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Institution: University of Southampton
Unit of Assessment: 10 Mathematical Sciences
<p>a. Overview</p> <p>Together, Mathematical Sciences and the Southampton Statistical Sciences Research Institute (S3RI) provide a focus for University-wide mathematical and statistical research, fostering a vibrant and highly collegiate environment. This strong partnership has been exceptionally successful in stimulating intra- and inter-disciplinary collaboration nationally and internationally. It effectively exploits Southampton's expertise across the range of the mathematical sciences to make an impact in fundamental research across the medical, physical, social and life sciences, and to develop applications in computing, engineering, business and healthcare.</p> <p>The wide range of modern mathematics hosted within a single department is a distinctive feature of the research environment at Southampton. Activities are coordinated by the four research group leaders in Mathematical Sciences (Applied Mathematics, Andersson; Operational Research, Potts; Pure Mathematics, Brodzki; Statistics, Gilmour), in collaboration with the leader of the Social and Official Statistics Group in Social Sciences (Smith). Determining strategy, they deliver management support and staff development, with overall leadership and coordination provided by the Head of Mathematical Sciences (Niblo) in collaboration with the Director of S3RI (Gilmour).</p> <p>S3RI is a university-wide institute which brings together researchers in Mathematical Sciences, Social Science, Health Sciences and Medicine to work on core statistical methodology for generic problems and on substantive applications. It partners with a wide range of end-users. The Centre for Operational Research, Management Sciences and Information Systems (CORMSIS) spans Mathematical Sciences and Management and is one of the largest research groupings of its kind in the UK. It is internationally renowned for its expertise in risk, optimisation, finance and health. The recently established Southampton Theory Astrophysics and Gravity Research Centre (STAG) brings together three research groups across Mathematical Sciences, Physics and Astronomy to study problems ranging from the ultimate building blocks of matter to general relativistic astrophysics and cosmology. It engages with high-profile international experiments and a range of observational facilities.</p> <p>Southampton has a dynamic mathematical culture, focussed on high-quality research and the training of the next generation of research leaders. Co-location of a wide range of complementary expertise and the close interaction of the different research groups provide an exciting opportunity to play a key role in shaping the future of mathematics and its applications as real-world problems become increasingly interdisciplinary.</p> <p>NOTE: The UoA includes staff from Mathematical Sciences and S3RI. Current staff are displayed throughout in boldface. Six members of staff were appointed to strengthen significant interdisciplinary links, and are being submitted to other UoAs. Their names are italicised throughout the document: MacArthur (UoA1, Medicine), Ho, Skenderis (UoA9, Physics), Buellens, Izady, H.Smith (UoA19, Management).</p> <p>b. Research strategy</p> <p>Evaluation of RAE 2008 strategic aims (<i>Identified in italics</i>)</p> <p>In the RAE2008, we described three research strategies according to the submissions that we made (Applied Mathematics, Pure Mathematics, and Statistics and Operational Research). Here we evaluate those strategies (stated in italics below), demonstrating that we fully achieved and often exceeded our objectives.</p> <p>Applied Mathematics. Our ambition in 2008 was:</p> <ul style="list-style-type: none"> • <i>To build on combined research strengths with the Astronomy and High-energy groups in Physics, to appoint at these research interfaces and establish an international centre for Mathematical Physics.</i> <p>We made three appointments at the interface between mathematics and physics (Ho, Skenderis and Taylor), and launched the STAG Research Centre in September 2013 establishing Southampton as a leading player in the mathematical modelling of fundamental physics.</p> <ul style="list-style-type: none"> • <i>To develop research income and to attract Research Fellows (RFs).</i>

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We continued to attract high quality young researchers throughout the period, funded by a range of sources including STFC, EPSRC, ERC, NWO (The Netherlands), NSERC (Canada) and the Royal Society. 14 RFs were in post on the REF census date, compared to the 3 RFs recorded on the RAE2008 census; clear evidence of an attractive research environment and growing international profile of the group. This is further evidenced by a research income of over £3.5 million in the REF period compared to £2.1 million across RAE2008.

- *To build on existing close links with the key gravitational-wave groups.*

Our researchers are active in large international collaborations engaged with the design of next generation instruments including advanced LIGO (**Jones**), eLISA (**Barack**) and the Einstein Telescope (**Andersson** and **Hawke**). We developed new links with both radio- and X-ray-astronomy, e.g. Chandra and LOFT (**Ho**).

- *To strengthen existing contacts with the world class ORC, ECS and Physics centres in light-matter interactions and the theory of Bose Einstein Condensates.*

Under the leadership of **Ruostekoski** and with the appointment of **Lobo** and fellowships for Borgh and Jenkins this area saw real investment and growth over the period, bringing new expertise in ultracold atomic gases, quantum optics and light-matter interactions. The expertise of **d'Alessandro** and **Sluckin** in liquid crystals led to a high-profile collaboration with experimental colleagues in UoA9.

Actively managing change, following the departure of senior academics, we refocused from fluid dynamics to develop expertise in stochastic modelling. We are currently advertising the Chair vacated by Please (Oxford) to bring new leadership in this area. Excellent ECR appointments (**MacArthur**, **Sanchez-Garcia**, **Zygalakis**) are building promising interactions with scientists, statisticians and operational researchers in fields ranging from bio-mathematics to the mathematics of networks, giving us a group with great future potential. Growing engagement with the university-wide Computational Modelling Group led to our bid for the Next Generation Computational Modelling CDT (awarded 2013, **Hawke**, CI) with access to IRIDIS4, the third largest academic supercomputing facility in the UK.

