Institution: University of Bristol

Unit of Assessment: 10 – Mathematical Sciences

a. Overview

UoA 10 consists of 87 cat. A staff (58 permanent staff and 29 independent research fellows making 83.5 FTE) in the School of Mathematics (**SoM**) together with 20 other postdoctoral researchers and 61 PhD students. Research can be loosely categorised under the headings of **Algebra**, **Analysis**, **Ergodic Theory & Dynamical Systems**, **Fluids & Materials**, **Mathematical Physics**, **Number Theory & Combinatorics**, **Probability**, **Quantum Information**, **Set Theory & Logic** and **Statistics**. The UoA has continued to thrive during the assessment period as evidenced by:

- **High profile research contributions,** recognised by many major national and international **prizes** (including 14 AMS, EMS, LMS and Philip Leverhulme prizes and the RSS Guy medal in gold), **Fellowships** (including 3 new FRSs, bringing the total in the **SoM** to 8, and 7 EPSRC Fellowships) and **invited addresses** at major international congresses (e.g. *ICM* & *ICMP*).
- **Exceptional levels of funding**: grants exceeding £18M, substantial personal awards (4 major ERC grants, 5 Royal Society Wolfson Merit awards) and 3 EPSRC **Programme Grants**.
- Significant expansion of activities associated with the **Heilbronn Institute**, the highly successful **SuSTaIn** grant to support the sustainability of UK Statistics, two EPSRC **DTCs** (in Complexity and Communications), leadership of major **international research programmes** (e.g. at the INI, IHP, MSRI, ICMS), and membership of **important national committees** (e.g. Steering Committee INI, RAE2008 and REF2014 panels, EPSRC Strategic Advisory Team).

b. Research Strategy

Overview At the end of 2007, the UoA had particular international excellence in fluid dynamics, mathematical physics, number theory, quantum information and statistics, as recognized in the International Review of Mathematics. Since then, the research strategy has been (a) to support and extend the range of these existing strengths (e.g. building up combinatorics, adding soft matter and materials expertise to fluids), (b) to seed new activity (e.g. ergodic theory), (c) to develop the interfaces between existing areas through targeted new appointments (e.g. between analysis and probability) and (d) to create greater connectivity with other disciplines (e.g. biology). This strategy has been pursued through high-level directed activity – e.g. the Heilbronn Institute for Mathematical Sciences (**HIMR**) – as well as through the bedrock policy of continuing to appoint internationally-leading staff, letting them set their own research agendas, and providing an environment in which this can flourish. It has been sustained by strong levels of external funding and continued investment by the University of Bristol (**UoB**) in facilities and appointments.

HIMR is a unique collaboration between Bristol Mathematics and GCHQ, and is a key component of GCHQ's strategy for providing national security. It contributes strongly to the vitality of the UoA with around 30 members, including about 20 Heilbronn Research Fellows employed by the University, who carry out their own research programmes as well as doing classified research. The UoA supports **HIMR** by funding 8 regular seminars, more than 4 international workshops annually, a Distinguished Lecturer series, international visitors, and by providing mentorship to the Heilbronn Fellows. Since 2008, areas from which **HIMR** fellows are recruited have significantly expanded, from discrete mathematics and probability into data mining and quantum information. To sustain this growth, the University has made 3 senior appointments: in arithmetic geometry (*Dokchitser*), probability (*Toth*), and combinatorics (*Wolf*) as well as a number of Lectureship appointments in cognate areas (see below).

During the review period, the spectrum of activity within the School has changed substantially, while the overall number of permanent staff has remained roughly constant: currently 60 (Beaumont and Fujimoto are returned to UoAs 5 and 32 respectively) compared with 58 in RAE2008 (Nonlinear Dynamics in Engineering Mathematics, entered under UoA 21 in RAE2008, is being returned under UoA 15 in REF2014). **SuSTaIn II** is continuing to drive Statistics forward and the UoA is a major component of two DTCs (The Bristol Centre for Complexity Sciences (**BCCS**) and a DTC in Communications - £10M in total from various sources).

Achievement of Strategic Aims

A. Exemplars for the successful continued development of existing research strengths

The **Fluids & Materials** group has undergone a significant transformation reflecting a strategy to

become more multidisciplinary while maintaining its core strengths in fluid dynamics. Appointments at the end of the RAE2008 period (*Chenchiah* 2006, *Slastikov* and *Liverpool* 2007) have added expertise in materials science and soft matter physics. This growth has led to the development of continuum theories for liquid crystalline, biologically-active, viscoelastic fluids and the study of their interactions with boundaries, magnetodynamics in nano wires, and the mechanics of biological macromolecules. Within fluid dynamics itself, the dynamical systems approach to turbulence has been further developed, e.g. giving rise to a novel variational algorithm to identify an optimal way to trigger turbulence. The group has also made world-leading contributions to techniques for the analysis of singularities in a variety of continuum mechanical systems. The group's work has been recognised by *Eggers* being made an APS Fellow (2009), *Kerswell*'s RS Wolfson Merit Award and his election as FRS (2012), and the recent award of an EPSRC Programme grant with Cambridge.

The **Mathematical Physics** group is particularly recognised for work in quantum chaos and the development of ideas relating random matrix theory and number theory. *Keating* and *Snaith*, who held respectively EPSRC Senior and Advanced Research Fellowships during the assessment period, collaborate closely with colleagues in the **Number Theory & Combinatorics** group. A recent highlight is the discovery of significant new connections between the extreme value statistics of the characteristic polynomials of random matrices, random energy landscapes in statistical mechanics, and the Riemann zeta-function. The impact of their work is evidenced by *Snaith's* Whitehead Prize (2008), *Keating's* Fröhlich Prize (2010), and his election as FRS (2009). *Keating* is a Co-I on the EPSRC Programme Grant with number theorists at Bristol (*Booker*, *Conrey*) and Warwick, and *Snaith* was a co-organiser of a semester-long programme at MSRI on Arithmetic Statistics. In Quantum Chaos, the group has made major contributions to the semiclassical theory of transport, spectral and eigenfunction statistics and the surprising discovery that anyonic statistics are kinematically possible on quantum networks. *Grava's* appointment represents an expansion into integrable systems and related PDEs, linking existing interests in random matrix theory with analysis and dynamical systems.

Over the assessment period, the **Quantum Information** group has obtained highly influential results in quantum Shannon theory, for example providing the key insights that enabled a resolution of the most important and long-standing problem of quantum communication: the "additivity conjectures". It introduced the crucial new concept of *information causality* in a paper in *Nature*; this beautiful idea gives new insight into the deep question of why the degree of non-locality in quantum mechanics is less than that allowed by relativity. The group has also made key contributions to the foundations of statistical mechanics: for example it showed that reaching equilibrium is a universal property of quantum systems. The group's continuing success is evidenced by numerous awards during the assessment period (e.g. *Winter*'s Whitehead and Philip Leverhulme prizes, RS Wolfson Merit Award, and ERC Advanced Investigator grant).

