Institution: Queen Mary University of London (QMUL)

Unit of Assessment: B10 Mathematical Sciences

a. Overview

The School of Mathematical Sciences within the Faculty of Science and Engineering at Queen Mary has attained an international reputation in areas such as algebra, combinatorics, design of experiments, dynamical systems and statistical mechanics. Whilst the School continues its focus on these traditional areas of strength, it has expanded into new fields such as applied probability and complex systems over the REF period.

The School is structured into the three broad subject disciplines of Applied Mathematics, Pure Mathematics and Statistics. Each of the three disciplines has a Subject Director who provides academic leadership within that section and, as a member of the Head of School's Advisory Group and the Research Committee, helps to shape the School's strategy. The Head of School is aided by the Director of Research in coordinating this process. The Director of Research is a member of the Faculty Research Advisory Group, represents the School within the Faculty and chairs the School Research Committee, which provides recommendations on the School's research strategy, policy and presentation. Until 2011 the Astronomy Unit was part of the School but, in a major realignment during the period, it has been transferred to the newly titled School of Physics and Astronomy. The School is now consistent with UoA 10 and its scope is more aligned with departments in other institutions.

In order to describe the research activity covered by the remit of the UoA, it is convenient to identify a number of research groups which reflect the key strengths of the School: algebra, applied probability, combinatorics, complex systems and networks, dynamical systems and statistical mechanics, geometry and analysis, and statistics. The groups are not formal entities, but define themselves by seminar series, study groups and other activities. The boundaries of these groups are flexible enough to encompass a small number of researchers working in areas such as relativity, computational complexity or logic. Many researchers are active in more than one group.

b. Research strategy

Our overall strategic aim during the REF period has been to pursue the highest quality research whilst cultivating a supportive research environment. The School's objectives were developed within the context of Faculty and College strategic priorities. The following highlights reflect the School's achievements and demonstrate progress against our strategy since RAE 2008:

- Sixteen permanent academic appointments, demonstrating Queen Mary's commitment to investing in the discipline.
- A 30% increase in research grant awards from an average of £770k per year (RAE 2008 period) to £999k per year (REF 2014 period), and a 46% increase in research spend from an average of £515k per year (RAE 2008 period) to £755k (REF 2014 period).
- An increase in the number of PDRFs and PDRAs from 3 at the end of the RAE 2008 period to 9 at the end of the REF 2014 period.
- 36 PhD completions (REF 2014 period) compared to 24 (RAE 2008 period), an increase of 50%.
- The establishment of the Centre for Discrete Mathematics, formed to facilitate interdisciplinary research, including, e.g., PhD students jointly supervised by **Arrowsmith** with Brohi (Blizard Institute), and **Latora** with Panzaraza (School of Business and Management), **Bandtlow** with Chew (School of Electronic Engineering and Computer Science).
- Active participation in Queen Mary's strategic partnership with Warwick University, including the appointment of two Postdoctoral Research Fellows in interdisciplinary fields who are facilitating new collaborations in the rapidly expanding area of discrete mathematics and its applications.

The School has a number of historic core strengths, and our strategy is to build on these at the same time as moving into rapidly developing new fields. New appointments have been made with a view to modernising existing areas, or to moving into topics, such as applied probability and complex systems and networks, which have synergies with our existing strengths. Aside from

rejuvenating our research activity, our staff recruitment strategy is designed to widen our range of expertise. The School's research groups are described below.

Algebra The algebra group has long been central to the School's international reputation. Our aim is to maintain the considerable status of the group, which has been largely built on group theory. At the same time, through ongoing high quality appointments, the research portfolio is being kept up-to-date and diversified into such topics as categorical/derived structures (**Noohi**) and C*-algebras (**Li**). Noohi has already made substantial contributions to the theory of stacks, including two extensive linked articles in *Adv. Math*. Li not only extends the scope of the group but makes links to functional analysis and operator theory. The online ATLAS of Finite Group Representations, developed and curated by **Bray** and **Wilson**, among others, is an important resource for those studying or using finite groups, and a model for the way in which the fruits of a mature research programme can be disseminated to a wide audience.