Operational Research (OR). Our strategy was:

- *To build on the EPSRC Science and Innovation Award on Fundamental Aspects of OR (LANCS Initiative).*

A £13 million collaboration between four leading OR groups and the EPSRC, the LANCS Initiative allowed us to appoint four lecturers and a senior lecturer during the period: **Battara**, **Izady**, **Nguyen**, **H.Smith**, and **Buellens**. This investment enabled CORMSIS to develop multi-skilled and multi-disciplinary research teams in new areas including transport, logistics, and game theory. The resulting, highly symbiotic, relationship with Management led to 9 jointly supervised PhDs during the REF period and three staff from the OR group have been submitted in UoA19.

- *To develop new theory and methodology in combination with applications-driven research.*

High-impact research lies at the core of our ambition and throughout the period we focused a large number of projects in our research portfolio on real-life problems. Examples include: scheduling of school buses (KTP project); spacecraft trajectory optimisation (European Space Agency), and increasing capacity utilisation of the UK rail network (EPSRC/RSSB).

- *To develop research themes within optimisation that include scheduling in dynamic, online environments where response to changes in demand and resource availability are needed.*

We actively engaged with the growth in end-user demand in a variety of challenging environments, including air traffic control (funded by EUROCONTROL), operating theatre allocation, hospital waiting list reduction and call-centre management.

Pure Mathematics Our goals were:

- *To build on our existing strength in geometric group theory and to appoint in new areas with a high degree of synergy with that group, developing stability.*

This goal was fully achieved, taking advantage of retirements and other staff changes to make a number of excellent permanent appointments (2.2 Chairs, 2 Readers, 4 Lecturers). This enhanced our existing research strengths in geometric group theory (**Kropholler**, **Leary**, **Petrosyan**), and established strengths in algebraic topology (**Grbic**, **Theriault**) and non-commutative geometry

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(**Plymen, Spakula, Wright**) while developing new intra-disciplinary links with the Applied Mathematics group (**Sanchez-Garcia**).

- *To introduce named postdoctoral fellowships, replacing Singerman's post when he retired, helping us to maintain a steady stream of high-quality postdoctoral staff.*

A dramatic growth in research income for the Pure group (exceeding £1.5 million across the REF period) supported a large increase in RFs funded by EPSRC, the ERC and the Leverhulme Trust. During the REF period, the group hosted 12 RFs with 6 in post at the census date. In 2011 we introduced the Mathematical Sciences Postdoctoral Research Fellowship scheme (see below). Although this was originally envisaged as a replacement for Singerman's position new financial support from the University allowed us to retain the Chair, attracting **Leary** back to the group from Ohio State.

- *To develop new research interactions and to build on our success at attracting external support.*

Research income more than tripled from £364K during RAE2008 to more than £1.5 million in the REF period, a sustained increase which formed the basis for a range of new appointments, collaborations and international links. Visits by leading researchers including Baum, Higson, Mischenko, Roe and Valette underpinned new work in non-commutative geometry leading to the appointment of **Spakula** in 2013. In addition, the Groups and Geometry in the South East Network and the South England Profinite Groups Network were established in partnership with London and Oxford.

- *To broaden our impact by delivering international conferences in our areas of expertise.*

In Section (e), we provide a list of the conferences that members of the UoA organised during the REF period. Examples of meetings organised by members of the Pure Mathematics group include: a Durham symposium; a Heilbronn Institute workshop; an ICMS meeting; a BIRS meeting, and an international conference at Southampton funded by EPSRC.

Statistics. Our priorities were:

- *To develop new theory and methodology in combination with applications-driven research. Stimulated by substantial new research grants, including awards from EPSRC and ESRC. Our main research activities are expected to include: 1) The planning and analysis of surveys, particularly involving the use of multiple surveys to understand the mechanism of nonresponse, 2) Modelling large and complex data sets, including those arising from demography, such as modelling migration flows, as well as from environmental science.*

Despite the loss of key staff, the appointments of **Zhang** (Chair) and **Tzavidis** (Senior Lecturer), and promotion of **Durrant** (Reader) ensured continued vitality in the planning and analysis of surveys. Our continued leadership in the modelling of large and complex data sets was enhanced by the recent appointments of **Lu** and **Shpitser**, and recognised by the 2013 award of the £7.6 million ESRC Administrative Data Research Centre for England to a consortium led by Southampton (**Smith**). This will facilitate a major enhancement of our ability to conduct statistical research with novel datasets and engage with non-academic data providers. In demographic modelling, **Smith** leads the stream of the ESRC Centre for Population Change (around £5 million, recently renewed for a further 5 years), which also includes **Forster**. **Forster** and **Smith's** research in this area has also been funded by NORFACE (a network of 15 national research funding organisations in Europe and Canada), the Actuarial profession and ESRC. For environmental modelling, significant grants have been obtained by **Sahu** (£356K from EPSRC and over £1.26 million in consortium grants from NERC and other funders).

- *To focus on the design of experiments for complex problems, including those involving hierarchical models and nonlinear structures.*

The appointments of **Gilmour, Mylona, and Parker** have expanded our expertise in the design of experiments particularly in designs for hierarchical models, nonlinear designs, and experiments on networks. **Woods'** EPSRC Leadership Fellowship (2012-17) on design of experiments for the complex nonparametric and mechanistic models required for modern scientific and industrial problems, as well as major grants on chemical manufacturing (EPSRC), process understanding and control (GSK) and ultra-cleaning of surgical instruments (NIHR) have made this a major area of success.

