Isaac Newton Institute
for Mathematical Sciences

Annual Report
2014–15

UNIVERSITY OF CAMBRIDGE

Contents

Director's Foreword

John Toland
Director

Throughout 2014 I had the opportunity to view the diversity of the UK's mathematical sciences research base nationwide, not only from the perspective of the INI Director, but also as chair of the REF (Research Excellence Framework) panel[1] charged by the higher education funding councils with assessing it.

The REF assessment exercise is a reflection of the research infrastructure, nationwide and across all disciplines, in which INI now operates. On impact, it is recognised that the time between mathematical research and its effect outside universities is often long, pathways are usually unclear and auditing an impact trail can be challenging. Nevertheless the quality, originality, reach and significance of mathematical impact case studies was found to be very impressive and representative of all the branches of the mathematical sciences

It is therefore worth noting that since its foundation INI has taken a similar holistic view of the mathematical sciences including their application and I am in no doubt that it contributed significantly to the inter- and intra-disciplinary quality of many REF submissions.

It was under the direction of Sir Michael Atiyah OM, the Institute's first Director, that in 1992 that the course was set: to address fundamental mathematical challenges and to encourage the development of mathematical perspectives on applications beyond traditional areas. Thus in 1993, when Andrew Wiles was presenting his work on Fermat's Last Theorem at the programme on L-functions, INI was simultaneously

running a programme on epidemics, including AIDS. Nowadays, in addition to strictly mathematical areas such Grothendieck–Teichmüller groups, random geometry, moduli spaces and set theory, INI deals with mathematical challenges from an overwhelming variety of applications: nano- and quantum-technology, biology, genetics, space science, earth science, climate science, social science, decision science, information science, materials science, imaging science, forensic science, economics, finance, big data analytics and the design of experiments for drug trials being some recent examples. In doing so it covers ground that is dealt with by seven or eight institutes in the United States. I am pleased to report that Sir Michael was guest of honour at the INI Annual Dinner held at the Royal Society in December.

INI continues to innovate, to keep ahead of the curve. The practice of seeking out programmes judged to be scientifically excellent, with the potential for significant long-term research influence as judged by international peer review, is paramount and will continue. But recently INI has developed an impact acceleration arm, the *Turing Gateway to Mathematics (TGM)*, to act as a conduit through which mathematical knowledge passes from academia to users, and through which, in the opposite direction, users bring mathematical questions to academics. Already the engagement by users of mathematics suggests that the Turing Gateway is tapping into an area where there is huge unmet demand and many opportunities. As described in greater details in the TGM Annual Report, included with this volume, much of this Knowledge Transfer activity is funded externally.

It is a special pleasure for me to congratulate the Chair of the INI Management Committee, Howard Covington, on his appointment as Chair of the Board of the new *Alan Turing Institute* which, located at the British Library in London, specialises in Big Data analytics. In recent years Howard has played an essential part in developing the profile of the Isaac Newton Institute and will no doubt enjoy further success in his important new national role.

Samantha Skehel

This year also there has been a significant churn of INI staff. In particular, Christine West, the Institute Administrator for 15 years, resigned. Her successor, Samantha Skehel from the Laboratory of Molecular Biology came into post on 1st June and I wish her well with her new responsibilities.

INI is an important national facility that helps maintain the UK's international position at the forefront of research in fundamental mathematics and in subjects allied to mathematics. There have been many events at INI through the year (some of which are detailed in this report), but I mention here a few.

In January, Barry Simon (California Institute of Technology), gave a series of eight lectures[2] during the *Periodic, Almost-Periodic, and Random Operators Instructional School* (see page 12) aimed at graduate students and recent PhDs which were so popular that an overflow video room had to be deployed. An additional public evening lecture by Barry entitled *Tales of our Forefathers*[3] provided an interesting historical context for the scientific programme.

Barry Simon during one of his lectures on Orthogonal Polynomials

In March, Dr Rebekah Higgitt from the University of Kent, gave a wonderful presentation, *Longitude Found!*[4] at INI as part of the Cambridge Science Festival. Rebekah explained how 250 years ago, the men of the Board of Longitude sat around a table to discuss how to spend life-changing sums of government money with tales of challenges, rewards, skull-duggery and sailors lost at sea. The lecture was illustrated with a variety of beautiful images from the National Maritime Museum collections (where Higgitt was a curator for 5 years).

As part of the workshop *Monitoring Systemic Risk: Data, Models and Metrics* (see page 10), Nobel Prize-winning economist Professor Robert Engle delivered a lecture *The Prospects for Global Financial Stability*[5]. In it he discussed how the failure of a single institution to meet its financial obligations can have serious

Robert Engle

Rebekah Higgitt explaining the story of longitude to the Cambridge Science Festival audience

consequences for the entire economy. He introduced the term 'SRisk', that is the amount of capital that a financial institution would have to raise in order to function normally through another financial crisis, and discussed the merit of a 'living will' for companies to ensure, in future, that they would not need rescuing.

These, and all other INI lectures, subject to speaker permission, are recorded and available to view on the web in perpetuity.

I hope that you enjoy reading the rest of the report.

John Toland

[1] www.ref.ac.uk
[2] See www.newton.ac.uk/seminar/20150106090010001
[3] See www.newton.ac.uk/seminar/20150112170018301
[4] See http://sms.csx.cam.ac.uk/media/1935784
[5] See www.newton.ac.uk/seminar/20140926113012151

Science at the Institute

CM Marr

Valerie Isham
*Chair of the Scientific
Steering Committee*

The goal of INI is to serve the research community in the UK by being, and being seen to be, a world-leading research centre that habitually identifies and organises original research programmes of high potential for impact at an international level across the widest possible range of mathematical sciences. The Scientific Steering Committee has the task of identifying the most promising proposals from among all those received and recommending acceptance or rejection of proposals on the basis of authoritative referees' reports. This is a challenging role because a large volume of high quality proposals in disparate areas makes comparative judgements extremely difficult. Nevertheless, I am happy to report that the committee, which is comprised of distinguished individuals with their own specialist interests, conducts itself in a professional and entirely non-partisan way.

On behalf of INI, and all its programme organisers and participants, I want to thank John Lygeros (ETH Zürich), Gert-Martin Greuel (Kaiserslautern & Oberwolfach), Sylvia Richardson (MRC Biostatistics, Cambridge) and Richard Thomas (Imperial College), whose service on the committee has come to an end, for their support, guidance and unfailing good humour.

Scientific Steering Committee

Membership of the Scientific Steering Committee at 31 July 2015 was as follows:

Name	Institution	End of Service
Professor Helen Byrne	University of Oxford	31 Dec 2017
Professor Steve Cowley	Atomic Energy Authority	31 Dec 2016
Professor Wolfgang Dahmen	Aachen	31 Dec 2018
Professor Gert-Martin Greuel	Karlsruhe	31 Dec 2015
Professor Michael Harris	Institut de Mathématiques de Jussieu	31 Dec 2016
Professor Valerie Isham (Chair)	University College London	31 Dec 2017
Professor Saul Jacka	University of Warwick	31 Dec 2018
Professor Marta Kwiatkowska	University of Oxford	31 Dec 2018
Professor John Lygeros	ETH Zürich	31 Dec 2015
Professor Sylvia Richardson	University of Cambridge	31 Dec 2015
Dr Emily Shuckburgh	British Antarctic Survey	31 Dec 2016
Professor Richard Thomas	Imperial College, London	31 Dec 2015
Professor John Toland	Director, Newton Institute	30 Sep 2016
Professor Cédric Villani	Institut Henri Poincaré	31 Dec 2015
Professor David Abrahams (*in attendance*)	ICMS	–

The Scientific Steering Committee (SSC) meets twice each year to consider proposals for programmes (of 4-week, 4-month or 6-month duration) to run two or three years later. Successful proposals are usually developed in a discussion between the proposers and the SSC conducted through the Director, and may well be considered at more than one SSC meeting before selection is recommended. Complete details of the Institute's regular call for proposals, including guidelines for submission, can be found on the Institute's website at **www.newton.ac.uk/science/proposals**.

Current and Future Programmes Schematic

| JAN | | JUL | SEP | DEC |

2014

Free Boundary Problems and Related Topics

Theory of Water Waves

Understanding Microbial Communities: Function, Structure and Dynamics

Inference for Change-Point and Related Processes

Mathematical, Statistical and Computational Aspects of the New Science of Metagenomics

Advanced Monte Carlo Methods for Complex Inference problems

Interactions between Dynamics of Group Actions and Number Theory

Quantum Control Engineering

Systemic Risk: Mathematical Modelling and Interdisciplinary Approaches

2015

Periodic and Ergodic Spectral Problems

Metric and Analytic Aspects of Moduli Spaces

Mathematical, Foundational and Computational Aspects of the Higher Infinite

Random Geometry

Coupling Geometric PDE's with Physics for Cell Morphology, Motility and Pattern Formation

2016

Stochastic Dynamical Systems in Biology: Numerical Methods and Applications

Probability and Statistics in Forensic Science

Mathematical Aspects of Quantum Integrable Models in and out of Equilibrium

Melt in the Mantle

Gravity, Twistors and Amplitudes

Theoretical Foundations for Statistical Network Analysis

For a trial period with, effect from July 2016, INI will be running three programmes in parallel.