Applied probability This field was identified as a fruitful direction for expansion, not only by the School itself, but also in an external review of the School's position conducted in March 2010. The group working in applied probability has been substantially expanded since the RAE 2008 through strong new senior appointments (**Fyodorov**, **Gnedin** and **Luczak**). Fyodorov deepens the School's expertise in random matrices, while all three appointments are designed to complement existing interests of the School, e.g., theoretical computer science (specifically, the analysis of randomised algorithms), combinatorics (specifically, the analysis of random structures), and statistical mechanics (e.g., stochastic non-equilibrium processes, interacting particle systems, and large deviation and fluctuation theorems). Luczak is supported by a prestigious EPSRC Leadership Fellowship (to study stochastic models for epidemics in large populations) for four years until 2016, a recognition of her past performance and future potential. In addition to the three chairs, there have been two junior appointments: **Ferreiro-Castilla** in stochastic processes and **Phillips** in random matrices. Although this theme is relatively new to the School, it has an established feel through the creation of a regular seminar series and an inaugural two-day workshop (in collaboration with other groups) in March 2013. It also holds current research grants totalling more than £1m.

Combinatorics The Combinatorics group is amongst the strongest in the UK (which is in turn strong in the worldwide context), and our aim is to maintain that position. It is one of the most productive groups in the UK, with 104 publications in combinatorics listed by MathSciNet for the period 2008 to 2012, placing it second in the UK on that measure. **Cameron** is one of the most prominent combinatorialists in the world, and a long-term chair of the British Combinatorial Committee. His positive influence on the School (e.g., through the running of the influential *Combinatorics Study Group*) continues in an emeritus role. In order to ensure the continued prominence of the group, we have made strong junior appointments in extremal combinatorics (**Ellis**) and in matroid theory (**Fink**); the research of these two goes beyond the boundaries of combinatorics, into theoretical computer science and algebra, respectively. The newly formed Centre for Discrete Mathematics (CDM) promotes the work of the group and provides a platform for funding applications. The CDM, jointly with its sister organisation the Centre for Discrete Mathematics and its Applications (DIMAP) at Warwick, successfully applied for postdoctoral research fellows under the Queen Mary/Warwick Strategic Partnership; one of these (**Falik**) is active in the mathematical foundations of social choice, and the other (**Patel**) is strong in graph theory and algorithms. Both of these strengthen the School's expertise in the computational aspects of the subject. On the more applied side, the group has been actively contributing to the design of experiments (**Soicher**).

Complex Systems and Networks This is a new group, though its origins could already be perceived within the statistical mechanics theme described in the RAE 2008 return. It has been strongly supported through a mix of one senior and three junior appointments (**Latora**, and **Bianconi**, **Danon** [returned to UoA 11] and **Lacasa**). A major theme of the research here is networks, which is currently a very active topic in the UK and worldwide, and one in which the School is shaping up to be a major player. The new appointments are internationally leading, as is evidenced by a strong citation record and invitations to leading conferences. The potential of this new group is confirmed by substantial recent grant awards totalling £530k. The complex systems group comes within the remit of the CDM, and we will exploit the clear connections both with combinatorics and with applied probability.

Dynamical systems and Statistical Mechanics This group was prominent in the RAE 2008 return, and remains one of the bases of the School's reputation. The group ranges from the pure to the applied ends of the spectrum, and has strong interdisciplinary interests extending beyond the School of Mathematical Sciences, e.g., to the School of Biological and Chemical Sciences. Within the School, it fosters research collaborations with Combinatorics (**Prellberg**), Geometry and Analysis (**Jenkinson and Bandtlow**), and Complex Systems and Networks (**Arrowsmith and Beck**). It has fruitful collaborations outside Queen Mary, e.g., with ergodic theorists in Warwick (Pollicott and Sharp). The group has organized numerous large international conferences (with about 100 participants or more), e.g., *Chaos* 2009, *Weak Chaos, Infinite Ergodic Theory, and Anomalous Dynamics* 2011, and *Delayed Complex Systems* 2012. The combined group working at the interface of statistical mechanics and complex systems is one of the largest in the UK, with a research output of about 30 publications per year in high impact factor journals. The group is of strategic importance for the School's research portfolio, reflected by ongoing investments, most notably the recent appointment of **Baule,** who supplements the expertise in the area of nonequilibrium stochastic modelling, with particularly important contributions on fluctuation theorems, shear flows, and nonlinear friction processes. In strategic terms the group has identified the potential for sustained research collaborations with biology, medicine and social sciences, building on work on movement ecology (**Klages**), social behaviour modelling (**Harris**), or the prediction of extreme events and natural disasters (Beck).

Geometry and Analysis A strategic aim of the School is to develop all the core competencies of a first-rate pure mathematics group, and exploit the rich connections between fields. To this end we are developing our strength in the general area of Geometry and Analysis. Recent appointment Reto **Müller** (differential geometry) joins existing staff members **Bandtlow** (operator theory) and **Chu** (functional analysis), while **Li, Majid** and **Noohi** form a bridge with algebra. The development of this theme will continue into the post-REF period.