Number Theory & Combinatorics. In a tour de force of analytic number theory, the conjectural bound on the exponential sums in Vinogradov's mean value theorem has been established for degree $k \geq 2$ and number of variables $s \geq k^2-1$. This is the first instance for any additive problem of large degree of a bound within a constant factor of being sharp. This breakthrough result is now being used in solving a host of problems in analytic number theory, arithmetic geometry, and additive combinatorics. The theory of higher-degree *L*-functions was for a long time considered computationally infeasible, until recent breakthroughs by the group that identified many generic examples of *L*-functions of degrees 3 and 4. Manin's conjecture describes the asymptotic growth rate of the counting function for rational points of bounded height on del Pezzo surfaces; an important milestone for the group was establishing the conjecture, for the first time, for a smooth del Pezzo surface of degree 4. *Wooley* is a 45 min invited speaker for ICM 2014 and was awarded the LMS Fröhlich prize in 2012. *Browning* won an LMS Whitehead Prize (2008), the Ferran Sunyer i Balaguer Prize (2009) and a Philip Leverhulme Prize (2010). The appointments of *Dokchitser*, *Saha* and *Wolf* reflect the UoA's continuing strong commitment to this area.

Highlights from the **Statistics** group include the synthesis of sequential methods and MCMC, via state augmentation, providing as a special case a solution to the problem of static parameter estimation in state space models; recent breakthroughs in the study of the stability properties of sequential Monte Carlo algorithms on general state spaces which has led to the development of novel algorithms; and the development of new wavelet based techniques of variance stabilization,

now making a significant impact on the astronomical image processing community. The EPSRC Science and Innovation award, **SuSTaIn,** has continued to drive growth in the group, with 4 new appointments (Stanberry 2008-2009, Beaumont*, Bowsher* and *Whiteley* in 2010 & *Cho* in 2013). **SuSTaIn**'s Brunel Fellowship programme was recognized by EPSRC to have been a particular success in the UK's capacity building and has led to follow-on funding specifically for this purpose: **SuSTaIn2** (£0.6M) currently funds 4 Brunel Fellows (*Battey*, *Papastathopoulos*, *Pereyra* & *Constantinou*). Recognition of the group's work includes *Nason*'s EPSRC Established Career Fellowship and *Andrieu*'s Programme Grant (with Lancaster, Oxford and Warwick).

The UoA has also had longstanding strength in the areas of **Algebra**, **Analysis** and **Set Theory & Logic.** Each of these has been supported with new appointments as detailed below.

B. Evidence for the success of new initiatives

The **SoM** has implemented a range of new initiatives, some of which we detail here while others are described in the following two subsections ***C*** and ***D***. In 2007 the **Ergodic Theory & Dynamical Systems** group was created with the objective of forming a natural bridge between Bristol's existing groups in **Number Theory & Combinatorics** and **Mathematical Physics**. In addition to an existing staff member (*Marklof*), the University committed three new permanent lectureships to this initiative (*Gorodnik, Jordan* and *Ulcigrai*). The group has already established a high international reputation, winning numerous awards including 3 ERC Grants, 3 LMS Whitehead Prizes, an EMS Prize (*Ulcigrai*), a RS Wolfson Merit Award, a Plenary Lecture at the International Congress of Mathematical Physics, and an invited ICM Lecture (*Marklof*). Highlights include the solution of a century old problem in statistical mechanics (the Boltzmann-Grad limit of the periodic Lorentz gas). There have also been important advances in the development of the ergodic theory of group actions and their application to long-standing counting problems in number theory, such as the Manin-Peyre conjecture. A complete classification has been given of all locally Hamiltonian flows that are mixing, and those that are not, thus solving a problem previously studied by Arnold, Sinai, Katok and Forni. Recent work answers, in the negative, the century-old question of ergodicity of the Ehrenfest wind-tree model, one of the classical models of diffusion.

Another initiative was to grow activity in fundamental probability theory to build new research links between the School's **Analysis**, **Ergodic Theory & Dynamical Systems** and **Probability** groups**.** To this end *Toth* was appointed to a Heilbronn Chair and *Balazs* to a Senior Lectureship. *Toth's* honours include the Knight's Cross of the Hungarian Republic awarded by the President of the Hungarian Republic in 2009, and the 2010 Szele Tibor Memorial Medal of the Bolyai Mathematical Society. His long-running collaboration with Werner has led to a number of influential papers on self-interacting random walks. *Balazs* received the Erdos Prize in 2012; his achievements include the proof of a 30 year old conjecture by van Beijeren, Kutner and Spohn on the current variance and diffusivity of the ASEP, and the fluctuation exponents of the KPZ equation.

C. Evidence for the success of developing interfaces

During the period a conscious goal has been to **broaden the research base** by building interfaces between existing research areas and ones not currently represented in the School. The initiatives outlined in subsection ***B*** both achieved this. In addition, the UoA has 4 **new appointees** linking existing groups to areas we see as key to the future of pure mathematics. *Wolf* has been recruited to the Heilbronn Readership in Combinatorics, focused on recent developments in additive combinatorics linking to the **Number Theory & Combinatorics** group. In joint work with Gowers, she obtained the first criteria for determining the so-called complexity of a given system of linear equations; her work spans modern additive combinatorics (including the higher degree Fourier analysis of Gowers, Green and Tao), additive number theory, ergodic methods and applications to theoretical computer science (in line with recommendations in the International Review). *Mackay* has research interests stretching from ergodic theory, via hyperbolic geometry, to geometric and topological group theory, for example obtaining new examples of compact doubling metric measure spaces supporting Poincare inequalities. *Burness* focuses on group theory, particularly subgroup structure and representation theory, and his research stretches from finite and algebraic simple groups, to permutation groups, thus interfacing with our emerging activity in Combinatorics. He has investigated the random generation of maximal subgroups of simple and almost simple groups, showing that the expected number of random elements generating such a subgroup is

bounded by an absolute constant. Finally, *Dokchitser* has been recruited as the new Heilbronn Chair in Arithmetic Geometry. Interfacing with the **Number Theory & Combinatorics** group, he is a specialist in elliptic curves and arithmetic geometry and a key player in our vision of building capacity in geometry. *Dokchitser's* work, conditionally resolving the famous Parity Conjecture for elliptic curves, is rightly celebrated as a key contribution to the subject. He also links with *Mackay* and *Burness*, in a loose constellation of group theorists, via his decisive work classifying Brauer relations in all finite groups, extending the Tornehave-Bouc classification in the case of p-groups.