Data Linkage and Anonymisation

2017

Non-Positive Curvature: Group Actions and Cohomology

Nonlinear Water Waves

Variational Methods and Effective Algorithms for Imaging and Vision

Homology Theories in Low-Dimensional Topology

Scalable Inference; Statistical, Algorithmic, Computational Aspects

Mathematics of Sea Ice Phenomena

Operator Algebras: Subfactors and their Applications

Big Proof

Growth, Form and Self-Organisation

Key: nominal programme duration | 6 months | 4 months | 6 weeks | 4 weeks

Theory of Water Waves

14 July to 8 August 2014

www.newton.ac.uk/event/TWW/

Report from the Organisers:
Tom Bridges (*Surrey*), Mark Groves (*Saarland*), Paul Milewski (*Bath*) and David Nicholls (*Illinois at Chicago*).

Waves on the surface of the ocean are dramatic and beautiful phenomena that impact on every aspect of life. At small length scales, ripples affect remote underwater sensing. At intermediate scales, waves on the surface and at the interface between layers of water of differing densities affect shipping, coastal morphology, and near-shore navigation. At larger scales, tsunamis and hurricane-generated waves cause devastation. At all scales, they play a crucial role in the exchange of momentum and thermal energy between the ocean and atmosphere which, in turn, affect global weather systems and climate.

> ❝ **Mathematically, the water-wave equations are famously very difficult**

However mathematically the water-wave equations are famously very difficult and challenges raised by participants at the programme

FACT FILE

Total participants on programme and workshops: **85**

Gender Balance:
Male: **71** Female: **14**

outset included: wave stability; numerical methods; wave breaking and singularities; resonances; spatial dynamics; 2D and 3D solitary waves; modulation theory; wave-current interaction; normal forms; waves with vorticity; bottom topography; 3D standing waves; shallow water hydrodynamics; well-posedness and validity; non-local formulations; wind-wave interaction. Although the programme was short, some highlights were its discussions of:

- jet currents, explaining the large waves associated with the Agulhas current;

- 2D and 3D solitary waves and high performance numerics for 2D- and 3D- large amplitude periodic standing waves;

- a dynamic cascade phenomena generated by a Benjamin–Feir instability;

- self-similar waves with acute crest angles;

- numerical methods for time-dependent problems;

- stability;

- numerical and experimental results on breaking, splashing, and singularities;

- extending results for non-linear Schrödinger equations (NLS) to 3D using Clifford analysis;

- rigorous results on large amplitude travelling waves with vorticity.

As part of the *Water Waves in Industry* Day, a talk from Aquamarine Power in Belfast was relayed live to the programme in Cambridge and was followed by reports on other successful academia-industry interaction in the area of wave energy harvesting.
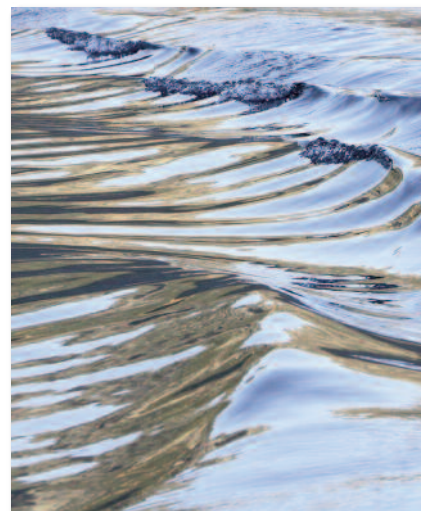
In a forward-looking session, topics identified for future work included: post-instability dynamics; the importance of well-posedness particularly for truncated models; the need for global well-posedness to validate nonlinear stability of solitary waves; what models and equations are appropriate for breaking, splashing, entrainment, and bubbles; a hierarchy of models and formulations; an encyclopedia of known results (analytical, numerical, rigorous) on all steady and time-periodic waves and their stability; new numerical methods and comparisons between different methods; any theoretical development on (a) wind-wave interaction, (b) three dimensional waves of every shape and form, (c) extreme waves, and (d) any type of breaking waves.

A blog ran during the programme to record informally accounts of talks and discussions, and to share with researchers around the world of the atmosphere at the programme. There were three introductory and tutorial events and a Summer School at which the speakers agreed to provide lecture notes which will be combined into a book.

Quantum Control Engineering: Mathematical Principles and Applications

21 July to 15 August 2014

www.newton.ac.uk/event/QCE/

Report from the Organisers:
John Gough (*Aberystwyth*),
Madalin Guta (*Nottingham*),
Matthew James (*Canberra*),
Hideo Mabuchi (*Stanford*) and Ian
Walmsley (*Oxford*).

At the dawn of a new technological era when systems performance may be limited by quantum mechanical effects and it is becoming possible to exploit non-classical phenomena in novel ways, there is considerable interest in quantum control engineering. At the same time it has become clear that a sound mathematical framework is needed to develop quantum control as an engineering discipline.

This programme was therefore designed to bring together specialists from various disciplines to work on quantum control with particular emphasis on the underpinning mathematics: quantum stochastic calculus, quantum open systems modelling, quantum statistics and estimation. The programme differed from other quantum control meetings insofar as it focused on feedback – both theoretical and experimental. Indeed, one of the most valuable of its outcomes was the extent to which participants began to understand how classical feedback control theory gives a foundation on which to better understand current developments in quantum control, system identification and parameter estimation.

There were tutorial lectures during the first two weeks, giving an account of the state-of-the-art, and an outline of the main challenges in the field. Lectures about experimental topics such as superconducting microwave networks, circuit QED systems, photonic networks, and non-linear

superconducting qubits led to collaboration with theorists and an exploration of new proposals for hybrid quantum systems. This theme was pursued during the workshop *Principles & Applications of Control to Quantum Systems* when further experimental set-ups that are now amenable to quantum control, such as ion traps, opto-mechanical systems, superconducting qubit systems, magnon modes, and nitrogen-vacancy (NV) centres in diamonds, were presented. Several topics (integrated quantum optics being a prime example) became better understood and the programme enabled experts to share recent progress in a manner that would not have been possible in a standard conference setting.

> **" It has become clear that a sound mathematical framework is needed to develop quantum control as an engineering discipline**

The programme included a *Turing Gateway to Mathematics* event which exposed researchers to quantum-based knowledge transfer initiatives from the technology strategy board Innovate UK. With participants from industry, including Sandia National Labs, HP Labs and SC Solutions, they heard about available resources for Quantum Technologies and about future research directions. This only emphasised the importance of quantum control in these developments.

There were a number of mathematical spin-offs. For instance,
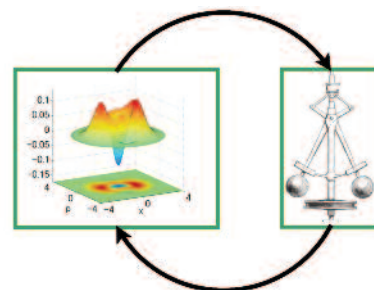
from the perspective of geometric mechanics new connections were made between quantum dissipation and metriplectic systems, Hamiltonian systems and geometric methods for classical and quantum stochastic dissipative systems. Regularizing feedback models were developed as a novel approach to non-renormalizable field theories.

The programme led to new collaborations and research grant applications, including several EPSRC standard and fellowship applications, an Australian Research Council application on "Integrated Optical Devices for Quantum Networks", and an application on "Quantum Filtering" to the Polish Research Council. A thematic issue of the journal EPJ Quantum Technology will be devoted to its output, and books by participants, on Quantum Feedback Networks (Gough and James) and Quantum Linear Control Systems (Nurdin and Yamamoto), will reflect the interactions and discussions throughout.

FACT FILE

Total participants on programme and workshops: **108**

Gender Balance:
Male: **96** Female: **12**

Understanding Microbial Communities; Function, Structure and Dynamics
11 August to 19 December 2014

www.newton.ac.uk/event/UMC/

Report from the Organisers:
Rosalind Allen (*Edinburgh*), Thomas Curtis (*Newcastle*), Thomas Pfeiffer (*Massey*), William Sloan (*Glasgow*), Orkun Soyer (*Warwick*) and Carsten Wiuf (*Copenhagen*).

Microbes – single-celled, microscopic living organisms – make up most of the biomass on earth and are found in all types of habitats, including soils, oceans and surfaces, and insides higher organisms such as plants and humans. Almost never are such habitats occupied by a single microbial species, but rather by many species that co-exist as a microbial community. Recent technological developments in DNA sequencing allow us to characterise the species composition of communities from a variety of environmental and medically-relevant habitats. However, there is an enormous gap between current empirical knowledge of microbial community composition and experimental and theoretical understanding of their function, structure, and dynamics. Key unresolved questions are:

- Do microbial communities achieve a higher-level function?

- How is this function stabilised?

- What drives evolutionary and ecological processes of community function?

- What determines the level of complexity in microbial communities?

- Could simpler and minimal communities for a given function be developed and stably maintained?

It is not possible to answer these questions using empirical data on microbial community composition alone. Data on functional traits within communities and their temporal and spatial distribution are also needed, and a theoretical foundation, involving mathematics, for evaluating biological data and testing hypotheses must be developed.

This programme was focused on the development of mathematical approaches to microbial community research and was timely because

data on microbial communities had been accumulating for about a decade and the field had started to attract attention from both experimentalists and theoreticians. Moreover, funding bodies, as well as industry had started to recognise the important role of microbial communities in the understanding of biology, with important biotechnology and medical applications.