Statistics This group is relatively small by the standards of the discipline. Nevertheless, it has achieved international recognition by focusing its attention on a particular area, namely the design of experiments. It is one of very few groups in the UK to have specialist knowledge and expertise in this area. The group has specific expertise in the statistical basis for medical trials, and has consulted for Pfizer and Novartis on early phase clinical trials, specifically procedures for determining safe doses for drugs (**Bogacka**).

Although the research of the School has been presented above by subject groups, the boundaries of these are not restrictive. For example, the interface between combinatorics and certain parts of algebra is very permeable; the design of experiments provides motivational examples for combinatorialists, who in turn contribute to the theory of experimental design; and at its more theoretical end, statistical mechanics shades into combinatorics (specifically, combinatorial enumeration). There is a lively programme of seminars across all groups, with around ten series of School seminars meeting regularly, and three series joint with other London colleges: Algebra (with ICL and City University), Topology and Geometry (with ICL and KCL), Analysis and Probability (with ICL, KCL and UCL) and the London-Paris Analysis seminar (with ICL, KCL, UCL and French partners).

A further strategic aim in the REF period was to pursue interdisciplinary research, and this has been a factor in a number of appointments (**Latora**, **Bianconi**, **Danon**). Working across subject boundaries provides inspiration for new mathematics and creates opportunities for generating impact. Many examples of interdisciplinary research are given in Section (d). A prime example of an initiative that crosses the boundaries is the recently formed interdisciplinary Centre for Discrete Mathematics (CDM). Although the Centre is grounded in the School's strong combinatorics group, its steering committee covers a wide range of interests from algebra to computer science (Riis, in the School of Electrical Engineering and Computer Science) and complex systems (Latora). Queen Mary has allocated £40k as a pump-priming exercise to support the early activities of the Centre, which include visiting researchers, workshops and summer schools. The visitors scheme has attracted strong researchers, including D. Mubayi (Illinois), A. Arenas (Rovira i Virgili, Spain), M. Barthelemy (CEA, Saclay, France) and P. Harremoes (Copenhagen).

Within the framework of the Warwick/Queen Mary Strategic Partnership (www2.warwick.ac.uk/about/partnerships/queenmary) the School successfully competed for two

PDRFs in discrete mathematics, one to be based at Queen Mary and one at Warwick. The quality of applicants was such that it was decided to make two PDRF appointments (**Falik,** and **Treglown**, who moved to Birmingham and is to be replaced by **Patel**) at Queen Mary, as opposed to the one originally envisaged. As part of their job-specification, the PDRFs are tasked with promoting joint research activity between the two sites. The CDM is largely complementary to Warwick's DIMAP, and we are collaborating with DIMAP on substantial initiatives, including one-day mini-workshops for PhD students and young researchers working in and around discrete mathematics, and workshops on combinatorial probability and statistical mechanics (one at QMUL, one in Venice).

Our strategy for future development is informed both by internal factors, such as the creation of the Centre for Discrete Mathematics, and external factors, such as the increasingly competitive academic world, admission to the Russell Group and the strategic partnership with the University of Warwick. The School has developed, for the post-REF 2014 period, a strategy which includes the following key aims:

- To sustain our traditional strengths in core mathematics, and strengthen where necessary (for example, in Geometry and Analysis), whilst also identifying and securing investment for emerging areas.
- To continue expanding our cohorts of post-doctoral and PhD researchers.
- To support ECRs in establishing their careers and making an impact on the subject.
- To exploit the Centre for Discrete Mathematics as a catalyst for interdisciplinary research, and as a platform to attracting research funding.
- To focus attention on real-world solutions for global challenges, capitalising on the expertise in our complexity and networks group.
- To consolidate our strategy for identifying and monitoring impact arising from our research.
- To expand existing research collaborations with industrial partners.
- To build upon our joint activity with the School of Medicine and Dentistry by engaging with and exploiting opportunities associated with Queen Mary's Life Sciences Institute. The Institute will establish a unique cluster of expertise across its East London campuses by focusing on the basic sciences underpinning medicine.

c. People, including:

i. Staffing strategy and staff development

Since 2008, the School has been engaged in an intensive period of appointing new academic staff. Of the staff in post at the REF census date, no fewer than sixteen, representing about a third of the current academic staff of the School, were appointed since RAE 2008. Whilst reinforcing our professorial complement where necessary, our strategy has been to reshape the School's age profile and ensure long-term sustainability; thus, twelve of the sixteen new appointments are lectureships, and nine of these are ECRs. Senior appointments (**Fyodorov**, **Gnedin**, **Latora** and **Luczak**) have been made in accordance with our strategy of identifying and developing new areas. In addition to the permanent staff, two research fellows have been appointed for three years under the Queen Mary/Warwick Strategic Partnership. The scale of the appointments signals the commitment of the School to fostering new talent and developing the next generation of research leaders. Within the period, six Professors, three Professorial Fellows, and three Senior Lecturers have retired and four staff have joined other institutions (Touchette to the National Institute of Theoretical Physics, Stellenbosch, Gilmour to Southampton and Keevash and Ardakov to Oxford).

