NATCOR, where **Currie, Potts, and Coniglio** have delivered lecture courses. **Woods and Overstall** have served on the APTS Executive Committee, with **Woods** also chairing the future planning committee. Furthermore, we are members of the MAGIC programme, a consortium of 18 UK universities providing introductory lectures for PGR students. Our staff are regularly invited to develop and deliver MAGIC lecture courses (**Brodzki, Gundlach, Koeck, Kropholler**, and **Skenderis**) as well as many courses internationally (§4.3).

Our PGRs are expected to participate in the relevant seminar series, some of which are run by the students themselves, as well as subject-specific workshops and summer schools.

All PGRs have access to a dedicated part of Southampton's Careers and Employability Service, which provides advice on and organises employability events discussing academic and non-academic career paths.

Destinations

Our PhD alumni embark on successful careers in academia, education, and industry. For example, Jacobs (PhD 2015) is a lecturer in Human Evolutionary Genetics and Bioinformatics at Cambridge (appointed July 2019), Wan (2014) is a Lecturer in Medical Statistics, Lancaster University, Lee (2016) is a Lecturer in Medical Statistics, QMUL, Ashton (2016) was a Research Fellow at the Albert Einstein Institute in Hannover and is now an Assistant Lecturer (since 2018) at Monash University, Australia; So (2018) is a PIMS Postdoctoral Fellow at the University of Regina, Canada. Robbins (2018) is a Senior Operations Analyst at Boeing, Harris (2015) an editor for Mathematical Sciences at the CUP. The list of employers includes IBM, Bank of America, Blue Brain, NAG (Numerical Algorithms Group), Biostrand (data science in biotech), and Cudos (cryptocurrency and data science).

3. Income, infrastructure, and facilities

3.1 Research income strategy

Our staff submitted 385 grant applications totalling over £100M, and received 133 *awards* of over £25M. Our *income* was £19,748,190 (£10,857,535 in REF2014). The average annual income over the assessment period was £2,821,170 (£2.17M in REF2014).

Our awards include six STFC consolidation grants and funding from the EU Horizon2020 programme. We were awarded grants from the UKRI Research Councils and The Royal Society (69%), the EU and the ERC (13%), the Leverhulme Trust and other charities (6%), UK Government, local authorities, health and hospital authorities (6%), and industrial sponsorships.

Research grant income of UoA10

2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
£2,917,414	£3,199,041	£2,516,045	£2,461,042	£2,876,529	£2,722,204	£3,055,915

Our staff also support major bids originating from the University of Southampton. For example, **Howls**, as Director of Doctoral College, led a successful bid for £18M for Southampton's EPSRC DTP with a further £1.8M for the Security and Mobility DTP pilot designed for PGR entrants directly from military and industrial roles to Mathematical Sciences. In addition, UoA10 members



actively seek funds from international organisations to run conferences and workshops. For instance, **Taylor** was granted £20K by CERN and £20K by Weizmann Institute to run workshops on EDI themes, while **Theriault** and **Grbic** were part of a team running a major programme at the Fields Institute in 2020 supported by a grant of \$350K.

The increase in grant income over this REF period testifies to the success of our strategy to secure funding for research. A central part has been an increased engagement with interdisciplinary calls that cross the traditional subject boundaries within UoA10, for example, a recent EPSRC New Horizons call (**Zemkoho**).

All staff members are expected to apply for grants, and we support them through an expanded and rigorous internal review process at all stages of grant applications, from the initial ideas, grant finances, through evaluating draft proposals, to submission and responding to reviewer reports. We hold staff training events to discuss the scientific and financial aspects of grant applications. The financial aspects of grant preparation are supported through the central Finance Research Hub. Further advice and support in all facets of grant preparation is provided by Research and Innovation Services (RIS) (REF5a§1.5), including advice on specific grant schemes, and a dedicated office dealing with applications for EU funding. Over the assessment period, we have actively exploited new interdisciplinary opportunities, e.g., **Brodzki** secured a £1.2M grant under the "Making sense from data" EPSRC call that brought together a team of medical practitioners, statisticians, computer scientists, and chemists. **Woods**, in collaboration with DSTL, secured funding from the US Defence Threat Reduction Agency (£700K) to develop and implement disease models, and funding from GlaxoSmithKline (£300K) enabled the development and application of new design of experiments methods for biopharmaceutical studies.