D. Cross-disciplinary activities

The Unit has a distinguished history of work in **Biology** notably *McNamara's* work applying mathematical ideas to behavioural and evolutionary biology, where he has an exceptional track-record of publication in journals such as *Nature* and *Science*. There is a strong link with Houston, and others, in Biological Sciences at Bristol. Their framework for the functional analysis of behaviour led to both being elected as FRS (2012) and receiving 2 major prizes in the assessment period. Recent highlights include work on the impact of individual differences in evolutionary game theory (*Nature*), establishing how differences select for other characteristics such as choosiness and social sensitivity, and completely change predicted outcomes. The Unit has followed a strategy of expanding its work in life sciences during the period, aligning with the University's strategy behind its £54M investment in a new Life Sciences building (to open early in 2014). The appointments of Beaumont (joint with Biology) and *Bowsher* bring expertise in population genetics and bio-molecular networks. Key results obtained include the development of a mathematical theory for information flow and signal representation, and dynamic conditional independence in bio-molecular networks.*Yu* has obtained the first rigorous result on the rate of adaptation, a key parameter in evolutionary genetics. The work of *Liverpool* and *Voliotis* on stochastic models of transcription is highly cited in the biological literature and was a significant factor in *Voliotis* winning an independent MRC fellowship. *Linden's* collaboration with experimentalists on protein design has led to papers in *Science* and *Nature Chemical Biology*, and a patent application.

The School also has longstanding collaborations with **Computer Science, Physics** (where there are numerous joint publications with members of the quantum information and mathematical physics groups) and **Earth Sciences**, and is growing connections with 8 other **UoB** departments through 4 successful EPSRC DTC applications announced in late 2013 (see section **d**). *Rougier's* statistical methods for the assessment of uncertainty in climate and other environmental models, as reported in an impact case study, is an example of a key research project with **Earth Sciences**, as is *Hogg*'s analysis of the dispersion of volcanic atmospheric ash, the results of which are being used in an operational context to assess the safety of airspace for aircraft flight by Meteorological Offices in Iceland and UK. The appointment of Huppert (jointly with Earth Sciences and returned to UoA 7) considerably strengthens this group. Work in dynamical systems as applied to problems in **Chemistry** is a distinctive feature of our research; notably *Wiggins* has made pioneering contributions to fundamental mathematical, modelling and simulation techniques in physical chemistry. We have continued to maintain the important collaboration with **Philosophy** with the joint appointment of Fujimoto who replaces Leitgeb. The most significant achievement during the period is *Welch's* obtaining of lower bounds on the strength of mutual stationarity properties of Foreman and Magidor. Important new links have been developed with **Psychology** stimulated by a £1.6M EPSRC grant `*Decision-making in an unstable world'* (*Leslie, McNamara*).

Vision and Strategies for the future In many areas progress is most rapid at the interfaces between mathematical sub-disciplines, and between Mathematics and other now data-rich disciplines. Part of our future strategy is to place ourselves in the best possible position to exploit this by continuing to make strong appointments at the boundaries of traditional subjects.

- **Scientific computation** is becoming increasingly pervasive in many branches of Mathematics (whether to test or suggest conjectures, simulate solutions or extract information from data). One particularly promising direction which exploits existing expertise is the interface of deterministic PDE modelling, scientific computation and stochastic modelling.
- With the impetus brought by **SuSTaIn** and the **HIMR,** the **Probability** and **Statistics** groups have strengthened and broadened their core expertise and developed new partnerships with science, social science and engineering; the recognised need for such expertise throughout the University and beyond will continue to drive research in traditional and emerging areas, e.g.

processes and inference on networks, and the evaluation of dynamic treatment strategies.
- We see exciting new opportunities for statisticians and mathematical modellers in life sciences and in environmental sciences where our track record, recent appointments and substantial **UoB** investment place us in a strong position to address challenges in biology and biochemistry and in major societal issues such as global change.
- Within pure mathematics, building on our emerging strength in arithmetic geometry and geometric connections to ergodic theory, we aim to develop a presence loosely spanning geometric group theory, geometric topology, geometric representation theory, differential geometry, algebraic geometry. The areas of interest for GCHQ's recruitment of research fellows to **HIMR** will continue to inform appointments and growth in some areas.
- Fostering the connections between the **Mathematical Physics** group and the **Number Theory & Combinatorics** group remains a key priority with an emerging focus on understanding the arithmetic statistics of elliptic curves. There are also rapidly developing connections between the **Mathematical Physics**, **Probability** and **Analysis** groups, especially concerning new directions in random matrix theory. The **Mathematical Physics** group is currently working on establishing the foundations for the theory of semiclassical time-evolution in non-Hermitian systems; this is very promising for developing collaborations with Chemistry and Physics.
- In quantum information we see major on-going opportunities in application to the foundations of statistical mechanics; in addition we expect the emerging field of quantum technologies to offer exciting theoretical challenges and opportunities for collaboration with experimentalists. There are rapidly developing connections between the **Quantum information** and **Mathematical Physics** groups focused on random matrix theory: this promises both new techniques for problems in quantum information and new directions for random matrix theory. The importance of this connection was recognized as a key theme in a recent INI programme and the UoA is ideally placed to exploit the associated opportunities.

The University is keenly aware of the increasingly central importance of Mathematics to its Science Faculty and beyond, and hence the need to maintain its sustainability and vitality. As a result, **UoB** is planning to invest £25.5M to re-house the School in a larger, specially refurbished building (projected to open in 2016) with space to allow for a 25% growth in activity. Further expansion is anticipated when this move is completed, fuelled in part by the continuing popularity of the undergraduate programme (intake numbers increased by more than 29% from 2011 to 2013, leading to the creation of new positions) and by the Unit's continuing grant success. The Unit has been alive to diversifying its funding streams from UK to EU-based sources (see section **d**) and continues to be a popular host for Research Fellows (e.g. Marie-Curie and EPSRC).

c. People

i. Staffing strategy and staff development

Bristol aims to foster collaborations with the strongest international research groups. To facilitate this, the staffing strategy is to maintain a number of central `hubs' of internationally leading researchers, connected by a web of dynamically interacting staff which extends outwards (through `spokes') to new mathematical sub-disciplines and application areas. On-going recruitment has been directed both at maintaining the hub strengths and targeted enhancement of the interconnecting web, as illustrated in the previous section. For example, losses in number theory (Pila, Helfgott) have been replaced by targeted recruitment (*Dokchitser*, *Saha* and *Wolf)*. The UoA successfully recruits from amongst the strongest institutions in the world, including Princeton, CalTech, ETH Zurich, Ecole Polytechnique. Extra leverage internationally comes from Bristol's key research centres (**HIMR**, the **SuSTaIn** programme).