Support for new/early career staff

Support offered to all new/early career staff includes mentoring, lighter teaching and reduced administrative duties (typically a half teaching load in the first year and a reduced load overall in the second), and financial support for travel and equipment. A comprehensive training programme (the Postgraduate Certificate in Academic Practice) is offered by Queen Mary's *Centre for Academic and Professional Development*, supplementing mentoring from a senior colleague. Areas addressed by these measures include research strategy, PhD student supervision, and support activities such as applying for and managing research grants. New staff are set probation objectives in teaching, research and supporting activities such as applying for grants, and regular

meetings are held to support staff development. In addition, new staff receive double the standard allowance for travel (£1k per year during their three-year probation) to encourage networking and development. Queen Mary was shortlisted for a THES Award in 2011 for offering outstanding support to early career researchers.

Support for established staff

Established academic staff have a generous entitlement to regular sabbatical leave (subject to the academic merits of their application), at the rate of one year in seven. Sabbatical leave is regarded as important to personal and career development, particularly with regard to generating high quality research. During the REF period, the average proportion of eligible staff on sabbatical at any time was 11%. A workload allocation model is maintained on an annual basis by the Head of School, which acknowledges and allows credit for responsibilities such as PhD supervision and allocates time on funded grants. The typical teaching load of two modules per year allows staff to devote considerable time to research. Annual appraisals are used to assist academic staff in their career and personal development, identifying the necessary support and training required for advancement. Staff are also able to undertake skills training with the Centre for Academic and Professional Development. During the REF period there were five promotions from Lecturer to Senior Lecturer, five from Lecturer to Reader, and one from Reader to Professor. Queen Mary is committed to the seven principles enunciated in the Concordat to support the career development of researchers. In 2012, Queen Mary received the European Commission's HR Excellence in Research Award in recognition of our Concordat Implementation Plan.

Equality and Diversity

A key part of Queen Mary and School strategy is to promote equality and diversity. The School is actively engaged in advancing its position with respect to the Athena SWAN Charter. This effort was recently recognized with a Bronze Award, and an Athena SWAN Committee, led by an academic champion, will now ensure that we deliver on our objectives in this area. Queen Mary is a member of the Stonewall Diversity Champions programme, which assists employers in improving the workplace environment for lesbian, gay and bisexual staff. Staff and research students are also invited to contribute to the Faculty WISE (Women in Science and Engineering) initiative, which is a networking group aimed at enhancing the role of female participation across all aspects of STEM.

Fellowships

Academic staff have been successful in winning personal fellowships: **Ardakov (**Leverhulme Early Career Fellow, 2007 – 10), **Baule** (Levich Fellow, Benjamin Levich Institute, The City College of New York, Sept 2010 – Aug 2011; Postdoctoral Fellow, Dana-Farber Cancer Institute, Harvard School of Public Health, Jun 2010 – Aug 2010), **Danon** (Leverhulme Early Career Fellow Oct 2011 – Sept 2014), **Ellis** (Junior Research Fellow in Pure Mathematics, St Johns College, Cambridge, Oct 2009 – Aug 2011), **Ferreiro-Castilla** (Royal Society Newton International Fellow Jan 2012 – Oct 2013), **Fyodorov** (Leverhulme Senior Research Fellow Jul. – Dec. 2008), **Jenkinson** (EPSRC Advanced Research Fellow, Oct 2003 – Sept 2008), **Luczak** (EPSRC Leadership Fellow, Oct. 2011 – Sept. 2016), **Majid** (Leverhulme Senior Research Fellow 2009 – 10), **Touchette** (Roberts Interdisciplinary Academic Fellow Jan 2006 – Dec 2011), **Valiente-Kroon** (EPSRC Advanced Research Fellow Oct 2005 – Sept 2010). The School has also attracted independent research fellows to Queen Mary, enriching the research environment: **Evseev** (EPSRC Postdoctoral Fellow Feb 2010 – Oct 2011), **Sisask** (EPSRC Postdoctoral Fellow Oct 2009 – Sept 2011), **Treglown** (Queeen Mary/Warwick strategic partnership Sept 2012 – Aug 2013)**, Falik** (Queen Mary/Warwick strategic partnership Dec 2012 – Nov 2015), and **López Peña** (Marie Curie Jan 2009 – Aug 2010),

