Isaac Newton Institute
for Mathematical Sciences

Annual Report
2018-2019

UNIVERSITY OF
CAMBRIDGE

Mission Statements

Isaac Newton Institute for Mathematical Sciences

The Isaac Newton Institute is an international hub for supporting mathematical sciences research of the highest quality and impact. It aims to attract the world's leading researchers, in all areas of mathematics and its applications, who interact through a variety of long and short thematic programmes as well as associated workshops. Based in Cambridge, and benefiting from a bespoke building and other world leading facilities of this great University, INI is nevertheless an independent forum serving the whole of UK mathematical sciences. INI's environment, and supporting mechanisms, enable its programmes to have a translational effect on their respective research areas.

All INI scientific programmes are carefully designed to allow for novel ideas to be created, nurtured and exchanged. Programme topics cover all areas of mathematics, with increasing focus on emerging intra and interdisciplinary fields, where engagement is with other scientists, social scientists, economists, policy makers etc. The Institute also helps to develop the next generation of mathematical scientists by encouraging participation of young researchers, by widening access, and by addressing the gender gap in mathematics.

The INI has broadened its role in the community in recent years, and informs policy makers and funders about the relevance, value and timeliness of emerging mathematics. Through the Newton Gateway to Mathematics it carries out stand-alone knowledge exchange events, and activities within programmes, aimed at end users of mathematical ideas in commerce, industry, government, and other sciences. Further, it assists universities in achieving their own goals; showcases UK research in the mathematical sciences; and engages with non-mathematicians through public lectures, exhibitions, and other activities for schools and the general public.

Newton Gateway to Mathematics

The Newton Gateway to Mathematics acts as a vehicle for knowledge exchange between the mathematical sciences and potential users of mathematics, including industry, government, business and other academic disciplines, both in the UK and internationally. It does this by facilitating interactions and activities such as programmes of work, research and training events, as well as bespoke projects. The Newton Gateway aims to widen access to mathematics generally, to shorten pathways to impacts for academic research, and to support education and training in areas where mathematical skills are needed.

Director's Foreword

Welcome to this year's Annual Report of the Isaac Newton Institute (INI). The Institute's remit is simple – to organise research programmes of the highest quality across the whole of the mathematical sciences, broadly defined; to attract to these activities the very best scientists from across the globe; and through these to ensure the health of the UK mathematical sciences community. My role, together with that of the Deputy Director and the Scientific Steering Committee, is to ensure that our programming includes the areas that are most pressing and timely for concentrated attention and reflects the ever-expanding domain of our discipline. We also, of course, have to work closely with the organisers of all of our programmes, workshops, and the increasing numbers of one-off events to ensure that they realise their full potential in terms of impact. To satisfy demands on our space and resources, we had to again run three programmes in parallel in the first half of 2019, and so the facts and figures listed later in this Annual Report reveal an exhilarating but hectic year for our participants and staff.

It is important for me to pay tribute to the first Director of the Newton Institute, Sir Michael Atiyah OM FRS, who died on 11 January 2019 in his 90th year. As well as a remarkable mathematician, Sir Michael was a force of nature, using his intellect, passion, enthusiasm and boundless energy to drive forward projects and to lead others in new endeavours. INI was most fortunate in attracting him to take on the project of creating a new research visitor institute in the UK, to assist in the raising of funds from several Cambridge Colleges and through private benefaction, and to win the initial grant from EPSRC for funds to run programmes. His vision was clear, and the programme structure, and the breadth of subjects, remains largely unaltered to this day. Sir Michael always recognised that the best science happens when you bring different communities together, in a