The School aims to ensure that all new staff contribute at the highest levels as members of the international mathematical community by providing a combination of support, responsibility and opportunity. New staff are initially given reduced teaching (typically one course of 30 lectures per year) and administrative loads, and targetted allocation of PhD students. Each is assigned an academic mentor to advise on all academic issues. In recruitment, at lectureship level, at least one current lecturer will participate to gain experience, while at reader level or higher, a panel of (international) experts is engaged to serve as consultants on the appointment. All research grant proposals are reviewed by a Research Committee to provide strategic advice and feedback on drafting and mock interviews are arranged if appropriate (e.g. for Fellowships). As a result, the UoA

has been very successful in winning

- **Fellowships** (EPSRC established career fellow*: Nason* 2013, EPSRC leadership fellow: *Booker* 2009; EPSRC career acceleration fellow: Haynes* 2011, *Brooke-Taylor* 2013; EPSRC postdoctoral fellow: Band* 2010, Ferguson* 2011, *Pawlowski* 2011; Kurt Goedel Centenary Prize Research Fellowship: Bovykin* 2010; Leverhulme Research Fellowship: *van den Berg* 2008, Pila* 2008, *Marklof* 2010, *Didelez*, *Browning* 2011, *Mueller* 2013; Leverhulme Emeritus Fellowship: *Green* 2012, Huppert 2013; MRC-EPSRC Fellowship: *Bowsher* 2008*, Voliotis* 2013*).* (* indicates staff member has left in the period 2008-2013).
- **Personal development grants** (ERC advanced investigators grants: *Winter* 2010, *Marklof* 2011; ERC consolidator and starting independent researcher grants: *Gorodnik* 2009, *Browning* 2012, *Ulcigrai* 2013; RS Wolfson Research Merit Awards: *Marklof* 2009, *Kerswell* 2012).

Other fellowships and awards held in the assessment period are: RS Wolfson Research Merit Awards: *Green* (2006-11), *Winter* & *Wooley* (2007-12); EPSRC Senior Fellowship: *Keating* (2004-09); Advanced Fellowships: *Snaith* (2004-10), *Andrieu* (2005-10), *Browning* (2007-13); Royal Society URF: *Dokchitser* (2006-14); RCUK Research Fellows: *Gorodnik*, *Ulcigrai* (2007-12). The Faculty of Science also supports Leverhulme Early Career Fellows (e.g. *Maltsev*).

The School operates the University's annual Staff Review system. Staff are encouraged to take courses from the University's Academic Staff Development programme, such as those from Research Staff Skills Development or the Grant Writing portfolios. The School has instituted a professional development programme tailored for its Heilbronn Research Fellows. This includes regular panel discussions on topics key to future career success, such as "Shaping a research programme", "How to apply for a job", "The interview process", "Effective teaching" and "How to get shortlisted"; evidence of the value of this is the number of fellows who have gained permanent posts (3 in 2013 alone). Further support is available for mock interviews and mentored teaching experiences. The success of this programme is evidenced by its adoption into other areas of the School's operations and the number of postdocs who have gone onto permanent positions (e.g. to Technion, NC State, Ohio State, Twente, to CNRS positions in Paris and Toulouse, 2 to York, 2 to Sheffield, to Glasgow, Reading and Warwick). The UoA is also keenly aware of the valuable mentoring role very senior staff can play and has therefore retained visiting Professors E. Rees, FRSE, C. Hooley FRS and J. Kingman FRS on long term appointments. Finally, the School operates a flexible sabbatical system in which no reasonable request has been refused. For example staff are encouraged to participate in (and often to organise – see section **e**) long term research programmes at international research institutes and very many have done so (e.g. INI (*Kerswell*, *Linden, Winter, Rougier, Green*), Institute Henri Poincare (*Eggers*), Banff, MSRI (*Conrey*, *Keating*, *Snaith*), Kavli Institute (*Hogg*)). In addition the University has a Research Fellowship scheme funding year-long sabbaticals (e.g. *Rougier*), and the Unit has been very successful in gaining Leverhulme Fellowships (see above).

As evidence of staff development, 9 staff (*Browning,* Delaigle, *Didelez*, *Gorodnik, Hogg, Johnson, Mezzadri, Rougier*, *Ulcigrai*) have been promoted to readerships and 7 staff (*Andrieu, Browning, Dettmann, Dokchitser, Gorodnik, Liverpool, Volkov*) to personal chairs in the assessment period. Several people have also successfully developed their careers here before moving to attractive positions elsewhere (e.g. Helfgott and Pila did work that has attracted significant recognition – e.g. major prizes and ICM addresses – before leaving for ENS Paris and Oxford respectively).

The UoA follows University guidelines on implementation of the Concordat, most of the key principles of which have already been addressed above. In particular, the UoA addresses Principle 6 (equality and diversity) by ensuring the presence of women (as an under-represented group in the School) on recruitment committees. External to the School, the University offers a mentoring program for women academics. The **SoM** is a supporter of the LMS Good Practice Scheme and has appointed a Director of Equality & Diversity (*Didelez);* amongst other activities, she organises Women in Mathematics lunches and a series of other regular events to support female academic staff and PhD students. The School is sensitive to its gender balance and is proactive: of the last 4 permanent appointments, 3 were women (*Cho, Grava, Wolf*) bringing the School's total to 8 women (5 of whom are readers). The School is diverse with 28 of its 60 permanent staff obtaining their PhDs in the UK, 16 elsewhere in Europe, 15 in North America and 1 in Australia.

International recruitment: Incoming (permanent staff): *Toth* (2012, from Budapest), *Saha* (2012, from ETH, Zurich), *Balazs* (2013, from Budapest), *Grava* (2013, from SISSA, Trieste), *Wolf* (2013, from Ecole Polytechnique, Paris). Outgoing (permanent staff): Barba (2008, to Boston U.), Stanberry (2009, to Washington Univ.), Delaigle (2010, to U. Melbourne), Riley (2009, to Cornell), Harrow (2010, to MIT), Leitgeb (2010, to Munich), Helfgott (2011, to ENS, Paris).

Visiting International Scholars: The Unit has a vigorous international visitor programme including long term visits (a week or more) by Bogomolny (Univ.Paris-Sud), Buchstaber (Russian Academy of Sciences), Davies (Duisburg-Essen), del Moral (Bordeaux), Forrester (Melbourne), Friedlander (Toronto), Gonek (Rochester), Its (Indianapolis), Kawahara (Osaka), Marchetti (Syracuse), Nevo (Technion), Oh (Yale), Rubinstein (Waterloo), Rudnick (Tel-Aviv), Soundararajan (Stanford), Stone (Princeton), Ungarish (Technion), Wolpert (NASA Ames) amongst others. There were, for example, almost 100 seminars by international speakers in 2012/3.

ii Research students

Recruitment. Postgraduate (PG) funding is strategically deployed at Faculty level to support **UoB** research priorities. These include key appointments (in line with EPSRC's Developing Leaders strategy), programme grants and DTCs; a recent example is DTG studentships used to support the Communications DTC. 10% of DTG funding is top-sliced for EPSRC International Scholarships and awarded through open competition. The **UoB** has a strong track record of obtaining 50% industrial funding for EPSRC-funded studentships. Within the School, studentships are allocated to ensure balance between fundamental and applied mathematics, with scope for strategic support of new staff and emerging collaborations. The **UoB** has recently invested heavily in PG recruitment, commissioning films and literature. Of our 61 PhD students 39 are funded by the EPSRC DTA. Exceptionally able international students apply to us, as evidenced by their success in winning **UoB** and EPSRC International Scholarships.