> **The programme may be seen as a landmark in the development and expansion of the field of microbial ecology**

The programme began with a keynote lecture by the Rothschild Distinguished Visiting Fellow, Stanislas Leibler (Rockefeller University) *On the (un)reasonable (in)effectiveness of Mathematics in Biology*. Over the next four months over 150 scientists, with a diverse

SJ Wilkinson
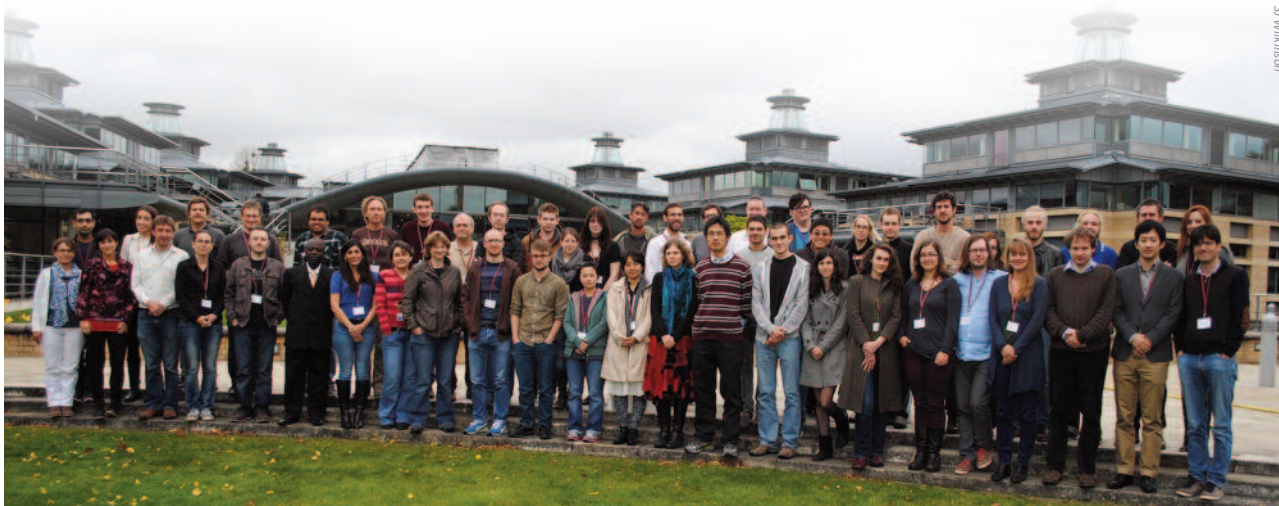
Participants at the PhD Summer School 'Methods for Mathematical and Empirical Analysis of Microbial Communities'

range of backgrounds in mathematics, physics, microbiology, ecology, economics, and computer science, participated. To nurture cross-fertilisation among this community and to encompass such a wide range of backgrounds there were many informal seminars, three short workshops, a PhD school and an industry-academia day.

A key scientific outcome was the establishment of networks among scientists with common interests from disparate research areas. Their enthusiasm for collaboration was reflected in the development of a co-authored opinion paper to help shape the future of the subject. This paper has been submitted as an invited review article to the ICME *Multidisciplinary Journal of Microbial Ecology* with about 50 co-authors. In addition to this very tangible scientific evidence of community building, the programme emphasised the need to move from empirical studies of microbial communities to their dynamical and functional analysis.

The programme succeeded in bringing together the majority of scientists currently working on microbial communities and in consequence the programme may be seen as a landmark in the development and expansion of the field of microbial ecology, with particular emphasis on microbial communities research.

> **…comments highlighted the success of the event, particularly in terms of networking and connecting empirical and theoretical scientists**

To encourage a healthy influx of young scientists into the study of microbial communities, several early career scientists and doctoral students were invited to the programme and lectures from leading scientists were specifically designed to help them become engaged in the field. Several students and early career scientists spend extended time at the Institute, developing their own ideas and establishing research areas that should help launch their careers.

Among the respondents to the post-programme questionnaire, 90% rated the programme as excellent. Specific comments highlighted the success of the event, particularly in terms of networking and connecting empirical and theoretical scientists. A majority said that they had become aware of new research questions and contacts as a result of participation in this programme.

The importance of microbial communities for health, industry and the natural environment cannot be overstated. This potential was explored with an *Open for Business*

event during which industrialists, academics and regulators came together to evaluate the industrial and medical potential of the emerging field of microbial communities research. The impact of the programme was reflected in the subsequent BBSRC announcement of a focus area within their current strategic funding plan with the same title as the programme.

FACT FILE

Total participants on programme and workshops: **228**

Gender Balance:
Male: 166 Female: 62

Rothschild Distinguished Visiting Fellow:
Stanislas Lieber

Turner-Kirk Fellows:
Thomas Curtis, Jef Huisman, Alan McKane, Frank Rohwer, Stephen Woodcock

Systemic Risk: Mathematical Modelling and Interdisciplinary Approaches

18 August to 19 December 2014

Report from the Organisers:
Rama Cont (*Imperial College*), Jean-Charles Rochet (*Zürich*), Chris Rogers (*Cambridge*) and Fernando Vega-Redondo (*Bocconi*).

The recent crisis in the financial markets which began in 2008 and triggered a global recession, has demonstrated the vulnerability of the world financial system and its linkages to the real economy. Academics and regulators have since been engaged in the search for understanding of the mechanisms underlying systemic risk in the financial sector and its interaction with the real economy. This 4-month programme at the Isaac Newton Institute brought together mathematicians, economists and regulators to accelerate the push for understanding.

A wide range of mathematical subject areas play a role in understanding systemic risk: stochastic optimal control, networks, game theory, risk measures, extreme value theory, statistics are perhaps the most obvious, and experts from all these areas participated. A lecture by Sir Robert May, entitled *Systemic Risk in Ecological and Financial Systems: Early Warnings?* illustrated how concepts from epidemiology and mathematical ecology provide insights into financial stability.

The discussions revealed different interpretations of what systemic risk might be and how it might be monitored and, to a certain extent, prevented: the programme confronted these views through interdisciplinary round table discussions, which were greatly appreciated by the participants.

The workshop on *Systemic Risk: Models and Mechanisms* organised in August by Darrell Duffie, Paul Glasserman, and Fernando Vega-Redondo brought together experts in financial economics, game theory, network science and mathematical finance to discuss mathematical techniques used to model systemic risk. One of the focuses of the workshop was the use of network models for understanding contagion of insolvency and illiquity in banking systems.

> " **The programme has contributed to the continuing effort of regulators and academics to get to grips with the most important economic issues of a generation**

The workshop *Monitoring Systemic Risk: Data, Models and Markets* was Organised by Rama Cont, Michael Gordy and Christian Gourieroux and was well attended by regulators, focused on indicators and data requirements proposed for monitoring of systemic risk by regulators. A key challenge is to incorporate contagion mechanisms in the indicators. The granularity of models turned out to be an important issue, with macro-econometric models on one hand and micro-level firm-level network models on the other.

The final workshop, devoted to *Regulating Systemic Risk: Insights from Mathematical Modeling* organised by Rama Cont, Martin Hellwig, and Jean-Charles Rochet, brought together macroeconomists, regulators and mathematical scientists to tackle the difficult issue of managing systemic risk through regulation. Recurrent themes of this workshop were the interlinkage of financial intermediation, regulation and the real economy and the need

Sir Robert May during his talk
'Systemic Risk in Ecological and Financial Systems: Early Warnings?'

for a model-based cost-benefit analysis of regulatory measures.

Distributed through the programme were a number of mini-courses whose purpose was part pedagogical, part review of recent research. Among these were:

- Over-the-counter markets (Darrell Duffie, Stanford);

- Mean-field games (Jean-Michel Lasry, Paris Dauphine);

- Stochastic control problems in portfolio liquidation (Ulrich Horst, Berlin);

- Macroeconomic models with a banking sector (Jean-Charles Rochet, Zurich);

- Mod-Phi convergence (Ashkan Nikeghbali, Zurich);

- Bank runs, deposit insurance and liquidity (Phil Dybvig, St Louis);

- Conflict and trading in networks (Sanjeev Goyal, Cambridge and Fernando Vega-Redondo, Bocconi);

- Risk measures (Stefan Weber, Hannover);

- Mathematical aspects of local vs global risk analysis (Hans Föllmer, Berlin);

- Risk measures, scenarios and stress testing (Alex McNeil, Heriot-Watt University).

Involvement of regulators was an important element of the entire programme, and added greatly to the relevance of the discussions. At various times through the programme, there were representatives of the Federal Reserve, the Bank of England, the European Central Bank, the European Systemic Risk Board, the Bank for International Settlements (Basel), the Japanese FSA, the Deutsche Bundesbank, the Central Bank of Brasil, and the Austrian National Bank presenting their research and contributing to the discussions. A highlight of the programme was a one-day *Open for Business* event entitled *Systemic Risk and Macroprudential Regulation: Perspectives from Network Analysis* was held in October at the Bank of England, with many participants and speakers from the Bank's Financial Stability Division. This workshop highlighted recent research contributions and regulatory initiatives, with an emphasis on the role played by network models in understanding systemic risk.

The programme has made research on mathematical modeling of systemic risk more visible to policy-oriented research teams in central banks, and triggered collaborations between mathematical scientists and researchers at the Bank of England, the European Central Bank, and the Deutsche Bundesbank, to mention a few. An early-career mathematician participating in the programme was hired by the Bank of England's Financial Stability Division.

The journals *Operations Research*[1] and *Statistics and Risk Modeling*[2] have agreed to devote special issues to the programme.

The programme has contributed to the continuing effort of regulators and academics to get to grips with the most important economic issues of a generation. Much remains to be done, and the legacy of connections among researchers and regulators generated by this programme may well prove to be an important step forward.

The organisers are grateful to Old Mutual plc, NATIXIS Foundation and Credit Suisse for their financial contribution towards elements of this programme.