Distinguished international visitors

Many distinguished international figures visited the School during the REF period including: A. Avila (Paris 7), L. Babai (Chicago), J. Conway (Princeton), P. Le Doussal (ENS, Paris), Ph. Flagolet (INRIA, Rocquencourt), M. Gell-Mann (Santa Fe), S. Majumdar (Paris Sud), C. Krattenthaler (Vienna) L. Pastur (Kharkov) D. Ruelle (IHES), R. Sedgewick (Princeton), A. Sokal, NYU/UCL, B. Sudakov (UCLA), A. Vershik (Steklov) and G. Whittle (Wellington).

ii. Research students

Recruitment and funding

Queen Mary aspires, through its Strategic Plan 2010-15, to a doubling in PhD student numbers, and the School is also pursuing an increase in numbers to further enhance our vitality and sustainability. As funding from traditional sources such as research councils decreases, the School has responded by seeking new funding streams and new sources of potential students. For example, two students starting in 2011 were funded by the China Scholarship Council (CSC), a route not previously exploited by the School. (Across all disciplines, the CSC supports more research students at Queen Mary than any other UK university.) In 2012 we leveraged external funding matching financial support from the School itself; the intake in academic year 2012–13, at 18 students was the largest ever seen by the School. Although we place greater emphasis on advertising now, our recruitment strategy still relies on contacts, both formal (e.g., with CMS, Cambridge), and informal. All these efforts led to a steady increase of the total number of PhD students over the past couple of years: from 32 in 2010 and 2011 to 43 in 2012, and to around 50 in 2013. Our completion rate is also on a strong upward trend, from 60% for the cohort starting in 2007 to 75% for the one from 2008, and the percentage of the cohort starting in 2009 is expected to be even higher, with the aim being for 85% completion (within four years) for students starting in 2013.

Training and support

The School participates actively in the London Taught Course Centre (LTCC). Academic staff are involved in both the delivery of courses and in strategic decision making at LTCC. All first-year postgraduate research students are required to attend, and be examined upon, four courses (a total of 30 credits). As an alternative, students may attend level 7 courses from the MSc/MSci programme, where relevant to their studies. Students are expected to participate in the School's regular seminar series in topics of relevance to them. They are also required to undertake a significant amount of transferable skills training per year, such as computer skills, mathematical typesetting, language skills, communication skills, and aspects of teaching. Students need to meet a target of 210 hours of taught courses and transferable skill activities, including the attendance of regular seminars, conferences and workshops. An over-arching Doctoral College was established at Queen Mary in September 2012. Its activities aim to ensure that all postgraduates meet the research training expectations of EPSRC.

The students themselves run a regular series of Internal Postgraduate Seminars (QuIPS), which provides them with early experience in presenting advanced mathematical ideas. Students have additional opportunities to practise and test their presentational skills at the annual Postgraduate Research Day. All second-year students produce a poster on their work and its context, while all third-year students give a 20-minute presentation on their research. Students are strongly encouraged to attend instructional conferences, particularly the LMS-EPSRC short courses. We also encourage and support them to attend research meetings at home and abroad. For students who would benefit from study at another institution for a longer period with an expert their area, there is the Eileen Eliza Colyer Prize, partly funded by a gift from alumnus Alan Camina.

Students are expected to undertake paid work (four hours per week during semester) in marking and teaching support, and are given the opportunity to conduct exercise classes for undergraduate students. Relevant training sessions are provided in-house, and also by Queen Mary's *Centre for Academic and Professional Development.* The School annually hosts a PG Teaching Workshop run by the Maths, Stats and OR Network (recently taken over by the Higher Education Academy). This workshop is also attended by PhD students from other institutions, and has been very well received by our students. The students are also supported in outreach activities. For some years, many of our students have been involved in a funded project to introduce schoolchildren to university-level mathematics, which involves bringing 15–20 teenagers to the School over a period of six days. This initiative has been developed and delivered by the PG students themselves.

Postgraduate research students are an integral part of our research community and are involved in many aspects of the School's business, from representation on committees and attendance at seminars to inclusion in social activities.