Training Environment. The School provides coordinated training in 3 overlapping domains: specialist, broadening and professional development. Specialist training is provided within research projects under the supervision of members of academic staff; for broadening training and professional development, see the following paragraphs. The School has played a leading role in setting up 2 of the **UoB**'s 7 DTCs, namely **BCCS** (Complexity) and the DTC in **Future Communications: People, Power and Performance**, as well as a 4-year PhD programme in **Neural Dynamics** funded by the Wellcome Trust and the EPSRC-funded EngD in Systems Engineering. The Unit's PGs are co-supervised with colleagues in Earth Sciences, Chemistry, Biology, Physics, Psychology, Computer Science and Electrical Engineering, and have had links with industrial partners including HP, Toshiba, Airbus, BT, AgustaWestland, Eli Lilly, the National Oceanography Centre and United Bristol Healthcare Trust. Industrial links are facilitated by CASE awards and also by direct funding (e.g. Airbus and Toshiba). Extensive professional training for a range of careers is provided by the **SoM** through the PG seminar for Mathematics in Business and Industry (with recent speakers from Google, Toshiba, and HP) as well as the **UoB**'s enterprise education, IT Service and Staff Development units. Students are allocated a Research Training Skills Grant, typically £1000 per year, which supports workshops, conferences, academic visits and courses. There are dedicated administrators for PG student affairs.

Broadening Training: Broadening training is provided through an extensive range of PG taught units and multi-disciplinary/industrial collaborations. PhD students are required to attend at least 100 hours of assessed courses, drawn from the Bath-Bristol-Imperial-Oxford-Warwick TCC (to which the UoA contributes 100+ lectures per year), the Academy for PhD Training in Statistics (APTS) (in which the **UoB** is an Underwriting Member, and *Rougier* the lecturer in Statistical Inference), PG lectures in the **BCCS** and Communications DTCs, MSc/Level M units, LMS short courses; and reading groups/journal clubs. (In line with the 2010 DTZ review of Taught Course Consortia (TCCs), the School, as part of the TCC, has championed broadly-aimed provision to balance more specialist units; the APTS lectures are supplemented for **UoB** students by locally-provided preparation and assessment.) Other forms of training include ECMI modelling weeks, European Study Groups in Industry, and internships with industrial partners. A training programme is developed for each PG to address their specific needs. PGs also attend at least one of 15 weekly research seminars to broaden their training. Every postgraduate student presents at least one talk at an internal seminar each year, is expected to attend an international scientific meeting

per year, and to present their research at an international meeting at least once during their PhD. Expertise in programming languages and packages is acquired through research as well as dedicated **UoB** courses.

The Unit runs a lecture series on mathematical research skills, delivered by senior staff. **Professional development** is also fostered by enabling service to the academic community. Recent examples include the 3rd annual UK Young Researchers in Mathematics conference, which attracted over 200 PGs, organised entirely by the Unit's PGs, and PGs contributed substantially to the delivery of the "Can you hear the shape of a graph?" exhibit at the 2011 Royal Society Summer Exhibition. PGs organise two weekly mathematics seminars given for and by students as well as an annual postgraduate conference, *MINGLE*, where each student beyond first-year gives a short presentation of their research aimed at a general mathematical audience. PGs are strongly encouraged to engage in undergraduate teaching. PGs who teach are required to attend a 1-day course from the Maths, Stats & OR Network as well as in-house training sessions, and receive mentoring from staff. PGs regularly enrol in external professional training; recent examples include the Standing Up for Science Media Workshop and the Vitae National Grad School. At the institutional level, the **UoB** is developing professional training resources for the whole PG community and establishing a Doctoral College, including 6 half-day events on communication, media training, industrial relationship building, and presentation skills.

Support Mechanisms & Monitoring. Postgraduates are assigned a second supervisor (in addition to their principal supervisor(s)) whose role includes pastoral and academic guidance. The **UoB** operates rigorous Annual Progress Monitoring in which a PG writes a detailed technical report of their research and describes the training they have received. Two members of academic staff interview the PG and provide detailed feedback and recommendations to the PG and supervisor for future training and research. Problems are addressed with additional reviews as needed, overseen by the Director of Graduate Studies and the Science Graduate Dean.

d. Income, infrastructure and facilities

Information on provision and operation of specialist infrastructure and facilities. All staff, RAs and PGs have access to an excellent research computing infrastructure. Firstly the School runs its own Intermediate Performance Computing (IPC) farm (*CREAM*, *C*luster for *RE*search in *A*dvanced *M*athematics) updated in 2013 (by investment of £37k from the University adding to roughly £100k of earlier investment), totalling 388 cores (including 4 GPU nodes), with associated storage and networking. *CREAM* is managed by the University IT's Linux and HPC specialists together with the IT subject specialist for the School. Secondly members of the unit have access to two High Performance Computing facilities. The University funds (£8M since 2008) "BlueCrystal" (https://www.acrc.bris.ac.uk/), operational in autumn 2007 and updated in 2008 and 2013 to have 5400 cores and several nodes with GPU cards available (BlueCrystal Phase 3 was listed in the world's top 500 fastest computers in June 2013; http://www.top500.org). A range of secured data storage systems are provided for personal data and separately for research data (5TB free for each PI) whether for short-term results or long-term retention. In addition, members of the University have access to "EMERALD", funded (£3.7M) by EPSRC through the e-Infrastructure South Centre for Innovation (EMERALD has a sustained capability of 114TF and on installation in March 2012 was one of the largest GPU based systems in Europe). Users of these systems are trained and supported by **UoB** centrally with a series of clinics, workshops and online guides.

All three facilities are ***free*** at the point of use. The first two are particularly heavily used, e.g. CREAM has 200 users and BlueCrystal, 18 from the UoA. Amongst many other papers, *Platt*'s "*Computing π(x) analytically*" arxiv:1203.5712 (Math Comp, to appear), used BlueCrystal extensively; in arxiv:1201.6656. Tao said of *Platt's* work that it was "likely that such results would be useful in future work on Goldbach-type problems"; this proved to be the case: *Platt's* recent work, also carried out using BlueCrystal, played a major role in Helfgott's resolution of the odd Goldbach conjecture. There are also computer clusters for particular projects; e.g. one costing £35k is associated with EPSRC Programme grant on *L*-functions & modular forms.

University library facilities are at the level one would expect of a leading research institution, including a subject librarian specific to mathematics. The University has recently invested heavily in a programme of enhancement for the mathematics library collection. This includes spending to

fill gaps in book collections: £100k in pure mathematics and a further £10k in statistics. The University has also invested in permanent online access to all of the Springer Lecture Notes in Mathematics series and to all Springer mathematics books published between 2005 and 2010.

Members of the UoA use a variety of University laboratory facilities. Examples include the Volcanology lab in Earth Sciences (*Hogg*, *Kerswell)* which has just been renovated by the University and restructured to focus pan-University activities (e.g. a new granular media lab is being set up and a new fluids lab together costing c. £700k). *Kerswell*'s paper (*J. Fluid Mech.* 682, 132-159, 2011) was directly based on work there. The experimental work in *Linden*'s paper (*Science* 1226558, 2013) was performed in Woolfson's biochemistry lab which received a £750k investment by the University.