- *To build on an EPSRC Bridging the Gaps grant to facilitate the development of methodological*

research motivated by bio- and nano-engineering problems.

This successful intra-disciplinary initiative between the Applied Modelling group and S3RI led to new collaboration with the Southampton Institute for Life Sciences (**Woods** and **Lewis**), now being further developed by **Parker** in collaboration with the Applied group (**MacArthur**, **Sanchez-Garcia**, **Zygalakis**). Deeper links with Medicine and Biostatistics were forged by strategic investment in the Chair appointment of **Boehning**. This area was further supported by the appointment of **Maruotti**, and a number of NIHR grants, e.g. on design of experiments under censoring. Over the period research income in Statistics exceeded £5.18 million, and S3RI currently hosts 6 RFs, another two co-hosted with the Third Sector Research Centre and two with the ESRC Research Centre for Population Change.

In summary, the evaluation of our Post RAE2008 research strategies demonstrates clearly the growth in research activity during the REF period. We more than doubled our number of RFs; PGR cohorts grew from 49 in 2007/8 to 78 in 2012/13; research income increased from £6.6 million during RAE2008 to £10.8 million; and awards since 2012 form a solid platform for an exciting and thriving environment for the future (over £4.7 million in grants; a £7 million award for the ESRC Administrative Data Centre; and nearly £10 million newly awarded funds for an EPSRC CDT).

Current and Future Strategy

Vision. Recognising the quality and wide range of our activities, the launch of a new Mathematical Sciences Institute at Southampton has been highlighted as the lead strategic priority for investment by the Faculty. This Institute will formalise existing, and facilitate new, inter- and intra-disciplinary links both within Southampton and with high quality external partners in academia and the end-user community. It will be a natural home for all practitioners of mathematics and statistics at the University and, building on our expertise in postdoctoral training and our wide-ranging research excellence, the Institute should become a leading European centre for research and applications across the mathematical sciences.

Our strategy going forward will be to build on our existing strengths and develop world class expertise in a selected range of areas across the Mathematical Sciences by:

- A.** *Enhancing the cohesive and collaborative research environment.* Our staffing strategy will continue to enable us to attract, recruit, and retain high-quality researchers who are a good fit with our strategic research areas, who broaden our horizons and enrich our excellent research culture. We will continue to provide a supportive environment that encourages collaboration, with high quality facilities and financial support for seminars, working groups, visiting scholars and international travel.
- B.** *Establishing new internationally acknowledged expertise in areas that enhance and diversify our research portfolio.* We will take every opportunity to develop critical masses and expertise at the interface between high-energy physics, astronomy and gravity; ultracold atomic gases and light-matter interactions; biomathematics, homogenisation, stochastic modelling and spectral methods in graph theory; optimisation and game theory; non-commutative geometry and algebraic topology; causal inference and biostatistics. These areas will be a priority for future staff appointments. Current vacancies vice Please (Applied) and Xu (OR) are in the process of being advertised and we anticipate making two high-quality appointments in 2014.
- C.** *Ensuring targeted impact of high quality research.* We will contribute mathematical insights at the interfaces with science and engineering, and the increasing focus on quantitative research in biology, computing, medicine, environmental, social and human sciences offers opportunities that we will exploit. In particular, the Applied group aims to make an impact in materials science and the critical area of future manufacturing challenges while the Pure group is very active in seeking ways to apply its research expertise to real-world problems, holding grants to study applications of geometry, analysis and topology to data analysis and the security of the National Grid. Relationships with a variety of end-users are central to the strategic ambitions of S3RI and CORMSIS and end-users are integrated into the research process from the outset. Many such links have developed from real-life applications-based MSc projects to high-impact research, supplying new challenging problems, data and information, test-bedding new methods and allowing a critical evaluation of the methods we develop. Building on our long relationship with the Office for National Statistics and the award of the ESRC Administrative Data Research Centre for England (2013), we expect to make significant impact on the public

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and private sectors, as well as the general public.

D. Consolidating our position as a leading centre for postdoctoral research and training.

Following our success in attracting an international postdoctoral research staff (at the REF census date we had 27 RFs compared with 9.5 submitted in RAE2008), we will continue to search for talent among the most able young scientists and to support and mentor them. We will provide an environment that offers opportunities for research in our core strengths, the development of independent research agenda, inter-disciplinary work, and applications to real-life solutions. We will continue to seek support for the recruitment and training of postdoctoral researchers from a diverse range of partners including the research councils in the UK and overseas and from our links with industry, NGOs and government agencies.

c. People, including:

i. Staffing strategy and staff development

A number of retirements and other changes have allowed us to reshape and refresh our research groups. Appointments were made in line with the strategic ambitions set out above in all areas and at all levels: **Applied**: 5 Lecturers, 2 Readers, 1 Chair; **OR**: 4 Lecturers, 1 Senior Lecturer; **Pure**: 4 Lecturers, 2 Readers, 2.2 Chairs; **Statistics/S3RI**: 4.8 Lecturers, 1 Senior Lecturer, 4.2 Chairs. Those attracted by senior positions at other leading institutions have often maintained strong connections with Southampton. For example: Please (Oxford) continues to work closely with **Richardson**, who holds a visiting position at Oxford; Brown (UT Sydney) maintains an active Visiting Professor position with S3RI; and **Voll** (Bielefeld) holds a 20% position in Southampton. **Leary** and **Forster** returned from Ohio State and Lloyds Bank, respectively, during the period.