3.2 Research facilities

Whilst most of our research does not require the use of large-scale external facilities, UoA10 members contributed to the design of LIGO, which was at the centre of the discovery of gravitational waves. The Gravity group were granted access to major international observatories: Chandra (\$29K in 2018-19), NICER (NASA), (\$54K in 2019-20; \$26K in 2020-21), XMM Newton (NASA) (\$48K in 2019-21). In 2017-19, the Strings group were awarded a substantial amount of time and storage on the Distributed Research utilising Advanced Computing (DIRAC) facility which represents about £1.1M over three years.

UoA10 members are users and supporters of the High-Performance Computing infrastructure (REF5a§4.2). At the centre of this facility is the IRIDIS cluster, one of the largest of its kind in the UK, which was an important part of our success in attracting the CDT in Next Generation Computer Modelling (2014-22) with **Hawke** as co-Director (2014-17) and then Director (2017-19). This facility is crucial for the computationally-intensive part of our interdisciplinary research, e.g., by the Gravity and Strings groups, as well as in Topological Data Analysis. Successful STFC infrastructure grants obtained by the Gravity and Strings groups have secured and supported dedicated nodes on IRIDIS. We have dedicated licences for specialist software including Maple, Mathematica, Matlab, and RShiny.

3.3 Improving the working environment

UoA10 is located in two adjoining buildings, with Statistics and S3RI partly based in an adjacent purpose-built facility. All staff have individual offices, with shared spaces provided for PDRAs and PGR students. The existing accommodation has been greatly improved with the investment of over £350K of UoS and UoA10 funds, which was used, among others, to create a dedicated



space for data science research, equipped with modern videoconferencing facilities for the delivery of MAGIC courses, CPD events, workshops and seminars. Furthermore, we used the available funds to provide health and disability adjustments to staff who need them.

We have created a new flexible space in an adjacent building with a modern layout, breakout rooms, and state-of-the-art videoconferencing equipment which is used for workshops and seminars. It was also used with great success for the DataKind data dive events, and outreach events. For larger impact and outreach events, we use other UoA10 and University facilities. For example, the Mathematics Building hosts the Schools Mathematics Challenge, and STAG workshops for school groups, while the STAG lectures take place in the Turner Sims Concert Hall.

Our success in attracting ECRs and PGRs, our recent appointments and our strategic plans to grow the UoA10 research base have put significant pressure on the available space. To realise our ambitions, the University's 10-Year Plan (REF5a§2.2) includes plans for significant new investment in the UoA, including a new building for Mathematical Sciences. The plans for development, developed in consultation with staff and PGR students, include a flexible student centre space, a dedicated data science laboratory for CPD and enterprise activities, and state-of-the-art videoconferencing facilities for use in remote and hybrid research and impact events. Modern, innovative, flexible and *accessible* accommodation is central to our future strategy.

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

4.1 Major collaborations

The collaborative and interdisciplinary ethos is central to our scientific and impact creation. We produced more than 1,200 outputs, of which more than 90% were the results of collaborative work; 75% of the outputs included collaborators external to Southampton, and 60% international. Our collaborators are based at 745 institutions in 56 countries including prestigious universities in the UK and worldwide (Oxford, Cambridge, Stanford, Harvard, Duke, MIT, Princeton), q companies (Novartis, General Motors, Roche, GlaxoSmithKline, Barclays), and governmental agencies (Bureau of Labor Statistics US, ONS, Met Office, Public Health England, Statistics Offices of the Netherlands, Sweden, Mexico). This level of collaborative activity is only possible through the active engagement of all our research centres, groups, and staff members.

An important example, mentioned in §1.2, is **Jones**'s work within the LIGO-Virgo collaboration, whose epochal discovery of gravitational waves was rewarded with a Nobel Prize in 2017. To ensure the growth of this engagement, **Andersson** coordinates the Gravity group's work with the LIGO-India collaboration and its Chinese counterpart Great Network.