An access grid node is located in the UoA, and is primarily used for PG training courses shared with Bristol's EPSRC TCC partners.

Evidence of investments (both current and planned) in infrastructure and facilities. At the time of RAE2008, there were plans for the imminent construction of a new £34M building for the School. The international economic downturn forced the University to change these plans. Now the intention is for the School to move to an iconic Victorian structure in the centre of the University precinct, the Fry Building, after it has been substantially remodelled and renovated. This is significantly larger than all our present accommodation, and equal in space to the new building that had been planned. It will allow for substantial (25%) expansion in activity and the co-location of all staff and students in a single building. The total budget is £25.5M. In addition, during 2010-2012 the University spent over £700k in capital investment improving **SoM** buildings, including an additional c. 1750m^2 of very high quality co-located office and seminar space.

The Unit plays a leading role in major research initiatives that have seen notable investment from the University. In 2009 *Linden* was the lead academic in establishing the Centre for Nanoscience & Quantum Information (**NSQI**), a world-leading research facility supported by a £11M investment from the University. **NSQI** is devoted to fundamental nano-scale experimental science as well as providing a home for the interdisciplinary research group in Quantum Information Theory.

The **UoB** funds the Cabot Institute, one of two University Research Institutes. Its mission is to promote interdisciplinary research in the areas of global change and risk, and to build links with agency and industrial partners (Sir John Beddington chairs the External Advisory Board). The UoA's current involvement includes statisticians (*Rougier*: floods, volcanoes, and avalanches) and applied mathematicians (*Hogg* and Huppert: volcanoes, avalanches and landslides).

Overall, the University has put £95M capital investment into the Science Faculty since 2008, including £54M in a new Life Sciences Building which will directly benefit activity in Mathematics through additional office space, access to labs, and dedicated high-speed computers.

Research funding portfolio, including future plans. Bristol has been extremely successful in obtaining grant funding; £18.6M was spent during the review period. £11.1M of grants from EPSRC and £10.5M from other sources were in progress on 31st July 2013 (not including DTCs) and have therefore contributed to the research environment during the census period. This was a contributory factor to EPSRC ranking Bristol as third in the UK for distribution of the Mathematics DTG in 2013. Amongst the grants from EPSRC is the **Statistics** group's EPSRC Science & Innovation award of £3.5M (**SuSTaIn**: **S**tatistics **U**nderpinning **S**cience **T**echnology **a**nd **In**dustry), at the time one of the largest grants ever awarded to a UK mathematics department. It ran from 2006 to 2012, generated substantial new activity in mathematical statistics and partially funded the appointment of 6 permanent staff and several research fellows, with additional provision for academic visitors and the creation of the MRes/PhD programme. Recently, as recognition of the success of the programme, **SuSTaIn II** has been funded until 2015 (£0.6M). In addition the Unit has recently been awarded 3 programme grants by EPSRC: to *Booker*, *Conrey* and *Keating*, £2.2 million to explore systematically the landscape *L*-functions, jointly with Warwick; to *Kerswell,* £2.3 million to apply dynamical systems ideas to stratified shear flows, jointly with Cambridge; and to *Andrieu,* £2.4 million to fund the i-like project, jointly with Oxford, Lancaster and Warwick.

The **HIMR**, established in 2005 by Bristol in partnership with GCHQ, continues to exert a profound influence on the Bristol mathematics culture. The salaries of more than 20 fellows per year are

funded, together with substantial amounts to support them and the overall scientific environment in Bristol including a series of major workshops.

The UoA is particularly successful at winning fellowships and other major personal awards (see sections **c** and **e**) and participates in a series of EU network grants. In addition it attracted funding totalling £1M from charities including the Wellcome, Templeton, and Leverhulme Trusts. There were also CASE awards and direct industrial funding from BAE Systems (*Leslie*), BT (*Nason*), EDF (*Nason*), Embley Energy (*Porter*), Garad Hassan (*Hogg, Nason*), GCHQ (*Nason*), General Dynamics (*Nason*), Met Office (*Rougier*), MOD (*Johnson, Nason*), QinetiQ (*Keating, Nason*), Renishaw (*Hogg, Kerswell*), Shell (*Nason*), Toshiba (*Andrieu, Johnson, Mezzadri*), Vattenfall (*Nason*), US Airforce (*Keating, Snaith*) and the US Office of Naval Research (*Wiggins*).

The Unit is particularly outward-looking and collaborative, being involved with a large number of grants with other Departments in the University. At the census date these total over £4.2M, including grants from BBSRC, EPSRC, and NERC. We also lead on a number of interdisciplinary awards for research and training. The UoA was one of the lead departments in establishing the DTC in Communications in 2011. This Centre is supported by £2.2M from the EPSRC and over £840k from some 11 major UK companies and trade organisations, and provides multidisciplinary PG training in a wide range of communications applications. The UoA also jointly led in establishing **BCCS**, the DTC in Complexity Sciences, a major collaboration across 4 Faculties; **BCCS** received a £3.6M EPSRC extension grant in 2011.

In the future we expect to continue with a diverse portfolio of grants from Research Councils, the EU, charities and industry, often, as now, with collaborators outside the UoA. This diversity provides a degree of insulation against fluctuations in the financial position of funders. The fact that GCHQ made **HIMR** permanent in 2010 considerably reduces uncertainty for this key activity. As described in REF3a, we plan a series of initiatives aimed at strengthening our industrial links, and hence potential funding. We also see specific opportunities where activity is developing in the UoA and beyond, and we are particularly well-placed, for example in Quantum Technologies, in the Life Sciences (notably Synthetic Biology) and Psychology. The sustainability of future funding of PhD students was considerably enhanced in late 2013 by our involvement with 4 successful EPSRC DTC bids in the areas of Communications, Quantum Technologies, Water and Theoretical Chemistry (in the first two we play a leading role as formal co-investigators).

Consultancies and professional services.