Staffing strategy and development is fully in line with the objectives outlined in section b:

- A.** Staff appointments were made to strengthen existing areas of expertise in general relativity (**Ho**), optimisation (**Battarra**, **Buellens**, **Nguyen**), geometric group theory (**Martino**, **Leary**, **Kropholler**, **Petrosyan**) and design of experiments (**Gilmour**, **Dean**, **Mylona**, **Parker**). These areas all continued to flourish by a process of renewal throughout the period.
- B.** Investment in new activity is focused on areas where there can be significant interaction with existing staff or where new synergy can enhance existing activities or links with cognate disciplines. In Applied Mathematics, the appointment of **Taylor** and **Skenderis** strengthened links between high-energy physics and the general relativity group and established a new area of research (string theory, AdS/CFT and holography) in Mathematics. The award of an ERC Fellowship to **Barack** was taken as an opportunity to further expand the general relativity group, with the appointment of **Ho** bringing strength in theoretical and high-energy astrophysics and an active link with the Astronomy group. Our interests in ultracold atomic gases were broadened by the appointment of **Lobo** and an Advanced Leverhulme Fellowship to Jenkins initiated an active collaboration with the Optoelectronics Research Centre on metamaterials. Investment in the modelling area included the appointments of **Zygalakis**, **MacArthur** and **Sanchez-Garcia**, broadening the skill set of the group to include homogenisation, stochastic modelling and spectral methods in graph theory. **MacArthur** has a successful track record of collaborating with members of the Pure and Applied Mathematics groups, resulting in high impact publications in Science and Nature. His appointment builds a significant bridge between Mathematics and the recently established Institute for Life Sciences. The appointments of **Kropholler** and **Petrosyan** in Pure Mathematics complemented the appointment of **Leary**. **Grbic** and **Theriault** have built a new subgroup in algebraic topology, while the appointments of **Plymen**, **Spakula** and **Wright** strengthen our expertise in non-commutative geometry. In Statistics, **Shpitser** brought new strength in inference, while **Boehning's** appointment (supported by a fixed-term lectureship, **Maruotti**) to a joint position in Medical Statistics enhanced the existing expertise of **Kimber** and others. In OR, **Nguyen** brings new strength in computational game theory, while **Izady** and **H. Smith** strengthen our work on healthcare modelling.
- C.** The appointment of staff that collaborate effectively with end-users is a key part of our strategy. The recent appointments of Okhrati and Ozkok-Dodd form the kernel of a new research subgroup in the mathematics of risk which we will develop over the next five years, linked to our highly successful UG and PGT programmes in Actuarial Science. We will continue to encourage collaboration across all groups to maximise the impact that

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theoreticians can have on real-world problems.

- D. Increasing grant activity and support for leading young researchers as they apply for competitive fellowships has seen the number of RFs across the UoA grow significantly to 27 on the REF census date. In 2011, we introduced the Mathematical Sciences Postdoctoral Research Fellowship scheme providing two rolling 2-year fellowships in areas of strategic importance (current holders: Capraro 2012 in Coarse Geometry; Caldarelli 2013 in String Theory). In addition, we are keen to offer RFs who particularly enrich our research portfolio long-term academic positions. During the REF period **Ho, Sanchez-Garcia** and **Wright** all benefitted from this strategy. Oscar Dias, who joins on a 5-year STFC Rutherford Fellowship in March 2014, will follow a similar career track.

Career development Annual Personal Performance and Development Reviews (PPDR) are carried out for all academic staff. Full training for the reviewers (e.g., heads of research groups) is provided by the Professional Development Unit (PDU). Expectations and aspirations of the individual and the University are identified and aligned with training and career development needs. We seek to ensure that staff at all levels are able to contribute fully to the life of the University and develop a rewarding career with advancement at the earliest opportunity. During the REF period **Barack, Brodzki, Nucinkis, Ruostekoski, Sahu** and **Woods** were all promoted to Personal Chairs, **d'Alessandro, Berger, Durrant, Jones** and **Voll** were promoted to Reader, and **Qi** and **Xu** to Senior Lecturer.

Academic development is encouraged by eight specialist seminar series and working groups, and cohesion is enhanced by the provision of Pure, Applied, S3RI and CORMSIS seminar series and by a Mathematical Sciences Colloquium, which meets bi-annually. In addition, postgraduate students and postdoctoral staff host their own seminar series for informal peer learning.

Study leave (sabbatical) is an essential element in staff development at all career stages, providing a concentrated opportunity to develop research programmes. Entitlement is 1 semester in 8 and applications for study leave are assessed by the Mathematical Sciences Management Group as part of annual strategic planning. We are flexible in the implementation of this scheme to maximise its effectiveness. Over the REF period, all eligible staff took advantage of this opportunity. In addition our workload allocation model takes account of the additional responsibilities often carried by mid-career and senior staff. Flexible mechanisms are in place to provide cover and to adjust teaching commitments enabling collaborative visits and term-time conference attendance.

Career development - Postdoctoral researchers: In line with the Concordat for young researchers, specific workshops, events and resources to support the career and professional development of RFs are provided at University level through the academic units and the PDU. Career development of each RF is the responsibility of a member of the relevant research group, typically the grant holder. Annual appraisal focuses on research goals and the next steps in career planning, while mentors from across the group provide informal support. RFs are encouraged to join research student supervisory teams, to participate in research bids and to organise seminars, workshops and conferences with experienced staff. RFs are fully integrated into our extensive network of collaborations as an important element in developing their international profile.