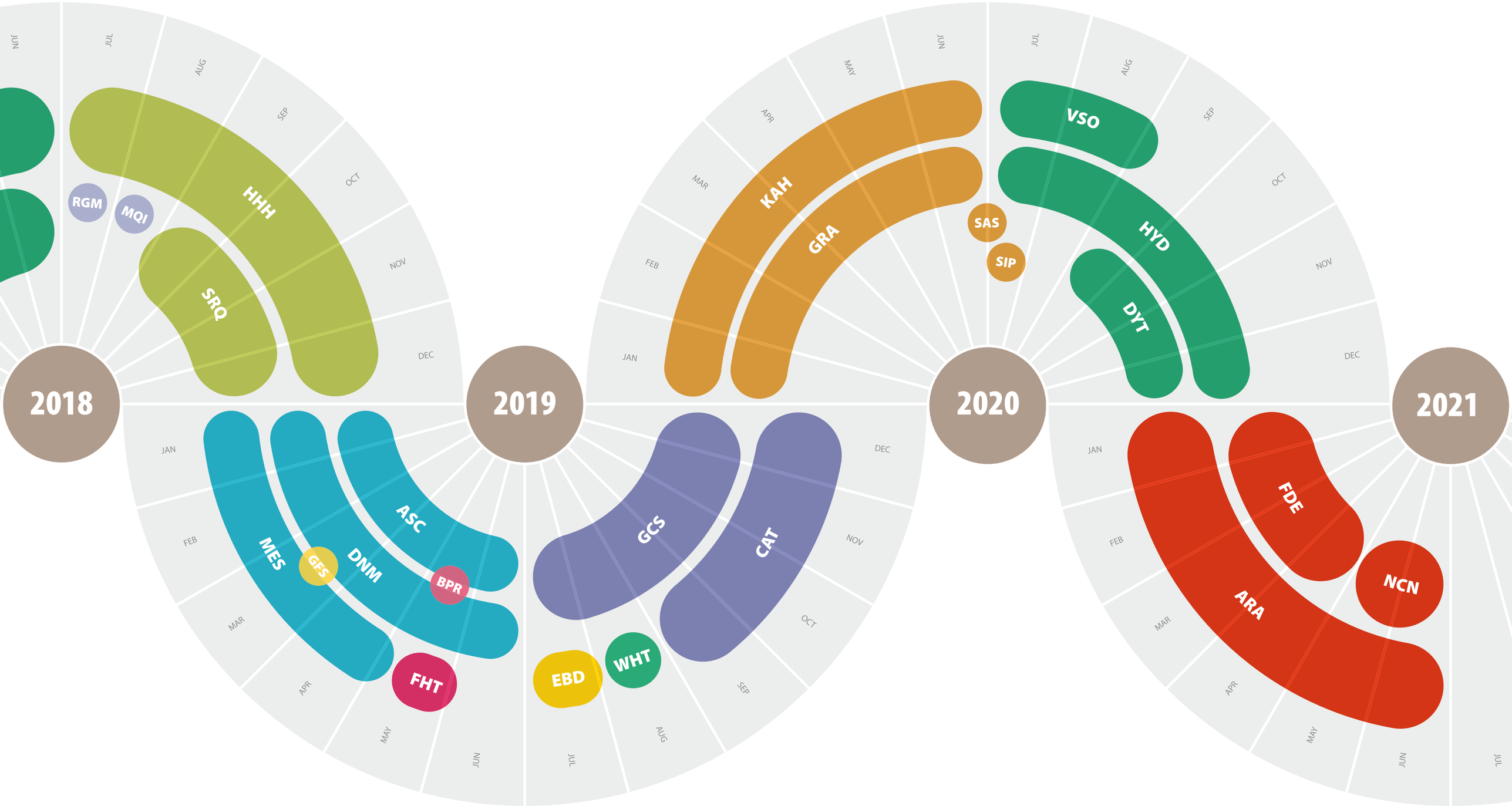
David Abrahams

focused long-term informal environment, and so almost all of our programmes are either intradisciplinary or interdisciplinary in nature. You will see later, in the short reports on each of our programmes, how this remains at the heart of all that we do. As lasting recognition of Sir Michael's contribution to mathematics and physics we have on display, via permanent loan from Trinity College Cambridge, the medals and many of his honours received during his lifetime.

I wish to draw attention to an important name change made over the last year – that of the transformation of the Turing Gateway to Mathematics to the Newton Gateway to Mathematics. This was a considered change to recognise the more integrated role that the Gateway now plays in the activities of the Institute. The Gateway's remit and activities, as defined and summarised in its Annual Report (attached as a pull-out to this Report) are to further knowledge exchange between the mathematical sciences community and those outside, either in other branches of academe or in business, industry, government etc. The Newton Gateway has expanded its range of mechanisms for promoting and supporting knowledge exchange, and in summer 2019 we saw the first integrated Newton Institute/Gateway short programme take place, on *Mathematical and statistical challenges in landscape decision making*. It was novel in a number ways, including being financed directly by the Natural Environment Research Council (NERC) with an accompanying funding call for collaborative research projects. It was a truly interdisciplinary project including an eclectic mix of communities from planners and legislators to statisticians and experts in uncertainty quantification.

As I have said in previous years, the success of the Institute relies heavily on the continued commitment and hard work of colleagues, associates and staff. I am indebted, in particular, to the many referees and the members of our various committees, who ensure that the quality and balance of our programming remains excellent. I thank all the organisers of our many events, who give their time selflessly for the good of their communities. Finally, I thank the INI and Gateway committee chairs for their dedication over the last 12 months: Ewan Kirk, Valerie Isham, Graham Keniston-Cooper, Peter Landrock and Alan Champneys.