Fliege led a collaboration between Southampton, Airbus UK and European Space Agency on trajectory optimisation in the near-Moon environment that is a part of ESA's four-mission programme which aims to return humans to the Moon. In the fight against Covid-19, **Currie**'s team created a template for modellers to support policy-makers in decisions on COVID-19 lockdowns and distancing, resource management, and care. Their paper was viewed almost 21,000 times. Many other examples are provided in §1.2.

4.2 Major contributions to society and the outreach programme

We contribute to society through our impact creation (§1.4), engagement with policy-makers, research councils, and the scientific community (§4.3), as well as through our very strong and varied portfolio of outreach activities.



The Cipher Challenge, designed and managed by **Niblo** over the past 18 years, is a national competition for young codebreakers, which involves about 700 schools from across the UK and a small number of schools from overseas. About 3,000 teams take part each year, and in 2019/20, 40% of the competitors, as well as the top three individual leaders, were female. The Challenge is sponsored by GCHQ, IBM, Netcraft and Trinity College Cambridge. Past sponsors included the EPSRC, The Royal Society, The Guardian, Winton Capital Management, Bletchley Park and the British Computer Society. The competition's website offers an enrichment resource for teachers with lesson plans, notes on code breaking and related mathematics, links to books and media. In recent years, the winners have been asked to write up their solutions to the most difficult challenges, providing another useful resource for teachers and competitors aiming to sharpen their mathematical skills.

Andersson, the author of a successful series of science-inspired books for children (Professor Kompressor), wrote a history of Einstein's general theory of relativity, which was distributed to 5,000 school children in India through a collaboration with LIGO-India, funded by a Newton-Bhabha grant, and was used to present Einstein's ideas at public events in Mumbai, Bengaluru, Kolkata, and Delhi in 2019-20. He also designed an information leaflet "India listens to the Universe" distributed using the Newton-Bhabha grant to the residents neighbouring the location of the LIGO-India detector under construction. **Skenderis** featured in a documentary based on his work "Is the Universe a Hologram?" in Space's Deepest Secrets made for the Science Channel and broadcast in the USA on 23 April 2019. **Taylor** received funding from STFC to support a programme of masterclasses and events for schools.

In addition, STAG have a comprehensive outreach strategy, which includes the STAG annual lectures (§1.2), as well as a thriving series of events for schools. Colleagues regularly give lectures, masterclasses and organise or participate in events like Maths in Action, Pint of Science, Southampton Science and Engineering Day, New Scientist Science events, and many others. Taylor talked at a number of national events, including the Cheltenham Science Festival (2019); New Scientist Live events (2016-2018); The Guardian Live at the Royal Institution (2018). Her article on black holes in The Conversation has been viewed over half a million times, and republished around the world. Her articles on working with Stephen Hawking were published in The Conversation, The New European and many other international media. Furthermore, Taylor contributed a chapter to a German book "Stephen Hawking: Denken ohne Grenzen" (Thinking without Boundaries), which is a companion volume to the German edition of "A Brief History of Time". **Taylor** has also been quoted in articles in The Times and The Guardian; interviewed by the BBC and filmed a documentary on Hawking with Sky (on general release in 2021). In a different direction, Greulich developed a board game ('A Fate of Cells') that explores stem cell differentiation dynamics and presented it at the 2018 Southampton Science and Engineering Festival.

4.3 Major contributions to the UK and international scientific community

Members of UoA10 make significant contributions through membership of major scientific bodies, editorships of leading journals, keynote lectures, conference organisations, and many others.