Monitoring progress

In addition to supervisors, postgraduate research students are overseen by a Director of Postgraduate Research Studies who chairs a co-ordinating committee, which includes student representation. All students have a second supervisor in the same general field as the first. From

2013, supervisors are required to undergo bespoke in-house training for the role, with periodic refresher sessions. Students are allocated two assessors (different from the first supervisor), whose role is to monitor progression and propose remedial action should that seem necessary. There is a review meeting at the end of every year, the outcome of which is a report to the PG tutor recommending progression or further actions that need to be taken in order to enable progression. Results of the LTCC exams are fed into the first-year review. In order to help students to complete within four years, we have recently introduced six-monthly reviews after the third year.

d. Income, infrastructure and facilities

Context

The School is accommodated within a single building which has benefitted from substantial improvements over the period, most obviously the £2.7m remodelling of the entrance area and refurbishment of the main lecture theatre, which has a capacity of 135. In addition, a range of other teaching spaces are provided, plus refurbished study space for postgraduate students. The School has a policy of allocating a personal desk and a desktop computer to every research student. Academic staff are housed in single occupancy offices, postdoctoral researchers and long-term visitors have shared offices. With the relocation of the Astronomy Unit by September 2014, the School will propose ambitious plans for the building and secure investment from the College to further enhance our space and support future expansion of both academic staff and postgraduate students.

Since RAE 2008, the School's professional support services have undergone major restructuring. The Head of School is now supported by a dedicated full-time School Manager, while the research activities of the School are co-ordinated by a Research and Enterprise Manager. The new structure allows the Head of School, along with the Director of Research, to concentrate on strategic issues, and academic staff to be fully supported across their portfolio of activities. In addition to the School-based support, staff also have the opportunity to work with central College services to support their research, including Queen Mary Innovation to exploit research and a Business Development team to support the development of relationships with industry. We also collaborate with the Queen Mary Centre for Public Engagement, to ensure that our research is reaching wider society.

Research Funding

The School recognises that its aim of recruiting excellent academic staff and optimising their productivity is contingent on attracting adequate research income. Therefore it promotes a culture which celebrates and supports the acquisition of grants, postdoctoral researchers and research students. Submitting competitive research grant applications is an explicit criterion for negotiating probation and securing promotion in the School.

Research grant awards increased 30% from an average of £770k per year in the RAE 2008 period to £999k per year during the REF 2014 period. Research grant expenditure rose 46% in the same period from £515k to £755k per year. Although all groups are expected to raise research grant income, it is a strategic aim of the School to respond in particular to the demand for interdisciplinary research. Among the topics currently funded by substantial current grants/fellowships (active for all or part of 2013) are: applied probability/healthcare (EPSRC, £822k), complex systems (EPSRC, £241k + £355k and ERC, €345k), computational complexity (EPSRC, £355k), extremal combinatorics (EPSRC, £329k and ERC, €780k), and random matrices (EPSRC, £366k).

RAVEN (*Resilience, Adaptability and Vulnerability of complex Energy Networks*) is an EPSRC-funded project that develops tools to measure, design and analyse large critical infrastructure networks (**Arrowsmith**). Two programmes of research in Extremal Combinatorics, an area of mathematics that combines accessibility and depth, are supported by substantial ERC and EPSRC grants (**Keevash**). *Insights into Disordered Landscapes…* is an EPSRC-funded project that explores statistical properties of random landscapes using tools and results from random matrix theory combined with concepts from statistical mechanics (**Fyodorov**). The EPSRC fellowship *Stochastic models for epidemics in large populations…* studies stochastic models for the spread of epidemics, and seeks answers to questions about the growth and long-term behaviour of epidemics in a population (**Luczak**). The EPSRC project *Computational Counting* investigates the computational complexity of counting problems, a less well understood area than the more classical decision and optimisation problems (**Jerrum**).