Career development - Early career researchers (ECRs): All new staff are offered start-up grants to pump-prime their research programmes, and teaching and administrative workloads are built up over a 3-year probationary period to allow time to establish a fully independent research programme, rising from one-third load in year 1 to a full load at the end of year 3. ECRs are integrated into supervisory teams at the earliest possible opportunity and are prioritised in the allocation of postgraduate research studentships. ECRs are given advice, support and training in the development of grant applications. The first study leave usually closely follows the end of the probationary period and staff are given full support in developing their plans for this crucial period.

Ten of our staff held personal competitive fellowships during the period: **Barack**, ERC Fellow 2012-17; **Leary**, Heilbronn Fellow 2008-09; **Lobo**, Advanced EPSRC Fellow; **Lu**, ARC Future Fellow; **Niblo**, Leverhulme Fellowship 2011-12; **Richardson**, MRC Discipline Hopping Fellowship; **Roose**, Royal Society URF 2004-13; **Ruostekoski**, Leverhulme Trust research fellowship 2010-2011; **Skenderis**, Visiting Fellowship CERN, 2008; **Woods**, EPSRC Fellow 2012-17; **Dias**, STFC Rutherford Fellowship, from March 2014. Such awards support the development of research groups at all levels, providing resources to bring in talented young researchers to support each

Fellow's programme. Applications for such schemes are strongly supported.

Internationalisation: Academic posts are advertised in international media such as the AMS or IoP websites, and of our 30 new staff, 21 have either come from non-UK institutions or have non-UK nationality (Austria, Belgium, Canada, China, Greece, Iran, Italy, Spain, Serbia, Turkey, Germany, Holland, Israel, USA). We hosted a number of research visits during the period (85 up to 3 months in duration, 20 lasting 3-12 months and 15 lasting a year or more), many resulting in joint publications. Two of these relationships developed into permanent positions at Southampton (**MacArthur** from Mount Sinai School of Medicine and **Roose** from Oxford).

Equality and diversity: The University-wide Equality Plan establishes the University's strategy for equality and diversity. It outlines key targets for each of the protected characteristics as defined by the Equality Act 2010, and staff involved in line management and selection processes receive training to improve cultural, ethnic and religious awareness to meet the demands of an increasingly diverse and internationalised campus. The Equality Plan is regularly monitored through Senate and the University Council. Reflecting its importance, the University's Equality and Diversity Strategy is Championed by one of the Deans. The University's Code of Practice for REF2014 sets out the governance arrangements for the selection of staff and the appeals processes, and all staff involved in REF decision-making have received training on the special considerations concerning equality and diversity this raises. We are signed up to the LMS Good Practice Scheme and will be applying for the Athena Swan bronze award in 2014. We actively promote the full use of parental leave and part-time or flexible working arrangements for carers and parents.

ii. Research students

A growing programme: A rise in our share of the EPSRC Mathematics DTG award from 2.1% in 2008/9 to 3.9% (6th highest in the UK) in 2013/14, underpinned growth in the PGR cohort from 49 in 2007-08 to 78 in 2012-13. Further investment by the University to support the new Mathematical Sciences Institute will expand this by 2-4 new studentships a year over the next 3 years. The quality of our postgraduate programme was recognised by a £9.9 million partnership award over 8 years, between EPSRC, industry, and the University for the New Generation Computational Modelling CDT in 2013 (**Hawke CI**). This provides an excellent opportunity to expand and broaden the mathematics and statistics PGR programmes, which will continue to be supported by a range of mechanisms, including research council studentships (MRC, EPSRC, ERC, ESRC, MRC, STFC), grant overheads, DTC/CDT funding, industrial sponsorship, University scholarships and overseas grant income.

An outward facing programme: Postgraduate researchers are encouraged to be outward facing through industrial sponsorship and ONS/ESRC CASE studentships. Our staff have leadership roles in inter-disciplinary PhD programmes including the EPSRC DTCs in Web Science and Complex Systems Simulation, the Academic Centre of Excellence in Cybersecurity, and the ESRC DTC in Social Sciences. In 2010 the University introduced new matched funding schemes for studentships attracting external support, and in 2012/13 Mathematical Sciences received seven of these awards to fund students in mathematical physics, mathematical modelling, operational research and statistics.

An enhanced programme: Between 2013-15, with EPSRC support, we will integrate our existing postgraduate programmes to provide a full 1+3 programme, supplementing our existing Master's level courses in Statistics and OR with a new range of specialist courses in Pure and Applied Mathematics, student led seminars and a range of skills training. We provide a highly competitive research training enriched by our engagement with the national training centres APTS, NATCOR and MAGIC.

A successful programme: Evidence of student success includes: 5 awards in the American Statistical Association's International Paper Competition for early-career researchers, leading to presentations at the JSM; 2011 Cochran-Hansen prize, awarded by the International Association of Survey Statisticians; 2013 Best PhD Thesis Prize awarded by the IoP Gravitational Physics Group. In 2008 we introduced the Mathematics Research Fellowships (MRF) in parallel with the EPSRC PhD Plus/Doctoral Prize programme. These competitive awards provide a package of advanced support and training for our leading PhD students and act as a springboard for the holders when applying for their first postdoctoral positions. Each year from 2008 to 2011 the School made two MRF awards and in 2012 we doubled the programme.