References

[1] http://pubsonline.informs.org/journal/opre

[2] http://www.degruyter.com/view/j/strm
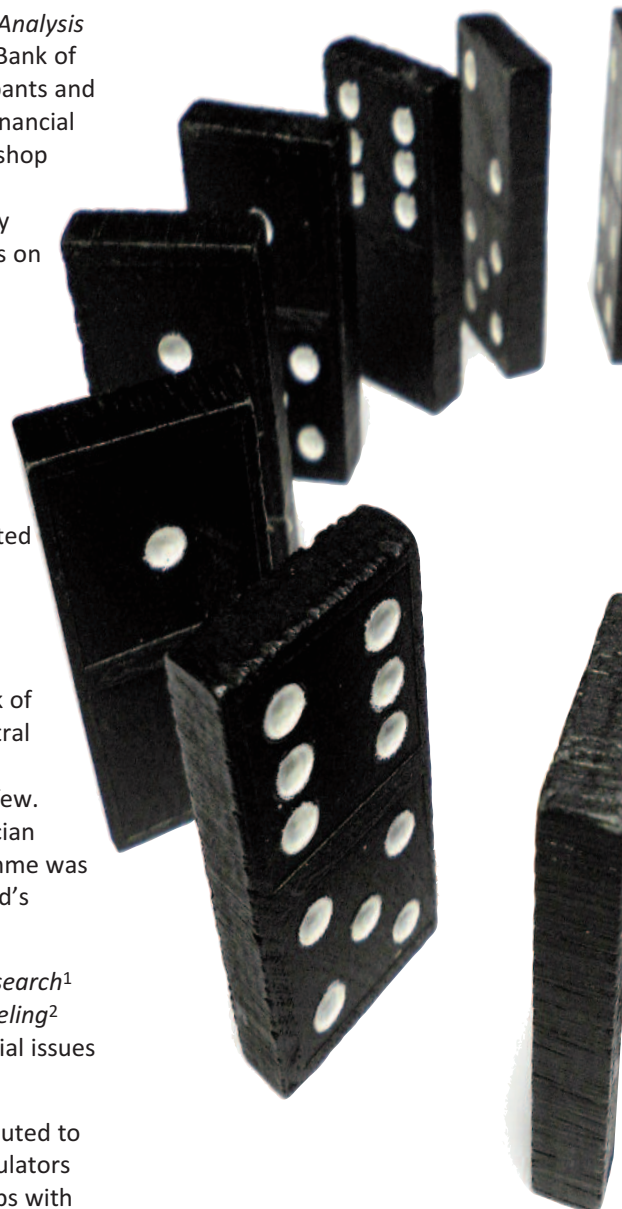
FACT FILE

Total participants on programme and workshops: 194

Gender Balance:
Male: 162 Female: 32

Rothschild Distinguished Visiting Fellow:
Hans Föllmer

Periodic and Ergodic Spectral Problems

5 January to 26 June 2015

Report from the Organisers:
David Damanik (*Rice*), Svetlana Jitomirskaya (*California, Irvine*), Frédéric Klopp (*Pierre et Marie Curie*), Leonid Parnovski (*UCL*) and Alexander Sobolev (*UCL*).

The study of differential and difference operators with periodic, almost-periodic, or random coefficients is motivated by applications in physics, especially in quantum mechanics and materials science, and in recent years there have been significant advances using methods specific to each of the three classes of operators. However all three types of operator are contained in a more general class, the ergodic operators, and may be studied in the context of that larger framework.

> **This programme was conceived to nurture [the] interplay of ideas by establishing opportunities for cross-fertilization and collaboration across the area boundaries**

This extended point of view has lead to insights on problems in one area motivating new lines of enquiry and discoveries in another. In particular, the theory of almost-periodic operators has benefited significantly from the wider perspective. This programme was conceived to nurture this interplay of ideas by establishing opportunities for cross-fertilization and collaboration across the area boundaries.

The programme began with a two-week instructional school with mini-courses during which leading experts made advanced material on the general framework, ergodic, periodic, almost-periodic and random operators, and on orthogonal polynomials, accessible to early-career researchers and non-experts. There were three further workshops:

Periodic and other Ergodic Problems

This one-week workshop brought together people working on periodic operators and their applications. Most of these applications were related to quasi-periodic or random operators, but there were several talks discussing applications of periodic problems to other areas of mathematics, like non-linear equations, dynamical systems, or topology. Presentations were selected with the intent to review the current state-of-the-art of the field. A special session was dedicated to the memory of the distinguished mathematician Boris Levitan (1914-2004) who is known for his work on almost-periodic functions.
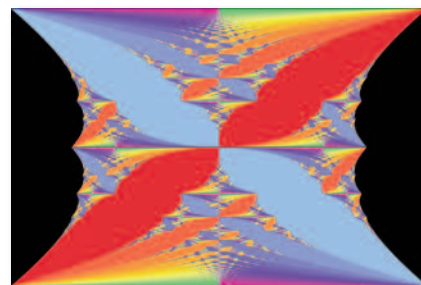
The programme image was Hofstadter's butterfly. This is a mathematical object describing the theorised behaviour of electrons in a magnetic field and it takes its name from its visual resemblance to a butterfly. It is a fractal structure and as such it shows self-similarity, meaning that small fragments of the structure contain a (distorted) copy of the entire structure. It is one of the rare fractal structures discovered in physics.

Quasi-periodic and other Ergodic Problems

This one-week workshop brought together people working on almost-periodic operators and experts in related fields. The selected talks covered a large range of topics with an aim to highlight a number of recent breakthroughs in the area of quasiperiodic operators and to cover some related fields. Over one half of

Barry Simon (CALTECH) gave a series of lectures on Orthogonal Polynomials as part of the two-week instructional school at the beginning of the programme. The talks were so popular that an overflow room with a live video link was set up to cope with the high number of attendees

Participants at the 'Almost-Periodic and Other Ergodic Problems' workshop

the talks were short focused presentations given by graduate students and recent PhDs.

Random and other Ergodic Problems

This one-week workshop brought together people working mainly on ergodic, more specifically random, operators and their applications. The selected talks covered a broad range of topics with the aim to give an overview of the state-of-the-art on random operators in the broad sense and to cover some related fields.

In addition to workshops, there were weekly seminars, informal presentations and lively dialogues that continued throughout the programme. A large number of working groups were organised, including those on point scatterers, discrete quasi-periodic operators, delocalization and the Bethe–Sommerfeld conjecture for multi-dimensional continuous quasi-periodic operators, the behaviour of Bloch surfaces near spectral edges, homogenization for time-dependent Schrödinger equation, and Wiener–

Hopf operators and entanglement entropy. The interactions between experts from different sub areas have led to new research directions and proofs of results using tools from adjacent areas. There was an especially fruitful exchange between the periodic and almost periodic communities, in both directions, and questions about almost periodic models were answered using methods from the theory of random operators.

The *Rothschild Distinguished Visiting Fellow*, Leonid Pastur, gave a special lecture on *Disordered Systems and Related Spectra*. Barry Simon gave a public lecture *Tales of our Forefathers* on personalities from the history of mathematics that, in addition to programme participants, attracted a large audience from the wider community.

The programme received additional financial support from the ERC (European Research Council). Following the success of the programme there are plans to organise further research activity,

including a session at the American Mathematical Society Fall Western Sectional Meeting in 2015, a workshop in London in 2016, and one or two follow-up meetings.

FACT FILE

Total participants on programme and workshops: **143**

Gender Balance:
Male: 126 Female: 17

Rothschild Distinguished Visiting Fellow:
Leonid Pastur

Simons Fellows:
Alexander Fedotov, Nikolai Filonov, Bernard Helffer, Svetlana Jitormirskaya, Frédéric Klopp, Leonid Parnoski, Tatiana Suslina, Yiqian Wang

Random Geometry

12 January to 3 July 2015

Report from the Organisers:
Itai Benjamini (*Weizmann Institute of Science*), Nathanaël Berestycki (*Cambridge*), Jean-François Le Gall (*Paris-Sud*) and Scott Sheffield (*Massachusetts Institute of Technology*).

Overview

Over the past twenty or thirty years, two-dimensional random geometry has emerged as a large and fascinating subject at the interface between analysis, probability, geometry and combinatorics. The mathematical theory is rich, with new problems and connections emerging regularly to other areas of mathematics, and the subject has been growing and changing at a tremendous speed. These developments have driven the theory far beyond its traditional boundaries, and have led to the development of radically new concepts and intuitions.

This relatively recent explosion of ideas was the main motivation for the programme, which was built around the long-term participation of both established experts and extraordinarily strong younger researchers, as well as a many short term visitors. Many striking research results were achieved by long-term participants with a great deal of positive effects on the community.