A notable feature of several grants is that they fund interdisciplinary research bringing together a consortium of institutions with diverse expertise. *MANMADE* was an EC Pathfinder programme to apply complex systems analysis to the protection of strategic infrastructure. With over €1M of EU funding, the project was coordinated by Queen Mary (**Arrowsmith**, **Carvalho**, **Just** and **Touchette)** and had six international partners. Flood MEMORY (*Multi-Event Modelling of Risk and Recovery*) is large (£1.7m in total) EPSRC-funded project bringing expertise from 11 UK universities/institutes to bear on critical flood scenarios caused by clusters of extreme weather events. Within this, **Beck** leads a work package employing superstatistical techniques to analyse of historical time series data. **Großmann** was co-investigator on the EPSRC-funded discipline-bridging project *Building a New Community: Modelling, Visualisation and Verification of Large Scale Systems,* a £248k EPSRC project bringing a multidisciplinary approach to the study of large-scale sytems. LASAGNE (*multi-LAyer SpAtiotemporal Generalized NEtworks*) is a three-year project funded by the EU FP7 to develop a coherent framework for analysing and modelling multiplex networks (i.e., networks with multiple types of connections) embedded in space and time. The project involves researchers from seven sites across Europe, including Queen Mary (**Latora**). GALE (*Global Accessibility to Local Experience*) is an EPSRC project bringing together three sites. It explores the potential to use data harvested from mobile phones and online social networks to deliver advice that closer to that provided by a local human guide than a book guide (**Latora**). Funded by the EPSRC, the REFLECT project (total £781k) is an interdisciplinary collaboration of researchers from six UK universities/institutes and one Danish university. The aim is to encourage people to reflect on their regular travel experiences and to investigate whether this will promote behaviour change. The mathematical aspects of this work include advanced data analysis and modelling of complex networks (**Harris**).

e. Collaboration or contribution to the discipline or research base

Research collaborations

Many members of the department made extended visits for collaborative research during the REF period. **Arrowsmith** visited the European Commission (EC) Joint Research Centre, Ispra, Italy, Oct – Dec 2011. **Bandtlow** held several one-month-long visiting positions (professeur invité) at the University of Cergy-Pontoise in July 2009, 2010 and 2011, and at the University of Nice in May 2011. **Ellis** was a full-time participant in the IPAM Long Program *Combinatorics: Methods and Applications in Mathematics and Computer Science* at UCLA, Sept – Dec 2009, then visiting researcher Jan, Feb 2010. **Goldsheid** was visiting fellow at the Fields Institute,Toronto Apr/May 2011. **Harris** was invited Professor at Université Henri Poincaré, Nancy for a total of several months between 2008 and 2011. **Johnson** was a funded visitor to the Alfréd Rényi Institute of Mathematics Budapest, to the University of Umeå, and to Tel Aviv University. **Prellberg** is Associate investigator of the ANC-funded Centre of Excellence in Mathematics and Statistics of Complex Systems, and Ausserplanmäßiger Professor at Clausthal University of Technology. **Touchette** visited the Laboratoire de Physique, ENS Lyon, Sept – Nov 2011, the Laboratoire de physique théorique de la matière condensé, Université Paris VI, Dec – Jan 2012, and the National Institute for Theoretical Physics, Stellenbosch, Feb – Apr 2012. **Bailey**, **Beck**, **Bogacka**, **Cameron**, **Fyodorov**, **Gilmour**, **Goldsheid**, **Großmann**, **Jackson**, **Jerrum**, **Khoruzhenko and Maruri-Aguilar** were all long-term participants (and several of them organisers, see below) of INI programmes.

The following are further examples of funded research collaborations. **Cameron** and **Jackson** are co-investigators with G. Farr, D. Delbourgo and K. Morgan from Monash University on an ARC-funded project to study algebraic properties of chromatic polynomials, 2011 – 14. **Klages** has an EPSRC-funded collaboration with A. Chechkin (Kharkov, Ukraine), and P. Dieterich (Dresden); the latter also supported by the LMS. From Jan 2007 – Dec 2009 **Vivaldi** was co-investigator with Roberts (UNSW, Sydney) and Baake (Bielefeld) on an ARC-funded project "Algebraic Dynamics" The award was AU$280,000 (about £170,000).

Interdisciplinary research

In addition to the examples given in Section (d), **Klages** won an EPSRC-funded discipline-bridging grant *Anomalous dynamics of foraging bumblebees.* **Beck** collaborated with the Harvard Medical School, the European Space Agency Paris, and the Research Center “Demokritos” Athens, and **Harris** was co-investigator on an £10,239 EPSRC-funded discipline-bridging project on *modelling*

of fluctuations in ion channels with M. Baker (Queen Mary Neuroscience).

Collaboration with research users

Bandtlow was part of a three-way collaboration with Tanner (Nottingham) and a Nuremberg-based company inuTech (including a three-month visit in 2011) devoted to predicting vibrational energy spectra. **Gnedin** had a project with Dutch bank SNS Reaal, and a consultancy for Gasunie concerning extreme-value analysis. **Jackson** collaborates with Owen (Siemens) on radical solvability of frameworks. **Maruri-Aguilar** has collaborated with industry partners GlaxoSmithKline and Rolls Royce on two separate analyses of simulation models. **Bullett** (2009–10), **Stark** (2010–11) and **Walters** (2011–12) were seconded to the Heilbronn Institute for one-year periods, to spend 50% of their time on classified research.