4.3.1 Prizes

Jones received several prizes with the LIGO-Virgo Collaboration, including the Special Breakthrough Prize in Fundamental Physics (2016); Gruber Cosmology Prize (2016); Princess of Asturias Prize for Technical and Scientific Research (2017); Bruno Rossi Prize, awarded by



the High Energy Astrophysics Division of the American Astronomical Society (2017); and Royal Astronomical Society 2017 Group Achievement Award in Astronomy (2017). **Hoyle** was awarded the 2020 Institute of Physics Rosalind Franklin Prize as a member of the Physics of Life UK Network steering group. **Woods** received the Jack Youden prize for best expository paper in Technometrics in 2014 (with co-authors). **Pfeffermann** was awarded the Royal Statistical Society West Medal (2017); Julius Shiskin Award, Washington Statistical Society and American Statistical Association (2018). **Richardson** won the 2018 John Ockendon Prize for best publication in the European Journal of Applied Mathematics in 2016-17 for his modelling of perovskite solar cells.

4.3.2 Service on Research Councils and Committees

The high standing of UoA10 in the research community is recognised through appointments to research councils and committees: 26 of our colleagues (about 40%) have or had prominent roles on national and international research councils, committees, and advisory groups of major international research projects.

Within the UK

Niblo is a member of the EPSRC Strategic Advisory Team for Mathematics (2015-present), the EPSRC Science, Engineering and Technology Board (2020-2023) and EPSRC Future Leaders Fellowship Panel College (2020-present). He chaired the EPSRC Strategic Advisory Team for Mathematics (2017-2019). Andersson is a core member of the STFC PPRP (Large grant panel, 2018-present). Currie is a member of the Research Committee of the OR Society (2018-); Hoyle serves on the IMA Research Committee (2015-present), the Scientific Board of the Smith Institute for Industrial Mathematics and Systems Engineering (2018-present), the steering committees of the Virtual Forum for Knowledge Exchange in Mathematical Sciences and the UKRI-funded Physics of Life network; she served on the LMS Council (2014-15). Howls is Chair of National Standing Committee of British Applied Mathematics Colloquium, Grbic is a member of the ICMS Programme Committee, and Fliege is a member of the Council of Mathematical Sciences. PA Smith chairs the Methodology Advisory Committee for Understanding Society, the UK's longitudinal household survey. PWF Smith served as Director of the Administrative Data Research Network (2016-2018) and was a Member of the Government Statistical Service Methodology Advisory Committee (2011-2016). Taylor was a member of the strategic review committee for the Scientific Computing Department of STFC (2017-2020), the Royal Society URF committee, and a member of UKRI Future Leaders Peer Review College. Tzavidis was elected to serve on the International Statistical Institute Council (2015-2019). Zhang is on the advisory board for Administrative Data Research Methods Programme of ONS. Fourteen of our colleagues (22%) are members of the EPSRC Peer Review College.

Internationally

Andersson was Elected President of the International Society for General Relativity and Gravitation in 2019, is a member of the International Advisory Board for the Max-Planck Albert Einstein Institute (since 2019), and served as external expert on the appointment committee for a new Max Planck Director in 2018. **Barack** is a member of the LISA Science Group for the LISA Consortium (2018-present) and of the management committee for the EU COST Action "Gravitational waves, Black Holes and Fundamental Physics". **Durrant** is Chair and external expert on the standing GESIS Leibniz Institute for the Social Sciences committee of the integrated data collection and data infrastructure (2017-present). **Pfeffermann** is the National Statistician and Head of Central Bureau of Statistics, Israel. **Skenderis** is an external member of the expert panel of Research Foundation Flanders (FWO) (2013-2019). **Taylor** was on the



Denmark Independent Research Fund advisory panel (2016-2020); Swedish Research Council fundamental physics (NT3) panel (2019-2021); CERN theory advisory panel (2018-present); leader of CERN working group Gen-HET (2017-present). **Theriault** served on the Scientific Committee of the research programme GDR 2875 of CNRS in Algebraic Topology and Applications (2014-16). **van der Heijden** is Chair of the Advisory Council on Methodology and Quality, Statistics Netherlands (since 2015) and member of the Executive Committee of the European Statistical Advisory Committee of EUROSTAT (2019-present). **Zhang** is a Member of the Methodology Advisory Committee of Italian National Institute of Statistics.