David Abrahams
Director, Isaac Newton Institute



RGM Random geometry follow-on workshop

MQI Mathematical challenges in quantum information: Beyond I.I.D. in information theory

HHH Homotopy harnessing higher structures

SRQ Scaling limits, rough paths, quantum field theory

ASC Approximation, sampling and compression in data science

DNM The mathematical design of new materials

MES The mathematics of energy systems

GFS Growth, form and self-organisation follow-on workshop

BPR Big proof follow-on workshop

FHT The fickle heart

GCS Geometry, compatibility and structure preservation in computational differential equations

EBD Mathematical and statistical challenges in landscape decision making

WHT Bringing pure & applied analysis together via the Wiener-Hopf technique, its generalisations and applications

CAT Complex analysis: techniques, applications and computations

KAH K-theory, algebraic cycles and motivic homotopy theory

GRA Groups, representations and applications: new perspectives

SAS Semantics and syntax: a legacy of Alan Turing follow-on workshop

VSO Verified software

HYD Dispersive hydrodynamics: mathematics, simulation and experiments, with applications in nonlinear waves

SIP Mathematics of sea ice phenomena follow-on workshop

DYT Frontiers in dynamo theory: from the Earth to the stars

ARA Applicable resurgent asymptotics: Towards a universal theory

FDE Fractional differential equations

NCN New connections in number theory and physics

Homotopy harnessing higher structures

ORGANISERS:
John Greenlees *(Warwick)*,
Paul Goerss *(Northwestern)*,
Stefan Schwede *(Bonn)*,
Ulrike Tillmann *(Oxford)*

Algebraic topology has roots in the observation that many problems in differential geometry and topology, or in related areas of mathematical physics, can be approached through homotopy theory. The work of Kervaire and Milnor analyzing differentiable manifolds with the homotopy type of a sphere is a paradigm for this, and the spectacular recent solution of the Kervaire Invariant One problem for framed manifolds is in the same spirit. But the field has gone far beyond these roots: old problems have been solved using new methods; new methods have led to new ideas; new ideas to new problems; and new problems to new theorems. The result has been a renaissance.

This programme sampled the fruits of this renaissance by highlighting four intertwined themes: the new algebraic topology of differentiable manifolds; equivariant and motivic homotopy theory; the interplay between arithmetic geometry and stable homotopy theory; and the analysis of foundations in these new contexts. It attracted a remarkable community of long-term participants from across all career stages who sustained over the six month period a vibrant intellectual environment.

The programme attracted a remarkable community of long-term participants from across all career stages who sustained... a vibrant intellectual environment.

The themes each served as a focus for one of the workshops. Incorporating tutorial lecture series on higher categories and K-theory, the first week was an intensive introduction to, and survey of, the applications of the emerging theory and language of higher structures. At the end of the summer, there was a week-long investigation of the significant interplay between equivariant and motivic homotopy theory. In the early autumn, the third workshop examined the classical field of chromatic homotopy theory and the emerging field of derived algebraic geometry which again have strong cross-fertilization. The final workshop focused on the algebraic topology of manifolds, covering a wide range of areas from the classical to the modern, and on topics that couldn't even be formulated before the development of infinity categories. In between, Lars Hesselholt's Rothschild Lecture provided a remarkable overview of our new modes of thought.

Outside the workshops, anchored by seminars on Tuesdays and a 'Gong Show' on Thursdays, there remained ample time for more informal interactions. The Gong Show — four ten-minute talks — was a highly successful experiment, with animated and friendly audience participation, and conversations extending well past the hour. The community thrived both inside and outside the Institute: there were often thirty people at lunch, as many at the pub on Tuesday evenings, and over the weekends a core group of dedicated hikers covered hundreds of miles of countryside across Cambridgeshire and surrounding counties. Additionally, participants ventured further afield, visiting many UK universities and invigorating the British Topology Meeting.

INI served as a nexus for the in-gathering of this field, superbly providing space and time for the realization of old projects and the fermentation of new ideas.

ROTHSCHILD FELLOWSHIP
Professor L Hesselholt

SIMONS FELLOWSHIP
Professor J Bergner
Professor P Goerss
Professor J Greenlees
Dr T Lawson
Professor S Schwede
Dr B Shipley
Professor U Tillmann

GENDER BALANCE:
(M : F, %)

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

AGE DISTRIBUTION
(≤29 : 30-49 : ≥ 50 : unknown, %)

Scaling limits, rough paths, quantum field theory

ORGANISERS:
David Brydges *(British Columbia)*,
Alessandro Giuliani *(Roma Tre)*,
Massimiliano Gubinelli *(Bonn)*,
Antti Kupiainen *(Helsinki)*,
Hendrik Weber *(Bath)*,
Lorenzo Zambotti *(Université Pierre et Marie Curie Paris)*

Our understanding of physics at very small scale is based on Quantum Field Theory (QFT), the offspring of a marriage between quantum mechanics and special relativity. Right from inception QFT challenged mathematics because the interrelations of the infinitely many degrees of freedom of a quantum field are beyond standard approximation schemes. Part of the response to this was the formulation of axioms that capture the essential properties of QFT, but these threw up further questions including: Are the axioms themselves consistent?