Research highlights

For many years a holy grail for this subject has been a unification of the diverse perspectives on random planar geometry that have emerged from disciplines such as conformal field theory, Gaussian multiplicative chaos, combinatorics, random planar map theory, statistical physics and string theory. These approaches have led to a plethora of highly sophisticated and powerful tools which describe distinct aspects of what, at a different level, might be perceived as one and the same theory. Thanks to this programme, through a coordinated effort by many programme participants, which included Field Medallists and a group of very strong, very young researchers, much of this unification has been achieved. In particular:
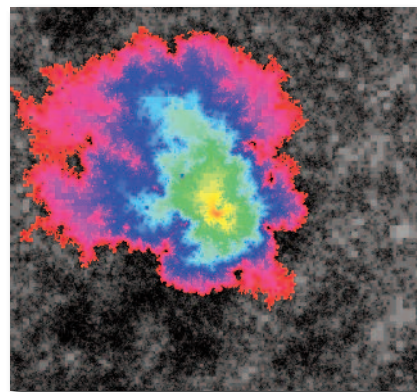
Metric ball in Liouville quantum gravity

- Miller and Sheeld have posted a series of papers that provides the first direct and rigorous connection between the two primary paradigms for random surface construction: Liouville quantum gravity and the Brownian map;

- A team of early-career researchers Aru, Huang and Sun has rigorously proved the equivalence of two existing random sphere constructions;

- Papers by (various subsets of) Gwynne, Mao, Miller and Sun and Berestycki, Laslier and Ray have unified the theory FK-decorated random planar maps

FACT FILE

Total participants on programme and workshops: **224**

Gender Balance:
Male: **185** Female: **39**

Rothschild Distinguished Visiting Fellow:
Gregory Miermont

Simons Fellows:
Louigio Addario-Berry, Omer Angel, Vincent Beffara, Itai Benjamini, Nicholas Curien, Bertrand Duplantier, Jason Miller, Scott Sheffield

An entertained audience during a lecture by David Aldous entitled 'Compulsive Gambler Process' which took place in March 2015

and the theory of CLE-decorated Liouville quantum gravity;

- Curien and Le Gall have shown that the metric on random planar maps is very robust in the sense that various distance processes (first passage percolation, Eden model) are identical on the large scale (thereby showing that the behaviour of these processes is surprisingly simpler in random geometry than on deterministic lattices);

- Gwynne, Miller and Sun have settled long-open questions about the multifractal behaviour of random SLE curves (SLE: Schramm-Loewner evolution is a family of random planar curves that have been proven to be the scaling limit of a variety of two-dimensional lattice models in statistical mechanics);

- Benoist, Dumaz, Werner have made rigorous sense of renormalization in the context of uniform spanning trees and FK random cluster models. Werner has announced fascinating new relationships between Brownian loop soups and the Gaussian free field;
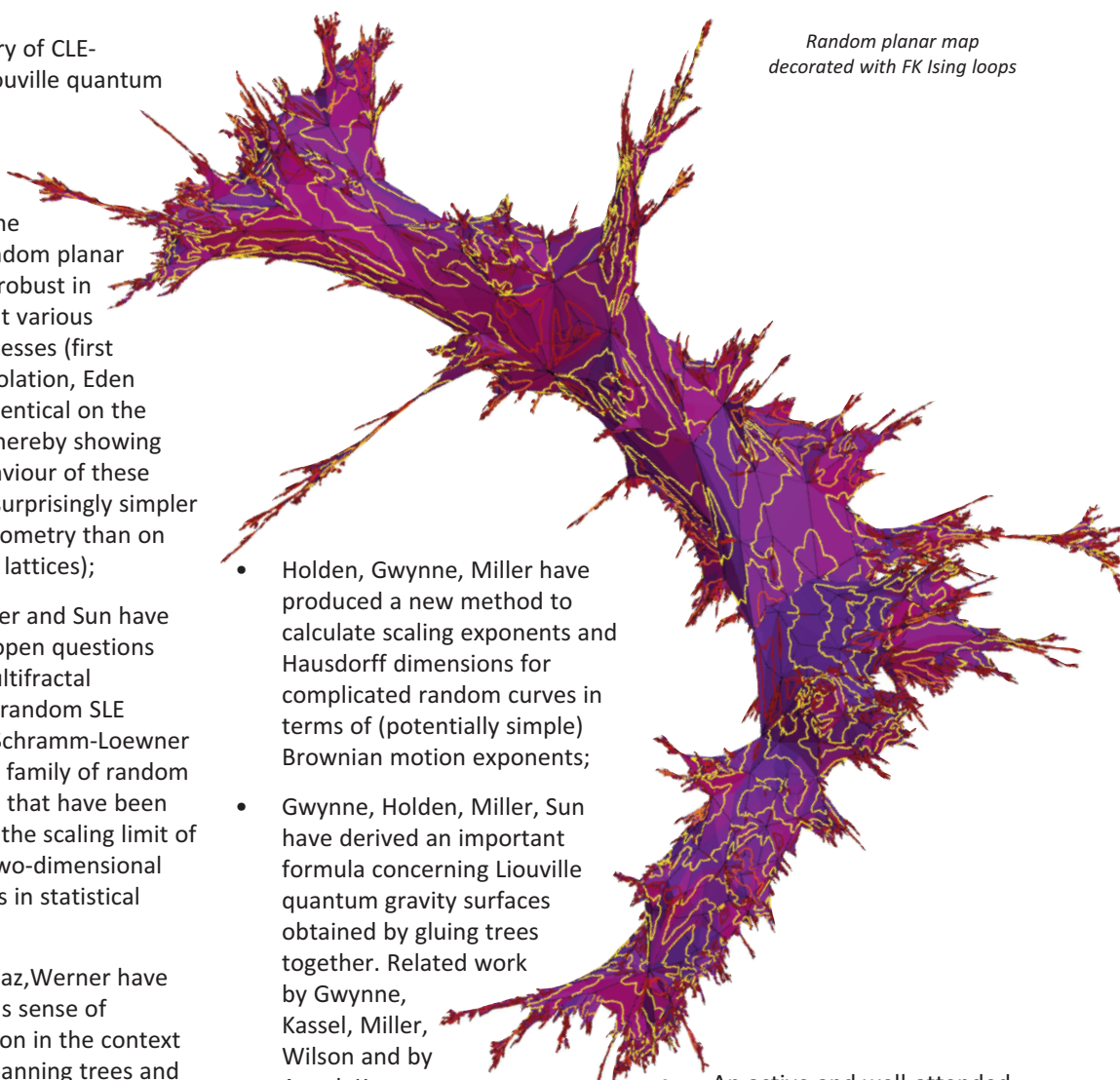
Random planar map decorated with FK Ising loops

- Holden, Gwynne, Miller have produced a new method to calculate scaling exponents and Hausdorff dimensions for complicated random curves in terms of (potentially simple) Brownian motion exponents;

- Gwynne, Holden, Miller, Sun have derived an important formula concerning Liouville quantum gravity surfaces obtained by gluing trees together. Related work by Gwynne, Kassel, Miller, Wilson and by Angel, Kenyon, Miller, Sheeld, Wilson has found new statistical physics models that fit into the SLE and quantum gravity framework.

Scientific interactivity and pedagogy

- Four highly successful workshops have highlighted different aspects of the subject. These were well attended with more than 100 participants for each workshop.

- A school for young researchers enabled a large crowd of early-career researchers to learn about the state-of-the-art of the subject in a unified way. This interconnectedness was cited by many participants as a key benefit of the programme.

- Two research seminars per week exposed participants to cutting edge ideas.

- An active and well-attended reading group, involving weekly meetings and discussions throughout most of the programme, has led to a deeper understanding of disparate fields. The last part of the programme was spent discussing recent advances on probabilistic approaches to the famous Yang–Mills problems, which shares some common features with themes already explored within random geometry. For this it was particularly useful to be able to set up a videoconference meeting with Chatterjee in Stanford to discuss his recent work on the subject. We hope that we have inspired some of the bright early-career researchers attending the programme to think about this outstanding problem.

> " **The programme has contributed to the continuing effort of regulators and academics to get to grips with the most important economic issues of a generation**

Serving the UK Community

Michael Singer
Chair of Correspondents

In this, my final year as Chair of Correspondents, I was an organiser of a 4-week programme *Metric and Analytic Aspects of Moduli Spaces* at the INI, and spent more time than usual on the premises. And I experienced at first hand the opportunities that the INI provides to the mathematical sciences and the quality of research that takes place here. While I may be perceived as biased in talking about my own programme, the feedback from reviewers and the comments of participants all point in the same direction: the quality of the research done at the INI remains stellar.

The arrival of new staff and the development of new infrastructure for the smooth running of INI programmes, as well as my own experiences here this summer leave me optimistic that the future of the INI is a very bright one.

During my years as Chair of Correspondents, I have developed something of a reputation for asking challenging questions on the Management Committee. I therefore leave the INI with a challenge: to set about creating virtual research communities so that research started in Cambridge can be enjoyably continued after everyone has gone home.

Annual Meeting of Correspondents

Correspondents' Day 2015 was held at INI on Friday 2 April, to coincide with the final day of BMC/BAMC which was held in Cambridge. There were 30 attendees approximately two thirds of whom were Correspondents themselves and a third of whom were their representatives.

A stated aim of the Correspondents Network is to act as a "channel of communication between the Institute and the mathematical sciences community in the UK" and the deliberately provocative theme for the day was "INI Correspondents' Network: A Lossy Channel?". Following lunch and a welcome from John Toland, Institute Director, Christie Marr, the Deputy Director chaired a wide-ranging discussion on the role of Correspondents, the best people to be Correspondents, and the purpose and efficacy of Correspondents' Bulletins.

There was a strong sense that Correspondents should act as "ambassadors" for the Institute and as such should have been INI programme participants or organisers themselves. Correspondents felt that those who were not actively engaged should be asked to step down. It was recognised that Correspondents are not forwarding on Bulletins and alternative methods of disseminating information were discussed.

Following on from this meeting, and with the support of the Management Committee, INI is in the process of updating its Communication Strategy and the Terms of Reference for the Network of Correspondents.

A list of INI Correspondents can be found on the web at **www.newton.ac.uk/community/correspondents/**

Short Visits

Any researcher associated with a UK University, academic institution or R&D group in industry or commerce may visit the Newton Institute for up to two days without an invitation, in order to attend seminars or to work with colleagues. We ask that reception@newton.ac.uk is emailed in advance to assist us with planning. Further details are at **www.newton.ac.uk/participate**.