4.3.3 Key Journal editorships

A total of 22 colleagues (about 35%) serve or served as Editors, Associate and Guest Editors, as well as members of Editorial Boards:

Editors-in-Chief

Böhning: Biometrical Journal (2015-present); **Currie**: Journal of Simulation (2016-present); **Leary:** LMS Student Text Series (2018-present); **Qi**: Asia-Pacific Journal of Operational Research (2016-present); **Peter W.F. Smith:** Journal of the Royal Statistical Society C (2013-16, 2020-present); **Skenderis:** European Physics Journal C, directing a team of 40+ editors; **Theriault**: Proceedings of the Edinburgh Mathematical Society (2015-18);

Associate Editors, Editorial boards

Andersson: Proceedings of the Royal Society A (2014-2020;) Berger: Computational Statistics & Data Analysis (2018-present), Journal of the Royal Statistical Society B (2020-present); Biedermann: Journal of the Royal Statistical Society B; Fliege: Computational Optimization and Applications (2014-present), Applied Mathematics and Computation (2016-present), Optimisation Methods and Software (2020-present); Grbić: Homology, Homotopy and Applications (2018-present); Howls: Proceedings of the Royal Society (2009-2015), Digital Library of Mathematical Functions, US National Institute for Standards in Technology, (2016date). Qi: Mathematical Programming Computation (2013-present), Journal of Operational Research Society of China, (2016-present). Skenderis: Universe; Paul A. Smith: Discussion Papers Editor for the Royal Statistical Society's three journals; Taylor: SciPost, Frontiers in Physics; Nguyen: Asia-Pacific Journal of Operational Research Tzavidis: Journal of the Royal Statistical Society A (2013-2017), International Statistical Review (2014-present), Journal of Official Statistics (2014-present); van der Heijden: Journal Statistical Modelling (2000-present), Advances in Statistical Analysis (2009-15); Woods: Technometrics (2010-present), SIAM/ASA Journal of Uncertainty Quantification (2017-present), Statistics and Computing (2019-present); Zhang: Harvard Data Science Review (HDSR).

4.3.4 Membership of grant committees

UoA10 members regularly serve on prioritisation panels for UKRI councils, national and international grant committees. Examples include the following:

Barack: DFG "Cluster of Excellence" (2018); DFG Research Training Group proposal (2019).

Brodzki: Vice Chair, EU FP7, Horizon2020 Marie Skłodowska-Curie Fellowship panels (2012-present).

Durrant: ESRC Peer Review College (2014-present).

Greulich: Programme grant review panel for a DFG (German Research Society) Collaborative Research Centre.



Niblo: Australian Research Council Assessor Panel (2015-present); EU Marie Skłodowska-Curie Fellowship panel (2016, 2017); EPSRC CDT interview panel November 2018; UKRI Future Leaders Fellowship interview panel (2020;) Leverhulme Prize award panel 2020; EPSRC New Horizons Panel D September 2020.

Skenderis: Dorothy Hodgkin Fellowships selection committee, The Royal Society (2016-2019); Special Research Programmes committee, Austrian Science Fund (FWF) (2018).

Taylor: STFC Ernest Rutherford Committee (2016-2018); Royal Society University Research Fellowships committee (2018-2021); UKRI Future Leaders panel (2019), EU Horizon2020 Marie Skłodowska-Curie and COFUND Fellowship panels (2017-2021).

Woods: EPSRC Mathematical Sciences Programme Grant Committee (2017) and New Horizons panel (2020); Canadian Natural and Engineering Sciences Mathematical Sciences Evaluation Group (2019-2021).

EPSRC prioritisation panels: Grbic (2019), Hoyle (2016), Leary (2019), Niblo (2014,2018).

4.3.5 Fellowships

UoA10 attracted a number of prestigious individual Fellowships: STFC 5-year Ernest Rutherford fellowships for **Dias**, **Schmitt**, Royal Society University Research Fellowships: **Mafra**, **Pound**, **Withers**, and a Royal Society Tata University Research Fellowship for Turton. **Aniceto**, **Nguyen** were awarded five-year EPSRC Fellowships. The following have been accepted as Turing Fellows: **Brodzki**, **Greulich**, *MacArthur*, **Ogden**, **Qi**, **Sanchez Garcia**, **Smith**, **Taylor**, **Woods**, and **Zemkoho**, from 2019, while **Leary** held a Leverhulme Fellowship 2016-2017.