Models satisfying the axioms of QFT have been constructed for two and three dimensional space-time, but not for the four dimensional space-time of physics. For two and three dimensional space-time these constructions required the invention of ingenious new methods which go under the name of Constructive QFT. By merging those efforts with Wilson's Renormalisation Group, QFT can be related to the probabilistic behaviour of assemblies of very many "almost" independent degrees of freedom, as formalised by the concept of scaling limits. A basic example of a scaling limit appears in the Central Limit Theorem from probability, but scaling limits can be far more interesting than this. Recent progress in understanding the non-Gaussian scaling limits described by non-linear stochastic partial differential equations (SPDE) has rested on Rough Path theory, the final ingredient in this programme. This is a systematic calculus for SPDE that incorporates the propagation of nonlinear effects from small to large scales.

...the goal of this programme was to create at the Newton Institute the best possible environment for each of the two communities to learn from one another.

Despite their shared interests, Constructive QFT and SPDE evolved separately over an extended period and the goal of this programme was to create at the Newton Institute the best possible environment for each of the two communities to learn from one another.

The 81 participants were drawn more or less evenly from both communities and related areas. A series of workshops, mini-courses and regular seminars fostered the interest of the younger generation in the problems and results of the older, and built foundations of friendship, collaborations and respect that were not there before. Long term participants Moinat (Warwick), Weber (Bath), Gubinelli (Bonn) and Hofmanova (Bielefeld) developed new SPDE proofs of some of the axioms for Euclidean scalar quantum fields in 3 dimensions that originally rested on difficult stability results of the constructive programme by Glimm and Jaffe. Gauge invariant QFT has been invigorated by participants Chandra (Imperial), Hairer (Imperial) and Shen (Wisconsin-Madison) using an SPDE point of view, which is very different from the classic work of Balaban. Gauge invariance is key to progress in four dimensions and rough path theory has applications in diverse fields including financial mathematics and fluid mechanics. This programme reviewed these applications in seminars and a wide-ranging workshop on statistical applications including handwriting recognition. However, the true signal of success of the programme will be the progress in coming years.

ROTHSCHILD FELLOWSHIP
Professor M Hairer

SIMONS FELLOWSHIP
Dr A Chandra
Professor G Da Prato
Professor M Hofmanova
Professor G Jona-Lasinio
Professor T Levy
Professor G Slade
Professor D Brydges
Professor P Mitter

GENDER BALANCE:
(M : F, %)

86	14

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

21	79

AGE DISTRIBUTION
(≤29 : 30-49 : ≥ 50, %)

21	48	31

The mathematics of energy systems

ORGANISERS:
John Moriarty *(QMUL)*,
Andy Philpott *(Auckland)*,
Almut Veraart *(Imperial)*,
Stan Zachary
(Heriot-Watt),
Bert Zwart *(CWI, TU/e)*

The Mathematics of Energy Systems programme brought together internationally leading mathematicians, power systems engineers and economists over a period of four months. Both academia and industry were strongly represented in its senior international scientific advisory committee, in order to create the broadest possible interest and engagement within the energy systems community.

Particular focus was placed on the contribution of the mathematics of uncertainty to energy systems research, including predictive modelling and ensemble forecasting; stochastic optimal control and scheduling; rare event analysis; and market pricing under uncertainty. These methods were applied to problems of planning, operation and trading in both present and future decarbonised energy systems.

The scientific programme, which was designed to promote cross-disciplinary collaboration, took the form of nine research tracks and three international workshops. The three workshops addressed problems respectively at short, medium and long timescales, while the research tracks focused on specific themes across the programme's scope. Beyond scientific excellence, a particular highlight of the workshops was their industrial participation. Senior industry figures from the US, Europe and the UK gave talks and participated in discussions, providing an invaluable perspective on the research agenda.

Senior industry figures from the US, Europe and the UK gave talks and participated in discussions, providing an invaluable perspective on the research agenda.

The research tracks were week or fortnight-long periods of cross-disciplinary exchange led by experts in the field, during which current research blockages were identified and potential routes forward proposed. Each track had goals appropriate to its theme. In some cases, collaborative projects were begun in which methodology from one domain was brought into another for the first time, in order to overcome current limitations in the state of the art. Other tracks resulted in the writing of opinion pieces assessing current research blockages and proposing routes forward over the coming years. In addition to their timeliness, all these projects will contribute to overcoming disciplinary 'language barriers' and fostering future interdisciplinary exchange.

The programme supported two satellite workshops, each presenting internationally leading mathematical research in a subdiscipline with emerging applications to energy systems. 'Stochastic control and games under ambiguity' at the University of Leeds comprised a two-day workshop and three further days of visitor research, while 'Mean-field games, energy systems, and other applications' at the International Centre for Mathematical Sciences included a one-day mini-course and four-day conference. Scientific dissemination was promoted through mutual exchange visits between the satellites and main programme.

Following the programme an open call for papers was made to all participants for contributions to a themed issue of Philosophical Transactions of the Royal Society A on the Mathematics of Energy Systems. This volume will present opinion pieces on future energy markets, predictive modelling for electricity systems, and short term security management, together with original, highly interdisciplinary research which was begun or significantly advanced at the programme in the areas of planning under uncertainty, data and analytics for short-term operations, and electricity trading.