The UoA has four individuals who provide consultancy to GCHQ on mathematics and on strategic aspects of mathematical research in the context of national security. *Rougier* was an external consultant to the UK Met Office (2007-2009) to contribute to the uncertainty assessment in the UK Climate Impacts Programme, 2009 (UKCP09); this formalised his long-standing collaboration with climate scientists at the UKMO (since 2004); he is a member of the Cabinet Office Expert Advisory Group for effective volcanic eruptions (2013 onwards); he has provided pro bono consulting to the Soil Association (sampling). *Dettmann* provides mathematics consultancy to Toshiba TREL in the areas of asymptotics and special functions. *Green* conducted a peer review project for the Health and Safety Executive (on corrosion studies at Sellafield). *Marklof* is on the REF2014 Committee; *Keating* is on the Hong Kong REF Committee, and on the Leverhulme Research Awards Advisory Committee; *Green, Keating* and *Kerswell* served on RAE2008 panels.

e. Collaboration and contribution to the discipline and research base

The **SoM** has been exceedingly successful in developing a collaborative ethos (as evidenced, for example, by the **HIMR)**. It facilitates this with a number of strategies. (a) It underwrites travel grant applications for all staff and no reasonable request goes unfunded; it operates a flexible sabbatical leave policy to facilitate external collaborations, and attendance at international research centres (as well as individual departments outside the UK). (b) It supports external collaborators who come to Bristol, often for long stays (e.g. Ungarish from the Technion for 3 months in 2013). (c) It assists in securing external funding and promoting a culture of seeking external funding; for example through its Research Committee, the UoA gives detailed advice in drafting and strategy for applications; and it encourages application for external fellowship opportunities to free up research time (see section **c.i.**). Science Faculty money and start-up money for new appointments is also used to facilitate collaboration. There is also financial support for staff travel, visitors and high-

profile workshops at Bristol from **HIMR** (29 workshops in the assessment period; invited speakers include Atiyah, Okuonkov and Werner) and **SuSTaIn**.

Support for and exemplars of mathematical collaboration beyond the UoA. Formal support is also given by the following organisations.

- Pan-University organisations such as the **Quantum Information** group; *Linden*, *Wiesner*, and *Winter* are part of this group which spans Physics, Electrical Engineering and Computer Science. This group is highly integrated with coordinated staff appointments, a joint seminar, and joint PhD students, and there are strong links with major international figures (e.g. Bennett and Shor).
- The **Institute of Advanced Studies** funds a programme of workshops and fellowships that facilitate interaction with outstanding external scholars. This includes a substantial visiting scholar programme (e.g. funding a semester visit by Gonek from Rochester in 2009).
- EPSRC funds the University's '*Building Global Engagements in Research*' program, which has enabled *Andrieu, Battey, Chenchiah, Eggers, Keating, Kovac, Liverpool, Welch* to strengthen their links with Michigan and Princeton through a variety of visits and workshops.
- For external ventures the UoA is supported by the University Research and Enterprise Development (RED) team which coordinates joint bids and provides contract support.
- **GW4**: the University has recently (2013) announced a formal collaboration with Bath, Cardiff and Exeter to share research infrastructure and promote thematic areas of expertise.

Exemplars of mathematical collaborations. In the assessment period members of the UoA have taken part in over 250 distinct collaborative groupings outside Bristol that have led to at least one publication. These range over 200 institutions that include most of the world's top universities (e.g. MIT, Harvard, Yale, Chicago, Princeton, Caltech, Penn State, Cornell, Stanford and Michigan just from the US). 90% of permanent academic staff in the UoA have published with an international collaborator during the assessment period; exemplars are:

Conrey's collaboration with Soundararajan (Stanford) and Iwaniec (Rutgers) led to the invention of the asymptotic "large-sieve", leading to spectacular theoretical evidence for the random matrix theory moment conjectures of *Conrey*, Farmer, *Keating*, Rubinstein and *Snaith*. *Booker* and Cremona (Warwick) (with *Conrey* and *Keating*) are co-PIs on a six-year £2.2M Programme grant.

Written in collaboration with Nevo (Technion, Israel), *Gorodnik*'s research monograph "Ergodic theory of lattice subgroups" is a new departure in ergodic theory, significantly expanding its scope, and has led to striking applications; e.g. to counting problems (*Gorodnik*-Nevo) and to sifting for (almost) prime points on algebraic varieties (Nevo-Sarnak).

Marklof's joint work with Strombergsson (Uppsala) on the Boltzmann-Grad limit of the Lorentz gas, solved a century old problem in mathematical physics. The collaboration led to a number of major awards for *Marklof* (listed elsewhere) and Strombergsson, who received Sweden's largest scientific research prize, the Göran Gustafsson Prize in 2012, from the King of Sweden.

Early career researchers are also highly active in collaborations. For example: *Battey*'s analysis of banking systems in PNAS with May (Oxford) and Nowak (Harvard) has given insights into regulatory interventions to promote systemic stability. *Gunderson* and Bollabas (Cambridge) resolved an open question in bootstrap percolation on the smallest possible critical probability for infinite trees with a fixed branching number, and give nearly tight bounds on the smallest possible critical probabilities among the class of random, Galton-Watson trees. Helfgott's proof of Goldbach's ternary conjecture is based on detailed analysis, but backed up by computations co-authored with Heilbronn Fellow *Platt* and a (400,000 hour) computation by *Platt*.

Support for and exemplars of interdisciplinary research

Interdisciplinary collaboration between members of the UoA and other university researchers is enhanced through the joint supervision of PhD students. Support includes that from two DTCs (**BCCS** and **Communications**). The links between *Leslie* and *McNamara* and members of the Psychology and Computer Science departments are supported by a £1.6M grant from EPSRC to establish a centre for research into '*Decision-making in an unstable world*'. This Cross-disciplinary grant which also involves Education, Neuroscience, NHS, Biology, Geography and Economics, funds 2 post-docs and 5 PhD students. The following umbrella organisations also facilitate within-

university interdisciplinary research.

• The *Centre for Nanoscience & Quantum Information* (**NSQI**).

• The *Centre for Behavioural Biology* (Director *McNamara*) links Biological Sciences, Veterinary Science and Mathematics and promotes collaboration between theoreticians and empiricists, and involves a large number of cross-UoA joint research projects.

• The *Environmental Risk Research Centre* (Director *Rougier*) aims to coordinate, promote and advance interdisciplinary research across the natural, engineering and social sciences in environmental hazard risk assessment and uncertainty science.

• *Didelez* is part of £23M *Medical Research Council Integrative Epidemiology Unit.*

• The interdisciplinary *Cabot Institute* carries out fundamental and responsive research on risks and uncertainty. For example, researchers in the Institute and in Earth Sciences, Geographical Sciences, Civil Engineering and Mathematics are part of 3 NERC initiatives worth a total of £7.6M exploring better ways to forecast and cope with volcanic eruptions and other natural disasters.

In total 21 members of the UoA have at least one publication or joint grant with a researcher in another UoA at Bristol, and these collaborations extend to 18 other departments.

Exemplars of interdisciplinary research beyond the University

• Collaborators include the National Oceanographic Centre, the Met Office and the Home Office in the UK; NASA, the National Institute of Health, the US Naval Academy and Los Alamos in the USA; and businesses such as IBM and Google.

• The UoA is the only UK Mathematics department to be involved in all three of the following NERC consortia: VANAHEIM (£2.7M, *Hogg*) (involving the UK and Icelandic Met. Offices); STREVA (£2.9M, *Hogg*); CREDIBLE (£2.0M, *Rougier*).

• *Rougier* is arguably unique in his position at the intersection of theoretical statistics and large-scale climate science. His published work (Climatic Change, 2007) formed the basis of the UK Met Office's uncertainty assessment for the UK Climate Impacts Programme's 2009 report (UKCP09), for which he was funded by the UKMO as an external expert.