Leadership in the academic community

We note the following exemplars of external recognition: Best paper award (with L. Goldberg, Oxford) at *Intl Colloq. On Automata, Languages and Programming*, Bordeaux, July 2010, and again at Warwick, July 2012 (**Jerrum**), European Prize in Combinatorics, 2009 (**Keevash**). Fellow of the Royal Society, Elected to Academia Europeae, Doctorate Honoris Causa, Edinburgh, 2011 (**Macintyre**). We also note the following services to the community: Member of the EPSRC Mathematical Sciences Strategic Advisory Team 2010–present; chair of the Heads of Departments of Mathematical Sciences (**Arrowsmith**). Co-organisers of the research programmes *Design of Experiments* and *Design and Analysis of Experiments* at INI in 2008 and 2011 (**Bailey**, **Bogacka**, **Gilmour**, **Großmann**, **Maruri-Aguilar**). Co-organiser of the programme *Combinatorics and Statistical Mechanics* at INI, 2008 (**Cameron**, **Jackson**). Organiser of international conference *Jordan theory and Analysis* at the National Center for theoretical Sciences, Taiwan, 2010 (**Chu**). Co-organisers of the programme *Mathematics and Physics of Anderson localization* at the INI, 2008 (**Fyodorov**, **Goldsheid**). Conference program chair for ANALCO 2012 (**Gnedin**). Secretary of the Business and Industrial Section of the Royal Statistical Society for about 3 years (**Großmann**). Member of the Pure Mathematics subpanel for the RAE 2008 (**Jerrum**, **Macintyre**). Member of the ICMS Scientific Committee (**Luczak**). President of the London Mathematical Society 2010–11, and member of the ERC peer review panel for Mathematical Foundations (**MacIntyre**). Invited article "Quantum groups" in the *Princeton Companion to Mathematics,* 2008 (**Majid**). Programme Secretary of the LMS (**Wilson**).

The following is a selection of invited presentations at major meetings during the REF period: Plenary speaker at ICM Satellite Conference *Functional Analysis and Operator Theory* at the Indian Statistical Institute, Bangalore, 2010 (**Chu**). Invited speaker at *Stat. Phys. 25,* Seoul 2013 (**Fyodorov).** Minicourses at *Thermodynamic formalism and applications,* Santiago, 2013, and *Ergodic Optimization & Related Fields,* Sao Paolo, 2013 (**Jenkinson**). Plenary lecture the *British Combinatorial Conference*, Exeter, 2011 (**Keevash**). Plenary talks at the ESF Workshop on *Quantum Geometry and Quantum Gravity*, Nottingham, 2008 and the *Intl Congress on Non-associative Algebras and Related Topics*, Coimbra, Portugal, 2011 (**Majid**). Invited lecture series at interdisciplinary international summer schools in at ESI, Vienna, 2008, and University of Oldenburg, Germany, 2011 (**Prellberg**). Plenary talk at the Spanish Relativity Meeting, Granada, Spain, 2010 (**Valiente-Kroon**). Invited Lecturer at the Summer School on Dynamical Systems at Göttingen University, 2011 (**Vivaldi**).

Various members of staff serve on the editorial boards of academic journals: *Chaos Solitons Fractals* and *Physica A* (**Beck**), *Stat. Methods Appl*. (**Bogacka**), *Asian-Eur. J. Math.* (**Chu**), *J. Stat. Plann. Inference* (**Coad**), *Adv. Appl. Prob., J. Appl. Prob., Latin Amer. J. Prob. Stat*., *Prob. Surveys* and *Stochastics* (**Gnedin**), *Bull., J*., *Proc.* and *Trans. LMS* (**Jenkinson**), *Combin. Probab. Comput.* and *Random Structures Algorithms* (**Jerrum**), *Chaos*, *Journal of Complex Networks* (**Latora**), *Electron. J. Probab., Electron. Comm. Prob.* and *Stochastics* (**Luczak**), *Oxford Logic Guides*, *Selecta Mathematica*, *European Journal of Mathematics*, *Journal of Mathematical Logic*, *Springer Undergraduate Mathematics Series*, *Quarterly Journal of Mathematics*, *Unione Matematica Italiana Lecture Notes* (**Macintyre**), *Int. J. Geom. Methods Mod. Phys* (**Majid**), *Abh. Math. Semin. Univ. Hamburg, J. Algebraic Combin.* (**T. Müller**).