The organisers would like to thank National Grid ESO and Google DeepMind for their generous sponsorship of the programme.

ROTHSCHILD FELLOWSHIP
Professor E Anderson

KIRK FELLOWSHIP
Professor C Sagastizabal

SIMONS FELLOWSHIP
Professor J Bialek
Professor M Ferris
Professor J Moriarty
Professor F Paraschiv
Professor A Philpott
Professor P Pinson
Professor A Veraart
Professor L Wehenkel
Dr S Zachary

GENDER BALANCE:
(M : F, %)

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

AGE DISTRIBUTION
(≤29 : 30-49 : ≥ 50 : unknown, %)

Approximation, sampling and compression in data science

ORGANISERS:
Alexei Shadrin *(Cambridge)*,
Anders Hansen *(Cambridge)*,
Vladimir Temlyakov *(South Carolina)*,
Sergey Tikhonov *(ICREA)*

Recently, driven by applications in engineering, biology, medicine and other areas of science, new challenging problems have appeared in approximation theory and related fields. The common feature of these problems is high, really high, dimensions: classical methods developed in multivariate approximation theory may work for moderate dimensions, say, up to dimension 40 but these problems become increasingly challenging due to the curse of dimensionality. The focus of this six-month programme was to develop approximation machinery to understand and solve challenging problems in high dimensions.

The main research periods were structured around four workshops, each of them with a different focus. Three of them: 'Challenges in optimal recovery and hyperbolic cross approximation', 'The Mathematics of Deep Learning, and Data Science', and 'Approximation, sampling, and compression in high dimensional problems' took place in the Institute. The fourth workshop, 'Mathematics of data: structured representations for sensing, approximation and learning', was organized in the collaboration with the Alan Turing Institute in London, further developing the links between these two institutions.

"... the participants achieved multiple breakthroughs in solving old problems from classical approximation theory"

The workshops attracted well over 300 participants, coming from diverse areas of pure and applied mathematics including, amongst others, approximation theory, harmonic analysis, functional analysis, signal processing, machine learning and optimization. Outside workshop weeks, seminars and open problem sessions took place. Further, two introductory courses were given for early career participants: the first, delivered by Erich Novak, was on information based complexity, and the second, by Ben Adcock, was on compressed sensing and sparse approximation. The programme included two special lectures by Ronald DeVore (Rothschild Distinguished Visiting Fellow) and Svitlana Mayboroda (Kirk Distinguished Visiting Fellow) which were aimed at a wide audience comprising experts and the general public. These lectures provided an overview of the state of art in numerical computation with special emphasis on high dimensional problems (DeVore) and localization phenomena under irregularities of systems (Mayboroda). We would also like to mention the very well attended talk given by Martin Buhmann as part of the Isaac Newton Institute Seminar Series about the Mathematikum in Giessen, Germany, an educational centre for the public with hands-on mathematical exhibits.

Scientific achievements of the programme can be summarised as follows: on the one hand, the participants achieved multiple breakthroughs in solving old problems from classical approximation theory, specifically, sampling problems, discretization, polynomial inequalities, function spaces; on the other hand, several interesting new directions were developed in multivariate approximation problems (including problems in nonlinear approximation, in particular, m-term approximation, greedy approximations, etc) where a classical multivariate approximation approach does not work.

The programme attracted many young researchers in early stages of their careers, who actively participated in the scientific life of the programme. During the programme, the Institute also welcomed several mathematicians from such countries as India, Kazakhstan, Russia, Ukraine, thereby achieving another of the programme's goals, to foster international collaboration among leading mathematical schools in the world.

ROTHSCHILD FELLOWSHIP
Professor R DeVore

KIRK FELLOWSHIP
Professor S Mayboroda

SIMONS FELLOWSHIP
Professor D Bilyk
Professor F Dai
Professor D Dinh
Professor A Hinrichs
Professor B Kashin
Professor G Nikolov
Dr V Temlyakov
Professor S Tikhonov

GENDER BALANCE:
(M : F, %)

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

AGE DISTRIBUTION
(≤29 : 30-49 : ≥ 50 : unknown, %)

The mathematical design of new materials

ORGANISERS:
Arghir Zarnescu *(BCAM)*,
Xian Chen *(HKUST)*,
Miha Ravnik *(Ljubljana)*,
Valeriy Slastikov *(Bristol)*

This six-month programme brought together participants with diverse expertise, including applied mathematics, physics, chemistry and engineering, all interested in materials with unusual properties. The main focus of the programme was on the design of new materials, rather than simply the understanding of existing ones. Alongside the core research periods, the programme included four academic workshops, two Newton Gateway knowledge-exchange events and one Spring school, all sharing a common theme: design of materials.

Soft matter was an important part of the research programme, especially focusing on topics of active and passive complex fluid materials. Research was performed along multiple research themes, such as mathematics of colloids in nematic fluids, topology and topological defect as signatures of material frustration, microfluidic application of complex fluids, active matter and active fluids, the role of molecular and micro-material design, and shape control by liquid crystal elastomers. As part of the activities on soft matter, a workshop on the 'Optimal design of soft matter', including a celebration of 'Women in materials science (WMS)', featured invited and contributed talks from top-level international speakers.