In recognition of their contributions to their disciplines, **PWF Smith** was elected a Fellow of the British Academy in 2019 and **Woods** a Fellow of the American Statistical Association.

4.3.6 Main invited lectures and conference chairs

The majority of UoA10 staff are regularly invited to speak at major international events, and a full list of invited talks runs into the hundreds. Notable examples include:

Keynote and plenary talks

Barack: General Relativity & Gravitation (2016), "50 years of the Kerr metric" (Potsdam 2013); D'Alessandro: "Nice Optics 2016"; Hoyle: British Applied Mathematics Colloquium 2017, Canadian Society of Applied and Industrial Mathematics Annual Meeting 2019, LMS Mary Cartwright Lecture (2017); Luna Hernandez: First Latin American ISI satellite meeting in Small Area Estimation 2015; Pfeffermann: 24th Annual Morris Hansen Lecture, Washington (2015); Pound: Capra Meetings 18-21 (2015-2018), 100 Years of General Relativity (Fields Institute, 2015), LISA Consortium #3 (Marseilles, 2018); Sahu: 2nd Bilbao Data Science Workshop (2017); PWF Smith: 22nd GSS Methodology Symposium (2017); Skenderis: 10-12 invited lectures per year, including ESI, Vienna (2017), Crete regional meeting in string theory (2017), The Many Faces of AdS/CFT, Princeton, USA (2017); Iberian Strings (2018), Indian Strings (2018), Gauge/gravity 2018, Supergravity 2019; Taylor: 10-12 invited lectures per annum which includes Fields Institute (2017); Banff Research Centre (2018); String Phenomenology (2018); Gauge/Gravity Duality (2018); KITP Santa Barbara (2018); Turton: NORDITA, (2016), Perimeter Institute, (2017), YITP Kyoto, Japan (2017), Eurostrings, London (2018), CERN (2018); Woods: 2016 Hunter Conference on Industrial Statistics; Zhang: 2019 Italian Conference on Survey Methodology; 2019 Spanish Conference on Statistics and Operational Research, 2020 Ken Foreman Lecture of the Australian Statistical Society.

Invited conference lectures

Brodzki: BIRS (Banff), Frontiers of Applied Topology, 2017; lecture series on applied topology at CIMAT, Mexico, (2018); Dias: Gravity Spring Conference, (2019); Grbic: Topology, Combinatorics and Mathematical Physics, Moscow, 2018; XIV Serbian Mathematical Congress (2018); ICERM, Brown University, 2016; Howls: CERN (2014); BIRS (2015); NIST Maryland USA (2016); RIMS Kyoto (2016); IST Lisbon Portugal (2016); KITP Santa Barbara (2017), ICMS Edinburgh (2019); Jones: GEMMA (Italy, April 2018); International Pulsar Timing Array meeting (South Africa 2016); CompStar meeting, (Turkey, 2016); Koeck: XV workshop on Geometry and Number Theory, Germany, December 2017; Kropholler: Polyhedral Products in Geometric Group Theory, Fields Institute, May 2020; Leary: Two Oberwolfach meetings (2015, 2020); Geometric Group Theory, MSRI, 2016; Martino: Hanna Neumann Conjecture, Bilbao, 2015; Minasyan: Groups with hyperbolic features, ETH Zurich, 2019; Geometric Group Theory at Infinity, Bielefeld, 2018; Niblo: Large Scale Geometry, Fields Institute 2018; Petrosyan: Manifolds and groups, Oberwolfach, 2020; Polyhedral Products in Geometric Group Theory, Fields Institute, 2020; Sanchez-Garcia: Theory and applications of Topological Data Analysis, Oxford, 2019; Discrete, Continuous Models in the Theory of Networks, Bielefeld, 2017; Schmitt: "Holographic dense QCD and neutron stars" Paris (2017); "QCD at nonzero baryon density" Moscow, (2017).