• *Nason* was co-PI and main technical liaison on a £1.25M GCHQ Applied Research Grant funding collaboration with GCHQ and five departments at Bristol (Mathematics, Engineering Mathematics, Electrical Engineering, Experimental Psychology and Computer Science).

• Commenting on the joint work of *Dettmann* and Coon (Toshiba), Toshiba have stated that “This work was exploited by Toshiba Corporation in key negotiations between Japanese industry and METI (Japanese Ministry of Economy, Trade and Industry) and led to the ratification of Toshiba’s proposal to standardise smart meter communication networks in Japan.”

Collaborations with research users, and impact on research activities and strategy

Developing interdisciplinary research through joint appointments (Beaumont, with Biological sciences; Fujimoto, with Philosophy; Huppert with Earth Sciences) has been an important part of the School’s strategy, and encouraging researchers to locate their Fellowships at Bristol (e.g. 6 Marie Curie in the assessment period) has also influenced members of the UoA, with Fellows bringing their own distinctive interests.

Various outside projects have resulted in a change of research activity within the UoA; including:

• The ALADDIN project was a £5.5M multi-disciplinary, multi-institution (Bristol–lead *Leslie*, Southampton and Imperial College) industry research collaboration (period 2005-2010, funding: two thirds BAE Systems, one third EPSRC), that won an Engineer Technology & Innovation Award in 2009.The project directly resulted in *Leslie* developing tools from economic game theory and machine learning for use in disaster management, and distributed optimisation more generally.

• *Dettmann’s* link with Toshiba led to a major shift of his work from theory to practical applications.

• *Nason* is joint-PI with Eckley (Lancaster) on a £0.66M EPSRC funded grant on “Locally stationary Energy Time Series” that involves Shell Research, EDF, GL Garad Hassan and Vattenfall. In this

project industry provides new problems, data and current expertise, and often has excellent methods which members of the UoA have learnt from.

Leadership and Esteem

Learned societies: *Keating* (2009)*, Kerswell* and *McNamara* (2012) have joined *Green* (2003), Hooley (1983), Huppert (1987), Kingman (1971) and *Wooley* (2007) as Fellows of the Royal Society. Rees was made CBE (2009), *Walling* and *Wooley* were elected Fellows of the American Mathematical Society (2013) and *Eggers* a Fellow of the American Physical Society (2009).

Prizes. LMS: 2 Fröhlich Prizes (*Wooley* and *Keating*) and 7 Whitehead Prizes (*Browning, Gorodnik,* Helfgott*, Marklof, Snaith*, *Ulcigrai* and *Winter*). RSS Guy medal in Gold (Kingman). European Mathematical Society prize (*Ulcigrai*). Philip Leverhulme Prizes (*Browning, Winter* and Helfgott*). The Ferran Sunyer i Balaguer Prize (*Browning*). Kurt Gödel Centenary Research Prize Fellowship (Bovykin*). The American Mathematical Society Conant Prize (*Conrey*). The International Society for Behavioral Ecology Hamilton Award (*McNamara*), the Association for the Study of Animal Behaviour Medal (*McNamara*). Tibor Szele Memorial Award (*Toth*). Royal Statistical Society Research Prize (*Cho*). IEEE Aerospace (Barry Carlton) award 2010 (*Whiteley*). (* indicates the staff member left during 2008-2013).

Fellowships. See **c.i.** above for a listing.

Keynote Lectures: The 2008 Hamilton Lecture at the International Society for Behavioral Ecology meeting (*McNamara*); the 2009 International Congress of Mathematical Physics *(Marklof*); the 2010 Lighthill lecture at the joint BMC-BAMC meeting (*Kerswell*); Royal Statistical Society Read paper, 2010 (*Andrieu*); 2011 conference of the Australian Mathematical Society (*Snaith*); the 2012 Bernoulli Lecture at the 8th World Congress in Probability and Statistics (*Green*); the Ess'en Lectures, Uppsala 2012 and Simons Lectures, Stony Brook 2013 (*Marklof*); the Bahadur Memorial Lectures, Chicago 2013 (*Green)*; Two 45-minute addresses at the International Congress of Mathematicians in Seoul, 2014 (*Wooley, Marklof*).

Committees and organisation: Executive Director, American Institute of Mathematics (*Conrey*), Organising committee of semester programme "Arithmetic Statistics'' **MSRI** (Jan-May 2011) (*Conrey & Snaith*); Annual Conference of the 2010 **Royal Statistical Society (RSS)** (*Didelez*); **Royal Society's** Newton International Fellowship Board (*Dokchitser*); **RAE2008** subpanel (*Green* UoA 22 deputy chair*, Keating & Kerswell* UoA 21); **Royal Society** Section 1 (Mathematics) Committee (*Green* 2011*, Keating* 2011-2013**,** *Wooley* 2012-14, *Kerswell* 2013-15); Scientific Steering Committee of **INI** (*Green* 2007-10*, Wooley* 2010-13*)*; Scientific council Eurandom 2004-10 *(Green*); **Royal Society** `Securing the Scientific Century' Core Steering Group 2012- (*Green*); **Leverhulme Trust** (RAAC 2006-2013 *Keating*, Advisory Panel 2013- *Marklof*); **Royal Society** UK Panel of Theoretical and Applied Mechanics 2008-12 (*Kerswell*); co-organiser of the **INI** programme "The Nature of High Reynolds Number Turbulence'' (Aug-Dec 2008) (*Kerswell*); **RSS** Council member 2009-12 (*Leslie*); Member of the tri-annual Long Term Strategy Group of the **RSS**, 2012 (*Leslie*); **INI** programme "Mathematical Challenges of Quantum Information'' (Aug-Dec 2013, *Linden* co- *& Winter* principal organisers); **REF2014** subpanel (*Marklof*); co-chair "Mathematical models in Ecology and Evolution, 2009" (*McNamara*); **EPSRC** Mathematics Strategic Advisory Team 2007-10 (*Nason*); Elected Council member and Trustee, **RSS** 2004-2008 (*Nason*); co-organiser of the **INI** programme "Mathematical and Statistical Approaches to Climate Modelling and Prediction" (Aug-Dec 2010) (*Rougier*); Bernoulli Society Committee for Conferences on Stochastic Processes and their Applications 2010-13 (*Toth*); Programme chair, **ICMS Edinburgh** 3rd European Set Theory meeting 2011 (*Welch*); Steering committee of Quantum Information Processing (QIP) conference 2007-12 (*Winter*), **Royal Society** Wolfson Research Merit Award selection (Mathematics) committee 2010-12 (*Wooley*), **LMS** Prizes Committee 2008-09 (*Wooley*).

Editorial duties: During the period, 24 of 58 permanent staff in the UoA have helped edit 28 journals (including **Ann. Stat., Biometrika**, **Comm. Math. Phys., J. Number Thy, J. Stat. Mech., Nonlinearity, AMS Mathematical Reviews**).

University Leadership: Dean of Science (*Keating* 2009-13), Graduate Dean (*Robbins* 2013-).