During the first and second workshops and the first Newton Gateway event the primary topics were the mathematical design of new phase transforming materials with emerging applications to medical devices, and phase-transforming multiferroic materials used in energy conversion devices. A mini-symposium within the satellite workshop at ICMS Edinburgh focused on machine learning approaches for algorithmic design of new materials. It showed that more and more experimentalists adapted to the rational material design strategy guided by the cofactor conditions, sets of mathematical conditions on material structural parameters.

Researchers from all over the world... gathered together to explore the differences in their approaches and to find common ground and new insights.

Thanks to the first knowledge exchange event, industry participants established close connections with their academic counterparts. For example, Andrew Bissell, CEO of Sunamp Ltd., a company interested in renewable thermal energy storage, showed great interest in energy conversion by first-order phase transforming ferroelectrics as described by academic participants. After the event, and following subsequent discussions, he sent engineers from his team to the Edinburgh satellite workshop and Spring School so that they might learn more about new mathematical ideas with application to thermal batteries.

Overall we discovered a multifaceted approach to design: in mathematics, design is based on minimization and optimization problems in the framework of calculus of variations; in engineering, design is a process of trial-test-correction; and in physics and mechanics it is related to understanding and proposing a constitutive law. Researchers from all over the world use their own tools to solve similar design problems, but here at the Newton Institute they gathered together to explore the differences in their approaches and to find common ground and new insights, establishing fruitful collaborations and possible new breakthroughs in the field of material design.

ROTHSCHILD FELLOWSHIP
Professor G Milton

KIRK FELLOWSHIP
Professor I Fonseca

SIMONS FELLOWSHIP
Professor J Ball
Professor C Calderer
Professor X Chen
Professor R James
Professor M Ravnik
Dr V Slastikov
Professor M Telo da Gama
Professor A Zarnescu

GENDER BALANCE:
(M : F, %)

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

AGE DISTRIBUTION
(≤29 : 30-49 : ≥ 50 : unknown, %)

The fickle heart

ORGANISERS:
Steven Niederer *(KCL)*,
Helen Byrne *(Oxford)*,
Colleen Clancy *(California, Davis)*
Richard Clayton *(Sheffield)*,
Gary Mirams *(Nottingham)*,
Ian Vernon *(Durham)*

Cardiac modelling and simulation is beginning to be applied within clinical settings. Applications include optimisation of patient treatment through the development of patient specific models of the heart. A key goal of this programme was to bring together the cardiac modelling and uncertainty quantification communities to develop mathematical approaches to quantify uncertainty in model predictions. Such advances are vital for future developments of clinical applications of cardiac models.

This programme brought together 34 experts from a wide range of mathematics and science disciplines - including medical imaging, physiology, numerical analysis, computational modelling, data science, statistics and uncertainty quantification - with the goal of developing tools to quantify uncertainty in cardiac model predictions. Such advances are needed to better inform clinicians, meet strict clinical safety regulations and ultimately ensure patient safety. A key success of the programme was the opportunity for researchers from different backgrounds to interact, allowing for the development of new collaborations.

Throughout the programme there was daily interaction with experimentalists at the Victor Chang Cardiac Research Institute in Australia. Exploiting the time difference, experiments designed by INI participants were run in Australia each night (UK time), with results analysed the following morning by programme participants. This led to the development and validation of a novel mathematical model of a cardiac potassium current.

Key highlights of the programme included a Newton Gateway Open for Business day attended by practising clinicians, experimentalists and representatives from the medical device and pharmaceutical industries. The day illustrated recent applications of cardiac models in the healthcare sector and highlighted the importance of uncertainty quantification to enable further developments in this area.

The workshop set an INI record with 28 posters displayed during the three-days primarily from early career researchers

A three-day workshop ended the programme with 85 attendees from both academia and healthcare professions. The workshop set an INI record with 28 posters displayed during the three-days primarily from early career researchers. The advances made in this programme will form a special issue of Philosophical Transactions of the Royal Society A.

This programme was in part supported by NFS funding.

GENDER BALANCE:
(M : F, %)

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

AGE DISTRIBUTION
(≤29 : 30-49 : ≥ 50 : unknown, %)

Mathematical and statistical challenges in landscape decision making

ORGANISERS:
Peter Challenor *(Exeter)*,
Peter Cox *(Exeter)*,
Felix Eigenbrod *(Southampton)*,
Paula Harrison *(CEH)*,
Simon Kerley *(NERC)*

Landscapes are complex systems, involving interactions between both biophysical and human processes. A key challenge facing those making choices about the future management of UK landscapes is how to make better evidence-based decisions that take a holistic view of the landscape. This NERC funded programme aimed to start the collaboration between environmental and mathematical scientists to begin to address this challenge through the use of mathematical modelling.