Junior Membership

To facilitate involvement in INI activities, early-career researchers (research students or individuals within 5 years of receiving a PhD taking account of career breaks) are invited to register as Junior Members of the Isaac Newton Institute. Junior members receive advance information about INI programmes, workshops, and other events, specific information about instructional workshops and about workshops likely to be of interest to early-career researchers and information about suitable funding for INI visits.

INI has limited funds for supporting Junior Members to attend programmes (for visits of up to two weeks to work with long-term programme participants) or workshops. Applications will be reviewed by the programme/workshop organisers, and applicants will be notified whether their application was successful.

Those wishing to join the scheme, or find out more information should consult the INI web site at **www.newton.ac.uk/community/junior-members**.

Institute Activities

Seminars on the Web

All INI seminars and lectures are, with the permission of speakers, advertised in advance, streamed live and made available on the web in perpetuity.

In addition to broadcasting its own lectures, the Institute uses its facilities to provide distinguished scientists who are unable to attend in person with the opportunity to lecture during programmes or workshops. These interactive sessions are held in the INI seminar room, with question and answer sessions between the audience and the speaker at a different location.

The library of online seminars is a significant scientific resource. During 2014/15 within the six programmes covered by this report and including other events, over 580 seminars were added to the collection taking the total number of recordings in the archive to over 5,500. All are available at **www.newton.ac.uk/webseminars**.

David Aldous checking £5.00 notes from members of the audience during his talk 'The Compulsive Gambler Process', part of the 'Random Graphs' programme. The talk is available to watch at www.newton.ac.uk/seminar/20150317100011001

Follow-up Meetings

As stated in the Institute's Scientific Policy Statement (www.newton.ac.uk/about/governance/policy-statement), it is intended that each INI scientific programme will have long-term impact well beyond the event itself in terms of breakthroughs, new research directions and collaborations. The Institute, therefore, arranges short *Follow-up Meetings* some years after programmes end, whenever the original organisers are enthusiastic.

Seminars in the UK

Participants on INI programmes are strongly encouraged to visit other institutions within the UK during their stay at the Institute, and 48 visitors did so during 2014/15 delivering a total of 79 seminars in 34 different institutions. To promote this activity, the Institute covers the travel costs within the UK for overseas participants.

Lists of future participants, with dates of their visits, can be found on the individual programme web pages. In addition, the Institute has set up a register, with titles of topics, of those participants who are willing to travel to other UK institutions to give seminars. Correspondents are urged to ensure that organisers of local seminar series know about and consult this register when planning their schedule of speakers. Potential speakers may be contacted directly using the details listed in the online register at **www.newton.ac.uk/science/outreach/speakers**. Advice on suitable speakers may be obtained from the programme organisers of the relevant programme.

Satellite Meetings

Satellite Meetings are organised on themes related to an INI programme, and involve a number of longer-stay overseas participants who are visiting the Institute at the time. They also, crucially, draw in and involve UK mathematicians and scientists who might not otherwise be able to participate substantially in the programme; and they enable the expertise of the Institute's overseas participants to be shared more widely within the UK.

Since 2000 there have been 61 INI *Satellite Meetings* held in Institutions across the UK. Of these, 16 have been held in Scotland and 7 have been held in Wales.

Future *Satellite Meetings* for 2016 include the International Centre for Mathematical Sciences (ICMS) in Edinburgh, Scotland. Further details are available at **www.newton.ac.uk/events/calendar**.
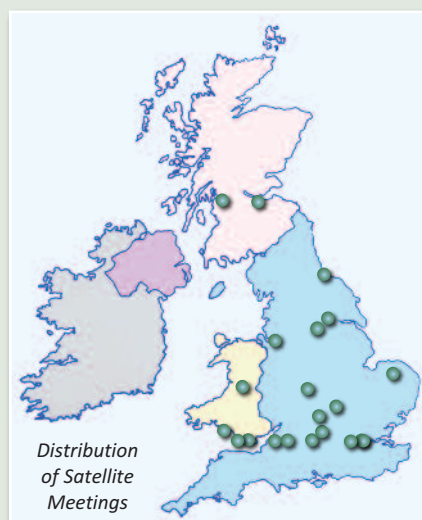
Distribution of Satellite Meetings

Management and Statistical Reports

Howard Covington
Chair of the Management Committee

During this golden age for mathematics, when there is huge demand for talent world-wide, the best researchers work in countries where research is at the cutting edge of developments and there are sophisticated international connections and highly developed facilities for networking. With its formidable reputation for mathematics and interdisciplinary research, INI has come to occupy an increasingly distinctive position that is simultaneously aligned with a strong commitment to basic research of the highest international standards, and to the impact agenda of the public funding bodies. As a leading international centre at the vanguard of research in mathematics it contributes enormously to the UK's international standing. But all this comes at a price.

The support needed for the mathematical sciences is modest when compared with its importance, because expensive equipment is not involved. For many mathematicians, a pencil, some paper, the time to think and the opportunity to interact with leading researchers in the field are the traditional requirements. However the fact that the resources required are small does not mean that they are non-existent. In an age of austerity public funding is not as generous as it once was and nowadays the Institute relies on the generosity of its philanthropic benefactors and generous donors to support about half of its activities. The entire mathematical sciences community is grateful to everyone who helps with this.

Management Committee

Membership of the Management Committee at 31 July 2015 was as follows:

Name	Affiliation	End of Service
Mr Howard Covington (Chair)	General Board	31 Dec 2018
Dr Gabor Csanyi	Council of the School of Technology	31 Dec 2018
Professor Mark Gross	Faculty of Mathematics	31 Dec 2018
Professor Peter Haynes	Head, DAMTP, University of Cambridge	–
Dr Phillippa Hemmings	EPSRC	–
Professor Valerie Isham	Chair of Scientific Steering Committee	31 Dec 2017
Dr Eric Lauga	Trinity College	31 Dec 2018
Professor Nick Manton	St John's College, Cambridge	31 Dec 2018
Dr Christie Marr (Secretary)	Deputy Director, Isaac Newton Institute	–
Professor Andy Parker	Council of the School of Physical Sciences	31 Dec 2018
Professor Gabriel Paternain	Head, DPMMS, University of Cambridge	–
Professor Michael Singer	Chair of Correspondents	31 Dec 2015
Professor Ulrike Tillman	London Mathematical Society	31 Dec 2018
Professor John Toland	Director, Isaac Newton Institute	30 Sep 2016

The Management Committee is responsible for overall control of the budget of the Institute and for its financial planning. The Director is responsible to the Management Committee, which provides essential advice and support in relation to fund-raising activities, employment of the staff of the Institute, appointment of the organisers of programmes and general oversight of Institute activities. Its aim is to facilitate to the fullest possible extent the smooth and effective running of the Institute's programmes and all related activities.

Programme Participation

A total of 1444 visitors was recorded for 2014/15.

This includes 328 Visiting Fellows and 197 Programme Participants. Within the 6 programmes during the year there were 22 workshops (periods of intense activity on specialised topics) which attracted a further 457 visitors (i.e., those not already attending the programme).

In addition to workshops, which serve to widen UK participation in programmes, INI occasionally arranges less formal special academic meetings, as well as talks for the general 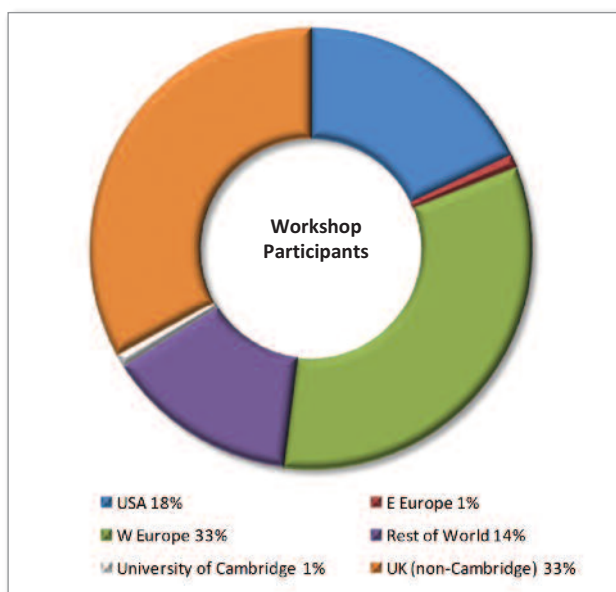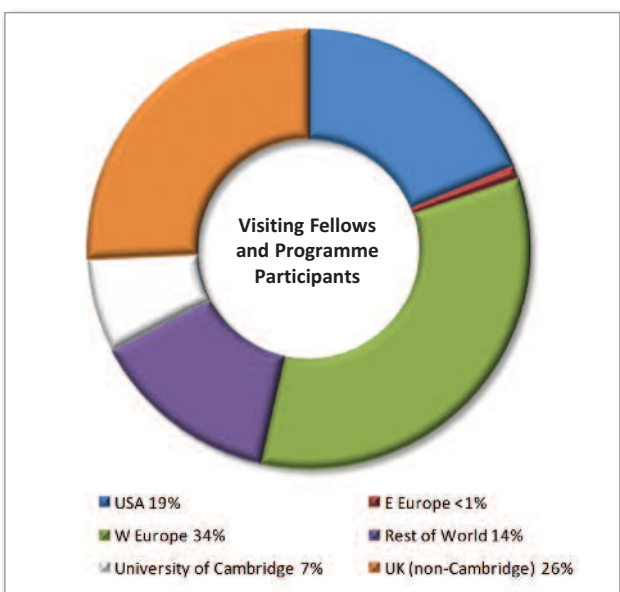public, so further opening up the activities of INI. More than 462 visitors attended such events and took part informally in INI activities.