Recruitment: Our annual Postgraduate Recruitment Fair is advertised nationally and allows candidates to explore the full range of PGR opportunities. Taught masters degrees in Statistics, Actuarial Science, Operational Research and Social Statistics provide a pipeline for the +3 part of the new PhD programme while our enhanced MMath curriculum encourages applications to the 1+3 degree in Pure and Applied Mathematics. Applicants are vetted and interviewed by Research Group Postgraduate Coordinators (PGRCs) and scholarships are awarded to support research and staffing strategy.

Progression: The Faculty Graduate School sets postgraduate research training policies and oversees student progression, which is actively monitored by the Mathematical Sciences PGR committee, chaired by the Director of PhD Programmes (**Fliege**). Supervisory teams, commissioned by PGRCs, balance the requirements for experience (often across multi-disciplinary teams) with the need to provide training and development for ECRs.

d. Income, infrastructure and facilities

Income - Rigorous internal review of grant applications at all stages of the submission cycle together with a strategic approach to the planning of submissions and a diversification in funding sources led to a step change in grant income over the period. Mathematical Sciences and S3RI receive funding from a range of sources including the ERC, ESRC, ESRC, MRC, Leverhulme Trust, The Royal Society and STFC. In a very challenging financial climate annual research income has increased steadily from the high point of the RAE2008 cycle of £1.25 million (2006/07) to £2.5 million (2011/12). Income growth was achieved across the full range of our research activities, with a particularly marked increase in the Applied and Pure Mathematics groups. With new grants in excess of £4.7 million, the forthcoming launch of the £7.6 million ESRC Administrative Data Research Centre for England, and new applications to major funding agencies totalling a value over £8 million so far in 2013, we are well placed for continued success.

At a time of uncertainty in higher education funding, our financial stability has been enhanced by the development of a successful and diverse portfolio of undergraduate courses leading to rising A-level entry grades, a growth in UK/EU recruitment across the period, and increase in overseas recruitment. New premium fee PGT programmes and sustained recruitment to existing Masters degrees led to increased postgraduate income. Overseas UG and PGT recruitment more than doubled from the RAE2008 period to 104 in 2013, with the introduction of a number of premium fees programmes.

Facilities - Staff, students, visitors and postdoctoral researchers are housed within three adjacent buildings, Mathematical Sciences, Social Sciences and the purpose-built Statistical Sciences Research Institute, which has secure facilities for the storage and analysis of confidential data. The University hosts the hub of the ESRC National Centre for Research Methods, coordinating activities across eight universities and promoting a wide-ranging programme of research into the methodology of the social sciences, in which Statistics plays a prominent role. The recent award of the Administrative Data Research Centre for England will facilitate a major enhancement of our ability to conduct statistical research. Additional support for collaborative research across the social and human sciences is provided by CORMSIS and S3RI, each hosting their own extensive seminar and visitor programmes, offering fully equipped offices, lecture space, administrative and IT support. This strategy has resulted in many active and fruitful research links with high profile researchers from around the world.

To fully exploit the synergies that joint appointments can bring (eg. with Medicine, Management and the Life Sciences), holders are offered accommodation in both host departments. Dedicated staff common rooms and our “coffee culture” encourage close interaction between staff that may spend only a portion of their time in each building. We seek to arrange accommodation to encourage, strong and active cohorts within the graduate school. Students are allocated their own desk and computer alongside others with similar research interests and in close proximity to their research group. More experienced students play an important role in supporting their newer colleagues via the PGR seminar series and informal reading groups, offering an opportunity to present their work within a friendly and supportive environment. Again the excellent coffee lounge is of major importance in fostering a healthy interaction across generations and research areas.

In January 2013 a working group, chaired by the Dean of the Faculty, began planning for the Mathematical Sciences Institute, which will formalise the wide range of inter- and intra-disciplinary

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links across the University. Infrastructure plans anticipate moving the Institute to new facilities some time during 2016-2020. In the medium term we will continue to invest in people, expanding staffing in line with income growth, and moving into adjacent space as it becomes available. We will take every opportunity to further improve facilities for graduate students and staff.

Significant increases in the number of postgraduate students, RFs and visitors, together with a marked expansion in the number of still-active Emeritus staff, placed significant pressure on our resources, establishing a clear need for improved and dedicated facilities for these important groups. In 2012 an investment of more than £300k in the Mathematical Sciences building allowed us to embark on a general refurbishment of the accommodation. Additional space within the Mathematical Sciences building, released by the Faculty and Computing Services, allowed us to commission additional high quality offices for 20 RFs and 24 PhD students. We constructed a new Taught Masters Base (39 hot desks) and dedicated suites for visitors (16 hot desks) and Emeritus staff (8 hot desks). We also refurbished a number of staff offices and breakout space in common areas throughout the building to further encourage collaboration. In 2014 new accommodation will be developed to provide Mathematical Sciences with additional space for collaboration, small group working and seminars. Meanwhile refurbishment and the introduction of SMARTboard technology in our conference room and the Mathematical Sciences common rooms has provided additional space for the growing number of seminar series and working groups.

Infrastructure - The University provides access to a range of high performance computing facilities including IRIDIS4, one of the ten largest supercomputers in the UK. Researchers also benefit from two dedicated 20-node Beowulf clusters and a secure computing facility. The University Library (with approximate funding of £6.4 million per annum) provides online access to all key journals and designated librarians provide support for all staff and students.

Our two Industrial Liaison Officers (ILOs) and Research and Innovation Services (RIS), provide guidance and training on research and enterprise, and we encourage staff to undertake consultancy work wherever there is a significant and interesting research element in the project. Specialist staff provide EU Bid/Contract support, Large Collaborative Bid Management, Major Contract Management, Knowledge Transfer support and IP management.

e. Collaboration or contribution to the discipline or research base

We have an outstanding track record of collaboration with world-class researchers both in theoretical work and in applications across the mathematical sciences.