Attended by mathematicians, statisticians, economists and environmental scientists, a key goal of the programme was to identify where mathematics could lead to a step change in the modelling currently done in environmental sciences, and thence to ultimately provide decision makers with the tools to enable them to make better evidence-based decisions regarding landscapes. A number of skype meetings with Department for Environment, Food and Rural Affairs (Defra) guided the key questions and challenges addressed, ensuring the relevance to key stakeholders of the research undertaken during the programme.

A key outcome of the programme was that it led to more than 10 proposals submitted to the "Landscape and Decisions mathematical and statistical challenges" NERC funding call.

The programme began with a three-day workshop, the first day of which was a Newton Gateway Open for Business Day, including talks from key governmental bodies including Defra, Forestry Commission and the Environment Agency. The first workshop set the scene of the current state of landscape decision making in the UK as well as the key challenges. This informed the discussions and research undertaken throughout the rest of the programme.

The programme ended with a three-day workshop, the last day of which was a Newton Gateway Open for Business day. The workshop synthesized new research frontiers and synergies identified during the programme. In particular, the Open for Business day, attended by the Duncan Wingham, Chief Executive of NERC, identified research road maps which will feed into the next phase of the Landscape Decision Making Strategic Priorities fund.

A key outcome of the programme was that it led to more than ten proposals submitted to the 'Landscape decisions mathematical and statistical challenges' NERC funding call. These involved new collaborations between mathematicians, statisticians and environmental scientists who attended the programme. Hopefully these collaborations will be built upon as part of the Strategic Priorities Fund (SPF) programme 'Landscape Decisions: Towards a new framework for using land assets'.

GENDER BALANCE:
(M : F, %)

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

AGE DISTRIBUTION
(≤29 : 30-49 : ≥ 50 : unknown, %)

Follow-on workshops

Mathematics of form in active and inactive media: follow-on workshop (25-29 March 2019)

ORGANISERS:
Professor A Boudaoud *(Lyon)*,
Professor A Herczynski *(Boston)*,
Professor E Lauga *(Cambridge)*,
Dr M Lisicki *(Cambridge)*

This workshop, held in Fitzwilliam College and partially supported by US government agency the National Science Foundation (NSF), was a follow-on to the programme *Growth, form, and self-organization* held in the second half of 2017. The principal goal of the workshop was to consider progress achieved in the two intervening years, and to address in particular themes that bridge active and inactive media. It also aimed to nurture and motivate scientists at the start of their careers with senior participants helping to identify promising junior researchers to be invited.

A major ambition was to bring into focus outstanding questions and directions with potential for breakthroughs relating to the mathematical aspects of form in inanimate and living systems, and also to highlight commonality in various strands of research on shape selection and deformations. Universal concepts such as chirality, viscoelasticity, and flow-structure interactions, were emphasized.

The interplay of morphogens and mechanics was one such broad theme, requiring coupling of the mechanistic approaches to biochemical fields. Among the new directions discussed were links between micro and macro scales, particularly in the context of active media (such as living tissues and self-organizing swarms), and also "transplanting" fruitful approaches in inactive media to active media (and possibly vice-versa).

The physics of living systems was addressed in the latter part of the workshop. Topics spanned many scales, from single cell organisms and the relation between their geometry and dynamics, to the collective motion of large assemblies of microswimmers. A number of talks illuminated in complementary ways longstanding problems such as the coupling between swimming organisms and the resulting flow, pattern formation in biofilms, and artificial flow generation in biomimetic systems.

Informal discussions and impromptu gatherings were an integral part of the workshop. The highlight of these social interactions was the conference dinner at St. John's College with the witty after dinner talk by Mimi Koehl (Berkeley) alluding to various notable episodes of the week.

Big Proof : follow-on satellite workshop at the International Centre for Mathematical Sciences (27 - 31 May 2019)

ORGANISERS:
Professor U Martin *(Oxford)*,
Professor N Shonkar *(SRI)*

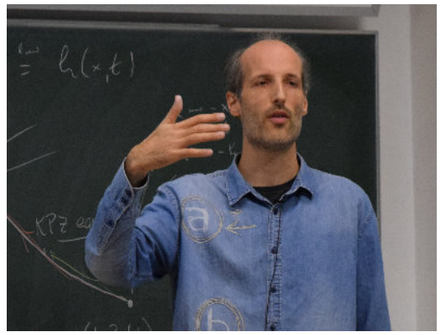
The Isaac Newton Institute programme *Big proof* during the summer of 2017 drew a great deal of interest from mathematicians, philosophers, and computer scientists. In May 2019 a week-long follow-up workshop funded by the Newton Institute was held at the International Centre for Mathematical Sciences in Edinburgh. This workshop followed up on a number of the key initiatives from *Big proof* including:

- Pragmatic foundations for the formalization of mathematical proofs;
- Social processes that support research, exposition, and learning in mathematics;
- Interchange formats and repositories for formal mathematical knowledge;
- Scalable proof automation;
- Applications of *Big proof* technology.