Within all programmes and workshops over 589 seminars were given at INI during the year. The Institute also funds visits by overseas programme participants to other UK institutions to give seminars (see page 17), and this year 79 such seminars took place.
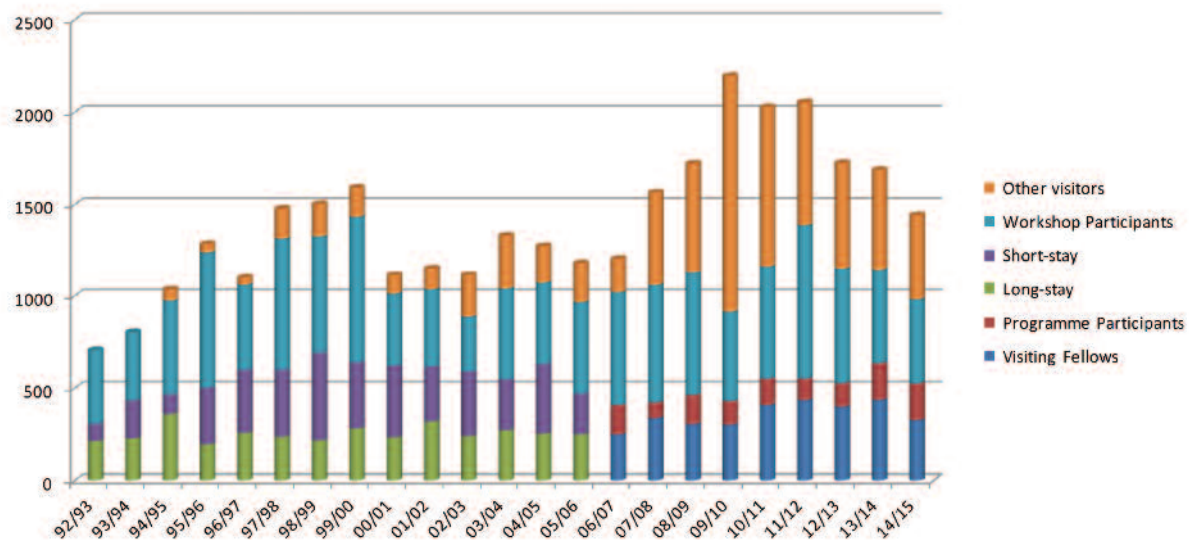
Open for Business events which are organised by the Turing Gateway to Mathematics (TGM) are recorded separately in the TGM Annual Report.

| Programme	Visiting Fellows	Mean stay (days)	Programme Participants	Mean stay (days)	Workshop Participants
Theory of Water Waves	37	15	22	13	26
Quantum Control Engineering: Mathematical Principles and Applications	26	22	22	16	60
Understanding Microbial Communities; Function, Structure and Dynamics	78	25	60	44	90
Systemic Risk: Mathematical Modelling and Interdisciplinary Approaches	45	36	31	36	118
Periodic and Ergodic Spectral Problems	68	52	22	48	53
Random Geometry	74	49	40	93	110
	328	**27**	**197**	**46**	**457**

The pie charts below show the percentages of Visiting Fellows, Programme Participants and Workshop Participants broken down by country of residence:

Visiting Fellows and Programme Participants

- USA 19%
- E Europe <1%
- W Europe 34%
- Rest of World 14%
- University of Cambridge 7%
- UK (non-Cambridge) 26%

Workshop Participants

- USA 18%
- E Europe 1%
- W Europe 33%
- Rest of World 14%
- University of Cambridge 1%
- UK (non-Cambridge) 33%

The following chart summarises the total participation figures since the Institute began:

The chart below summarises the total number of person-days for Visiting Fellows and Programme Participants combined, *excluding* Workshop Participants.
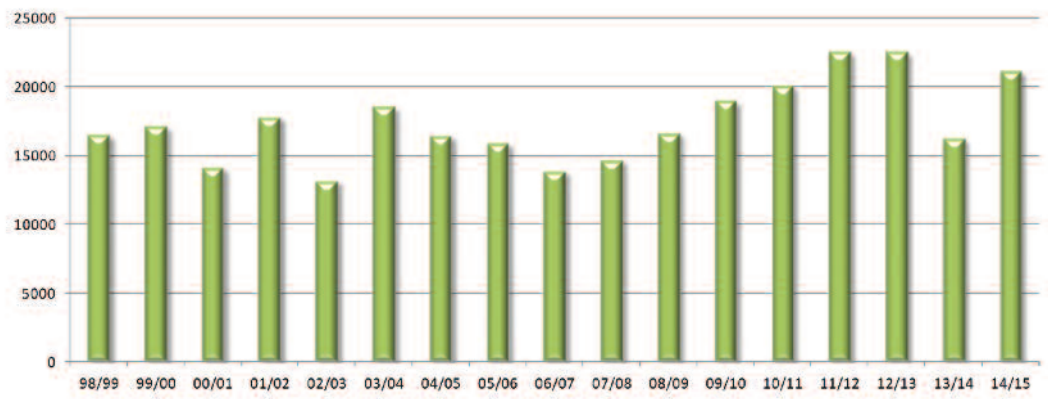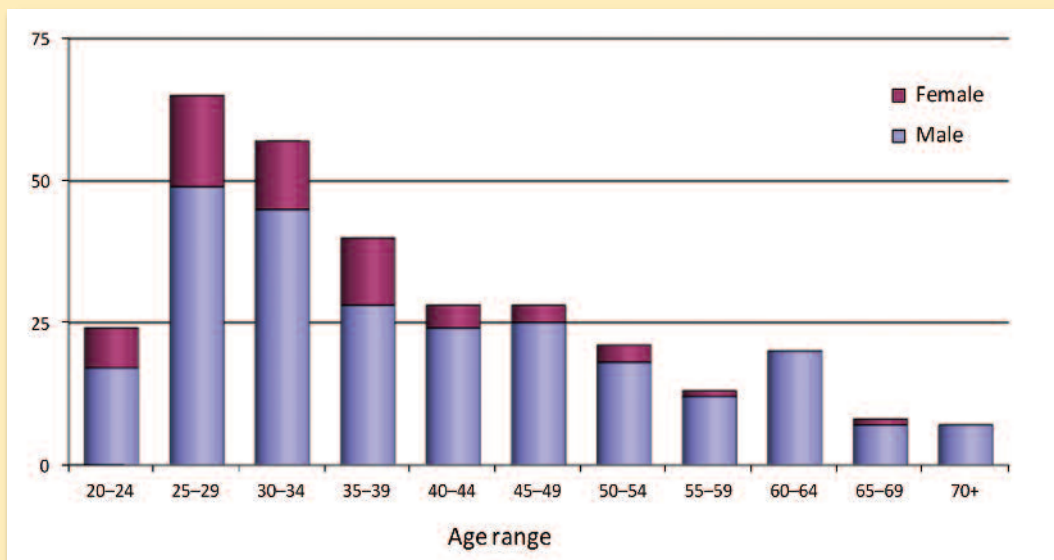

The numbers of all Visiting Fellows, Programme Participants *and* Workshop Participants combined in 2014/15 are shown below, by age and gender:
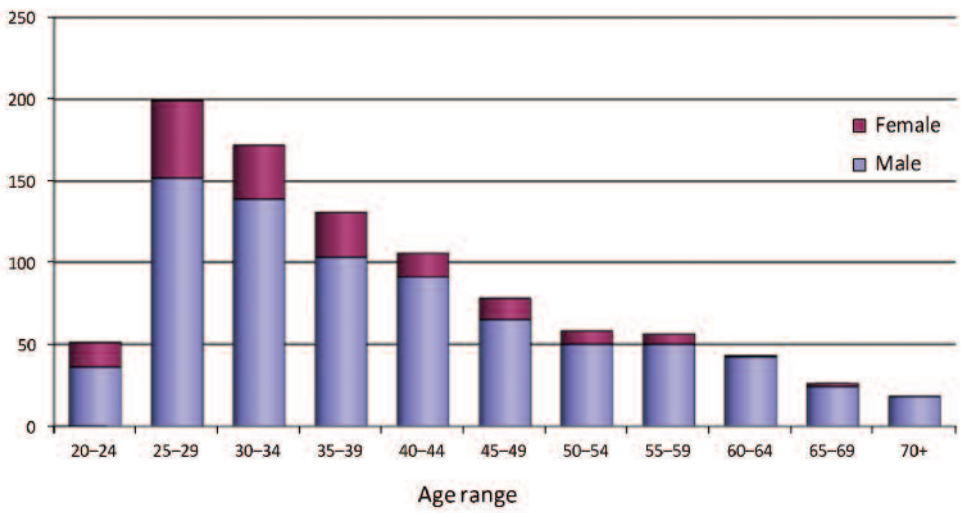
The statistics presented on this page relate only to visitors whose home institutions are in the UK: overseas visitors data are not included.