Conference chairs

Barack: Co-Chair, Thematic program on GR at Fields Institute (2015); **Schmitt**: Co-chair at "Quark Confinement and the Hadron Spectrum", editions XIII (Maynooth, 2018), XII (Thessaloniki, 2016), XI (St Petersburg, 2014); **Woods**: Programme Chair for 2020 Royal Statistical Society International Conference; Conference Chair for the 2015 workshop "Designed Experiments: Methods and Applications (DEMA)" in Sydney, Australia.

4.3.7 Refereeing

Most UOA10 members serve as referees for leading journals in their research areas, and about 35% serve as referees of grant proposals for EPSRC, STFC, ESRC, Leverhulme, Royal Society, the European Research Council, the EU Maria Skłodowska-Curie programme, as well as national research agencies of many countries: NSERC (Canada), Max Planck, the NSF (USA), National Science Foundations of Armenia, Austria, Belgium, Chile, Denmark, Finland, France, Germany, the Netherlands, Ireland, Israel, Poland.

4.3.8 Contributions to PGR training

UoA10 firmly believes that PGR education, in the UK and internationally, is a key contribution to the international scientific community. UoA10 members are regularly invited to speak at or organise such events, and the list below highlights some examples.

Andersson and Pound lectured at PGR Summer Schools at ICTS Bangalore, India (2017, 2019); Barack delivered invited lectures at Kavli Summer School on Gravitational Waves (Cambridge 2019); Dias, Pound gave invited lectures at ICTP PhD Schools, Sao Paulo (2017, 2018); Grbic, Kropholler, lectured at postgraduate schools at the Fields Institute, 2020. Howls acted as advisor on strategic review of Maths PGR provision at Imperial College, 2018. Leary gave post-graduate lectures at Geometric and Asymptotic Group Theory, Spain, 2017; Pound was invited to lecture at Yukawa Institute (Kyoto, 2018); Schmitt gave invited lectures at PhD events in Spain (2019), Italy (2018); Austria (2016); "Neutron stars: gravitational physics theory and observations" Portugal (2016); 27th Engelbrecht Summer School, South Africa (2016).
Skenderis lectured at International School on "Amplitudes and Cosmology, Holography and



Positive Geometries" Italy, 2019; "Theoretical Frontiers in Black Holes and Cosmology", Brazil, 2015. **Taylor and the String Group** organised STFC-funded (inter)national PhD school on Strings, Gauge Theory and Holography, Southampton (2019); **Taylor** delivered lectures at the Mandelstam School in South Africa in January 2020, one of the main southern hemisphere events of this type; **Theriault** gave invited lecture series at ICM 2014 Satellite Conference in Algebraic Topology, (Dalian, 2014) and at the Vietnamese Institute for Advanced Study in Mathematics (2019); **Turton** lectured at the Summer School in Mathematical Physics, Belgium (2016); **Woods, Overstall** and **Ogden** have all lectured on the Academy for PhD Training in Statistics since 2013, with **Woods** and **Overstall** also serving on the Advisory and Executive Committees, and **Woods** chairing the Future Planning Committee.

4.3.9 Conference organisation

Examples of the conferences and workshops organised by members of UoA10 include:

Anderson: Joint Mathematics Meeting of the AMS/MAA, 2017;

Fliege: 1st and 2nd IMA/ORS conference on Mathematics of Operational Research (2017, 2019);

Grbic: Combinatorial and Toric Homotopy, Singapore 2015;

Leary: Polyhedral Products in Geometric Group Theory, Fields Institute, May 2020;

Niblo: MSRI Workshop, 2016; Newton Institute Workshop, 2017;

Theriault: Programme organiser, Fields Institute 2020; Mapping spaces in Algebraic Topology, Kyoto, 2018; Unstable Homotopy Theory, Fields Institute, 2015; 29th British Topology Meeting, Southampton, 2014;

Skenderis, **Taylor, and the Strings Group**: annual Southampton meetings on "Holography, gauge theory, and black holes" (2014-present);

Zemkoho: Organiser of (Bilevel) Optimization, Data Analysis and Forecasting (BODAF 2017).