1) Collaborations with other researchers Our general relativity group is active in leading international collaborations including the multinational LIGO-Virgo Scientific Collaboration (where **Jones** plays a leading role in the Continuous Wave group), and **Andersson** and **Hawke's** membership of the EU-wide Einstein Telescope Design Study Team. International impact is further evidenced by **Vickers'** leading role in the DIANA collaboration with Vienna (€3 million awarded in the REF period). In OR, **Qi's** work with SUN (Singapore) on nearest correlation matrix problems has been implemented recently in the Numerical Algorithms Group standard library and is attracting interest from the finance sector for portfolio optimisation. Finally, in Statistics, **Durrant's** and **Smith's** ESRC funded project on paradata, with collaborator Kreuter (*University of Michigan* and *IAB Nuernberg*) and **Gilmour's** work with Trinca (UNESP) on *response surface methodology* provide excellent examples of our international collaborative research.

2) Collaborations with users of research including industry, government and other bodies Nationally and internationally, our staff have worked with and for a range of industrial, governmental and other bodies: Highlights include **Fliege's** work as a member of the Steering Committee of the European Space Agency Project STA (Space Trajectory Analysis), **Brodzki's** invitation to serve as a member of the EPSRC Policy shaping workshop on Smart Grids and **Leary's** classified work with the *Heilbronn Institute*. In Statistics, **Pfefferman** contributed to the US Bureau of Labour Statistics and served as Government Statistician of Israel; **Smith** is a member of the Government Statistical Service Methodological Advisory Committee from 2010; **Tzavidis** is member of the ONS panel for the Beyond 2012 project; and **van der Heijden** serves on the Advisory Council Methodology and Quality Statistics Netherlands from 2007.

3) Exemplars of interdisciplinary research Our increasing reach across the mathematical sciences is evidenced by the EPSRC invitation in October 2013 to **Brodzki** to submit a £2.3 million programme grant application on Networks and Topological Data Analysis, supported by Carlsson

Environment template (REF5)

(Stanford, Ayasdi). **Brodzki** also coordinated an EPSRC funded consortium with Bialek (*Durham*) and McKinnon (*Edinburgh*) studying power grid resilience, while **Sahu** was active in a collaboration on hierarchical Bayesian modelling of spatio-temporal processes with Gelfand (*Duke*), Holland (*US Environmental Protection Agency, USEPA*), Mardia (*Leeds*) and Challenor (*National Oceanography Centre*);

4) Leadership Our researchers played an active role across the academic community, including funding councils EPSRC, ESRC, STFC in the UK and DFG, ERC, FOM, FWO, ISF NSF, EU FP7 and NOW overseas. In particular, we took part in 17 EPSRC prioritisation panels over the period including programme grants, the full range of Fellowship panels, the 2013 CDT panel and the Future Mathematics for Manufacturing call. Panels were chaired by **Niblo**, **Forster** and **Gilmour**. Other examples of academic leadership in the REF period include:

Anderson, was Deputy Publications Secretary for the LMS from 2010, having been Editor with **Brodzki** until 2009; **Andersson** was elected Honorary Chair of IoP Gravitational Physics Group 2009-2012; **Brodzki** was a member of the LMS nominating committee for Publications from 2010 and Vice Chair and Reviewer on 12 Marie Curie grant panels and Chair of the IRSES panel; **Currie** chaired the OR Society Special Interest Group on Simulation; **Dean** was Chair of the ASA Section for Physical and Engineering Science 2012; **Forster** was a member of RSS Council 2010-13, Chair of the Committee of Professors of Statistics, UK and Ireland 2007-09, RSS Director of publications theme 2010-13, and member of European regional committee of the Bernoulli Society 2006-10; **Gilmour** was a member of the RSS Council 2008-12 and RSS director of sections and local groups theme 2009-12; **Howls** was Chair of the Standing committee of the BAMC from 2006; **Jones** acted as UK representative on the Steering Committee of CompStar (2008-2012), an ESF-funded Research Networking Programme, and was instrumental in the successful renewal application in 2013; **Pfefferman** was elected President of the International Association of Survey Statisticians 2011-2013; **Ruostekoski**, was a member of the steering group for the Quantum dynamics in Atomic Molecular and Optical Physics consortium; **Taylor** was a member of the working group for COST action MP1210 The String Theory Universe; **Theriault** served on the Scientific Committee, GDR Topologie Algebraique et Application.

5) Leadership in conferences Over the REF period, staff organised a number of international meetings and **gave over 200 invited plenary talks** at conferences (including 7 invited lecture courses). Highlights include:

Organisation:

- European Liquid Crystal Conference, Rhodes 2013 (**d’Alessandro, Sluckin**).
- Nordita Programme Neutron stars – the crust and beyond, Stockholm 2009 (**Andersson**).
- Numerical relativity at ICMS, Edinburgh 2011 (**Gundlach**).
- Neutron Stars and Gravitational Waves, Boston 2011 (**Jones**).
- CompStar, Tahiti 2012 (**Jones**).
- Newton Institute Meeting, Polynomial Optimisation 2012 (**Fliege**).
- EURO Working Group conference VeRoLog, Southampton 2013 (**Potts**).
- International Conference on Homotopy Theory and its Applications, Beijing 2009 (**Grbic**).
- Durham Symposium, Geometric and Cohomological Group Theory 2013 (**Kropholler, Leary**).
- Cube Complexes at ICMS in Edinburgh 2012 (**Leary**).
- EPSRC Workshop on Geometric Group Theory, Southampton 2011 (**Martino, Minasyan**).
- Heilbronn Institute Workshop, Bristol 2012 (**Niblo**).
- BIRS meeting on Cohomological Methods in Geometric group Theory, Banff 2012 (**Niblo**).
- Newton Institute programme, Design and Analysis of Experiments 2011 (**Biedermann, Woods**).
- DEMA conferences, Cambridge 2008 and 2011 (**Biedermann, Gilmour, Lewis, Woods**).
- Newton Institute meeting on Design of Experiments 2008 (**Gilmour, Woods**).
- 2nd International Workshop on Sequential Methodologies, Troyes 2009; 8th International Conference on Multiple Comparison Procedures, Southampton 2013 (**Liu**).
- Annual conference of the International Environmetrics Society, Hyderabad 2012 (**Sahu**).
- European Association of Methodology and Multivariate Analysis in the Behavioral Sciences, Potsdam 2010 (**van der Heijden**).
- Sample surveys and Bayesian Statistics, Southampton 2008 (**Pfefferman, Forster**).

– Hierarchical Models and Markov chain Monte Carlo, Crete 2011 (**Forster**).

Plenary Speakers:

Andersson: "IV Mexican Meeting on Mathematical/Experimental Physics" Mexico City 2010; "Quark confinement and the hadron spectrum", Madrid 2010; "Superfluids under Rotation", Finland 2010.

Barack: "Numerical Relativity meets Data Analysis" Perimeter Institute, Canada 2010; "100 years after Einstein in Prague" Prague 2012; "LISA Symposium", Barcelona 2008.

Forster: "12th annual Florida winter workshop on Statistics" Gainesville 2010; "CRISM workshop on model uncertainty", Warwick 2010.

Grbic: "Algebraic Topology", Nankai University, China 2013, "Algebraic Topology and Geometric Topology" at Chern Institute of Mathematics, Tianjin 2013; "Algebraic Topology and Abelian Functions in honour of Victor Buchstaber's 70th birthday, Steklov Institute, 2013.

Howls: "Recent Developments in Exponential Asymptotics" RIMS Kyoto 2011; "Foundations of Computational Mathematics", Budapest 2011.

Kropholler: "Cohomological and Combinatorial Methods in Groups Theory", Ubatuba, Brazil 2011

Leary: "Arolla Conference on Algebraic Topology" Arolla 2012; "Group Actions in Topology and Geometric Group Theory", Poznan 2010.

Niblo: "6th Hamilton Topology and Geometry Workshop, Knots, Surfaces and 3-manifolds", Dublin 2010; the "Kervaire Seminar at Les Diablalets", 2012; "Topology and Functional Analysis", Fudan University, Shanghai 2012.

Potts: "Statistics and Operational Research International Conference", Sarawak, 2012; "Multidisciplinary International Scheduling Conference: Theory and Applications", Ghent 2013.

Shpitser: 25-27th "International Conference on Uncertainty in Artificial Intelligence", Corvallis 2009-11.

Theriault: "Toric Topology and Automorphic Forms", Khabarovsk, 2011; "Algebraic and Geometric Topology, Chern Institute, Tianjin, 2013; "Algebraic Topology", Beijing 2010

Zhang: IAOS Conference, Shanghai 2008.

6) Journal Editorships Members of the UoA play an important and active role in a wide range of scientific publications across the profession, with at least 30 editorial board memberships registered in the REF period. Highlights include:

Andersson: *Physical Review Letters*, Associate Divisional Editor 2007-2013 (renewed 2010)

Currie: *Journal of Revenue and Pricing Management*, member of Editorial board from 2006 (renewed 2012); *Journal of Simulation*, Managing Editor from 2011.

Dean and Gilmour: *Statistica Sinica*, Assoc. Eds. 2009-11;

Durrant: *The Journal of the Royal Statistical Society, Series A*, Assoc. Ed., 2009-12

Forster: *Biometrika*, Assoc. Ed. 2008-12

Gilmour: *Statistics and Computing*, Assoc. Ed. from 2009.

Howls: *Proceedings of the Royal Society*, Editorial board member from 2008; *Journal of Engineering Mathematics*, Editorial board member from 2013

Kropholler: *Glasgow Mathematical Journal*, Subject editorship from 2012

Leary and Niblo: *Editorial Advisory Board of the Journals of the LMS* (renewed 2008 and 2013, respectively).

Potts: *International Journal of Planning and Scheduling*, Assoc. Ed. from 2010

Qi: *Asia-Pacific Journal of Operational Research*, Assoc. Ed. from 2011.

Ruostekoski: *Scientific Reports, Nature Publishing Group*, Editorial Board from 2013.

Smith and Woods: *Series C* (Smith, Editor, from 2013; Woods, Assoc. Ed., from 2010)

Theriault: *Proceedings of the Edinburgh Mathematical Society*, Topology Editor, from 2008, Deputy Convener from 2012.

Zhang: *Journal of Official Statistics*, Assoc. Ed. from 2010.

7) Honours and distinctions awarded to staff in this UoA in the REF period include:

Andersson: Fellow of the Institute of Physics, 2013.

Pfeffermann: *Waksberg award* for outstanding contributions to survey methodology, 2011; appointed Government Statistician of Israel, 2013.

Taylor: *FOM Minerva Prize* 2008.

Zygalakis: *Leslie Fox Prize in Numerical Analysis* 2011.