The age range and gender balance of all Visiting Fellows, Programme Participants and Workshop Participants from UK institutions in 2014/15 are illustrated below:

The following diagrams indicate the academic status and geographical distribution of all Visiting Fellows, Programme Participants and Workshop Participants from UK institutions during 2014/15:
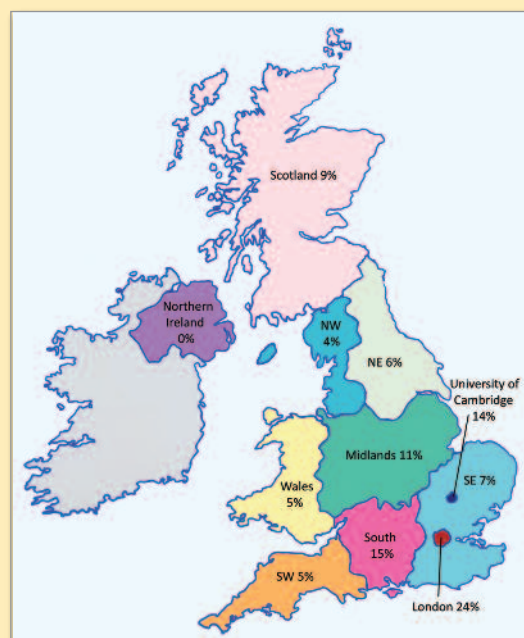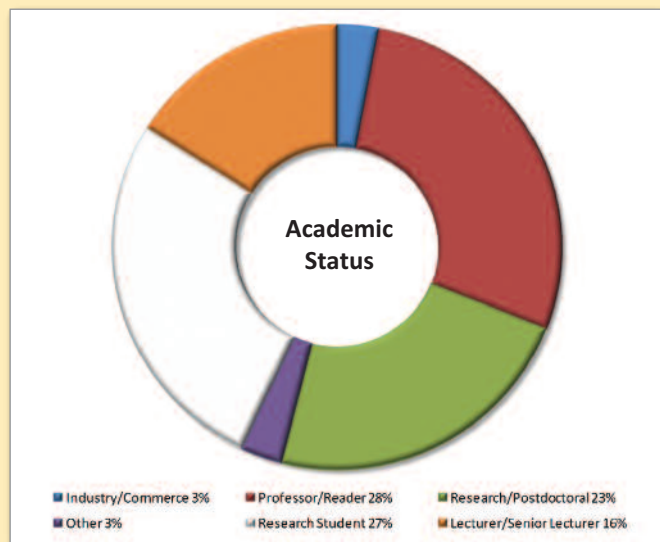
Finances

Accounts for August 2014 to July 2015 (Institute Year 23)

	2013/14 Year 22 £'000	2014/15 Year 23 £'000
Income		
Research Grants and Contracts[1]	1,800	1,591
Contribution from the University of Cambridge[2]	410	388
Donations[3]	173	219
Additional Workshop Income	78	98
Endowment and Investment Income[4]	205	203
Net Housing Surplus[5]	-18	31
Other Income	10	3
Total Income	**2,658**	**2,533**
Expenditure		
Staff Costs	715	681
Travel and Subsistence[6]	844	1,312
Workshop Expenditure	297	162
Other Institute Activities[7]	36	12
Other Operating Expenses[8]	250	111
Overheads paid to University[9]	265	293
Total Expenditure	**2,407**	**2,571**
Surplus / (Deficit)	**251**	**(38)**

Notes to the Accounts

1. Research Grants and Contracts. The income breaks down as follows:

EPSRC Salaries	306	247
EPSRC Travel and Subsistence	837	813
EPSRC Workshop Income	195	178
EPSRC Other Costs	208	14
EPSRC Estates and Indirect Income	172	339
Leverhulme Trust	82	0
Total	**1,800**	**1,591**

2. Contribution from the University of Cambridge. The amounts received break down as follows:

Rothschild Visiting Professorships (drawdown)	28	11
Rothschild Mathematical Sciences (income)	108	112
Contribution Towards Institute Operating Costs	274	265
Total	**410**	**388**

The University also provides the main and Gatehouse buildings and pays for all gas, electricity and rates, which have not been included.

3. Donations. A total of £97k received via the Cambridge University Development Office was capitalised and is not included in this figure.

Cambridge Philosophical Society	2	2
Garfield Weston Foundation	32	12
London Mathematical Society	40	33
Microsoft	25	0
NERC	45	0
PF Charitable Trust	3	1
Turner-Kirk Charitable Trust	26	108
Others		63
Total	**173**	**219**

4. Endowment and Investment Income. Income received from the Newton Trust fund, the Anonymous Donation Endowment, reserves and deposits.

5. Net Housing Costs.

Income	665	748
Expenditure	683	717
Total	**-18**	**31**

6. Travel and Subsistence. Expenditure incurred by Programme Visitors including Junior Members. This figure is significantly higher for 2014/15 due to a one-off adjustment to synchronise INI accounting for research grants with University of Cambridge Financial Procedures

7. Other Institute Activities. These costs relate to *Open for Business* and fundraising activities as well as expenses from meetings of the Institute's committees, Institute Correspondents, programme organisers, and the travel expenses of overseas participants who visit other UK institutions to give seminars during their stay.

8. Other Operating Expenses.

Building maintenance	37	52
Catering	17	17
Consumables	12	28
Computing and Audio Visual	179	9
Equipment and Furniture	2	1
Library	2	2
Publicity	1	2
Total	**250**	**111**

9. Overheads Paid to University. Includes Estates and Indirect costs on grants and overheads on Trust Funds.

Grants and Donations August 2014 to date

In addition to substantial funding from Research Councils UK, the Institute is indebted for support from the Cambridge Philosophical Society, the European Research Council, the London Mathematical Society, PF Charitable Trust, NM Rothschild and Sons, the Simons Foundation and the University of Cambridge.

INI is very grateful to the following organisations for their specific support during the year: Clay Mathematics Institute, Credit Suisse, the Garfield Weston Foundation, GLC Charitable Trust (with special thanks to Lawrence Staden), Henderson Global Investors, NATIXIS Foundation, the Office of Naval Research, and Old Mutual plc.

Individuals gave generously in support of INI activities and thanks are extended to: Iain Bratchie, Howard & Veronika Covington, Thomas W Cusick, Kenneth Falconer, Mrs Ann and the late Professor Roy Garstang, Dr Jonathan Hodgson, Dr EM Kirk & Dr PJ Turner, Simon Yun-Farmbrough, David & Elizabeth Wallace as well as individuals who prefer to remain anonymous.

Cumulative Financial Grants and Donations above £10,000
(listed in order of cumulative value)

SERC/ EPSRC/ PPARC/ STFC/ NERC/ BBSRC/ ERSC
Trinity College (Isaac Newton Trust)
NM Rothschild and Sons
University of Cambridge
European Union
Leverhulme Trust
Hewlett−Packard
Anonymous Donation
Dill Faulkes Foundation
St John's College
NATO
London Mathematical Society
Dr EM Kirk & Dr PJ Turner
CNRS
Simons Foundation
Rosenbaum Foundation
PF Charitable Trust
Clive Humby & Edwina Dunn
Garfield Weston Foundation
Henderson Global Investors
Microsoft Corporation/ Microsoft Research
Clay Mathematics Institute
Howard & Veronika Covington
Old Mutual plc
GLC Charitable Trust (Lawrence Staden)
John Templeton Foundation
Sun Microsystems inc.
Apple Computers Ltd.
Gonville and Caius College
Prudential Corporation plc
David Harding Foundation
David & Elizabeth Wallace
Institute of Physics
National Science Foundation
Wellcome Trust
Met Office
Nuffield Foundation

Deutsche Forschungsgemeinschaft
Cambridge Philosophical Society
TSUNAMI
Daiwa Anglo−Japanese Foundation
BNP Paribas
Anonymous Donation
Hamish Maxwell
Office of Naval Research
European Science Foundation
Emmanuel College
Jesus College
Medical Research Council
Royal Commission for the Exhibition of 1851
Schlumberger
British Aerospace
Rolls Royce
Thriplow Trust
Autonomy Systems Ltd.
British Gas
DERA
Magnox Electric
Paul Zucherman Trust
Steve Mobbs
William Craig
Nomura Corporation
Bank of England
Michael Astor
Credit Suisse
Iain Bratchie
European Molecular Biology Organisation
Elena Ambrosiadou
Applied Probability Trust
Benfield Greig
Trinity College
Unilever

TGM | Turing Gateway to Mathematics

The *Turing Gateway to Mathematics* (TGM) is an impact acceleration initiative for knowledge exchange based in the Isaac Newton Institute. The TGM acts as a vehicle for knowledge transfer between the mathematical sciences and potential users of mathematics, such as industry and other academic disciplines in the UK and internationally. It helps to bridge the gap between those engaged in frontier mathematical research and those working in more applied areas. There are synergies and strong lines of communication between the INI and the TGM, but their short-term goals are different.

The *Turing Gateway to Mathematics* is a unique venture and fulfils a critical national need for mathematicians and businesses to have ready access to each other's ideas and expertise. Mathematics plays a vital part in all aspects of modern society and underpins the technologies and processes that drive modern business. Without research and training in mathematics, there would be no engineering, economics or computer science; no smart phones, MRI scanners, bank accounts or PIN numbers. Mathematics is all pervasive and adds value across all sectors. The TGM has the potential, and capacity, to offer industry-focused activity as well as helping to facilitate engagement between individuals and organisations who were not previously working together and helps to achieve greater synergy and more creative and imaginative approaches.

A full breakdown of TGM activities for the past year is available in a separate printed *Annual Report*, or online at **www.turing-gateway.cam.ac.uk**.

Front cover

Liouville Brownian motion

Liouville Brownian motion is the canonical diffusion process in the random geometry of Liouville quantum gravity; equivalently this is the geometry defined by a natural notion of random surface. Informally, it has a diffusivity given by the exponential of the so-called Gaussian free field. In the picture, the green landscape represents a portion of the Gaussian free field, while a piece of the trace of Liouville Brownian motion is pictured in golden yellow. (Image courtesy of Henry Jackson)