A broad range of topics were covered during the 2019 workshop such as the relevance of foundations for formalization; the need to build digital mathematical libraries; the formalization of definitions and paper abstracts; bridging the informal-formal gap in mathematical discourse; diagramatic reasoning; challenges mathematicians face in using current interactive proof assistants; applications of proof technology in mathematics, physics, education, and research; the use of machine learning technology in generating conjectures, proofs, and proof strategies; outreach to new communities of users; and large-scale formalization projects like Flyspeck, Stacks, and Perfectoid spaces. Professor Donald MacKenzie (Edinburgh) delivered a stimulating public lecture on the impact of high-frequency trading technology.

A number of significant themes emerged from the lively presentations and discussions during the workshop. Collectively they emphasized the potential for interactive proof technology to genuinely transform the sociology of mathematics from an individualistic pursuit to a community enterprise that enhances human creativity, understanding, and exploration while preserving rigour and precision. As an example of engagement and impact during the workshop, on the first (Monday) afternoon session of the workshop, Larry Paulson (Cambridge), one of the organisers of the 2017 programme, posed the challenge of formalizing Littlewood's informal proof that a cube cannot be dissected into smaller cubes of unequal size. By Wednesday morning, Floris van Doorn (Pittsburgh) had elegantly formalized this argument using the Lean proof assistant.

It has been another busy year at the Institute with seven programmes running over the course of the year and 25 weeks of workshops including five satellites and two follow-on workshops. There were over 1500 registered programme participants, over 500 registered workshop participants, and a further 400 additional visitors to the Institute.



The quality of science at INI remains stellar with participants including Fields Medalist Martin Hairer (Imperial), who was the Rothschild Distinguished Visiting Fellow on the SRQ programme, and Sir Andrew Wiles (Oxford), now an Honorary Fellow of the Institute, who returned to INI for a workshop to celebrate the 25th anniversary of his proof of Fermat's last Theorem. Additionally, we were delighted to welcome Professors Svitlana Mayboroda (University of Minesota), Irene Fonseca (Carnegie Mellon University) and Claudia Sagastizabal (Universidade Estadual de Campinas) who were the inaugaural Kirk Distinguished Visiting Fellows on the ASC, DNM and MES programmes. This prestigious new fellowship for field-leading individuals from under-represented groups was created in 2019 following a generous donation from Dr Ewan Kirk, Chair of the Institute's Management Committee.

With over 700 new seminars by over 550 speakers added to the Institute's seminar archive **www.newton.ac.uk/webseminars** over the course of the year, INI continues to be the single largest provider of hosted video content on the University's Streaming Media Service. Of these seminar speakers, where this data is known: 20% were female; 27% were either students or postdocs; and 34% were UK-based. Additionally, 31 papers were added to the INI Preprint Series **www.newton.ac.uk/documents/preprints** taking the total in the archive to a little under 1,400.

Serving the UK Community

We are delighted to announce that Niall MacKay (York) took over the role of Chair of the Institute's Network of Correspondents at the end of 2018 and would like to repeat our thanks to Ulrike Tillmann (Oxford) for acting as interim Chair. Following the extension of the remit of the Network to include the International Centre for Mathematical Sciences (ICMS), Edinburgh, the 2019 Correspondents Day was held in Scotland and Niall used this opportunity to introduce himself to the Network and to challenge Correspondents to think about how INI and ICMS can best serve the UK mathematical sciences community.

INI's commitment to supporting and engaging with the UK mathematics community remains strong and over a third of all programme and workshop participants were UK-based, representing 120 different institutions, companies and government agencies. Of the 551 UK-based workshop participants, 23% were based in Scotland and 25% were from institutions in England that are North of the line from the Severn Estuary to The Wash; participation numbers from Wales and Northern Ireland remain low. In addition to the five satellite workshops held during the year, located in Edinburgh, Leeds and London, 50 long-term programme participants gave a total of 83 'Talks Elsewhere' seminars at 29 institutions across the UK, with 10 talks in Scotland, three in Wales, nine in the North-East and North-West and 13 in the South West. Talks Elsewhere speakers are now asked to embed within their talks a brief presentation about INI and how to participate in its activities. Additionally, Correspondents are asked annually to give a similar presentation to colleagues at a departmental meeting.

Fields medallist Caucher Birkar will be the guest speaker at the 2020 Correspondents Day meeting.

Equality and Diversity

INI remains committed to supporting early career researchers; and of the programme participants who gave their work status information, 8% were research students and 13% were postdoctoral researchers. For workshops participants these figures rise to 18% and 17% respectively. We have begun collecting data indicating whether participants identify as early career researchers according to EPSRC's criteria. Although data is still sparse, 50% of programme participants and 43% of workshop participants who provided this information self-identified as early career researchers (ECRs). By a different metric, and for comparison with past years, we note that 30% of all programme participants and 42% of workshop participants for whom we have that data were aged 35 or under.

The Institute's Provision of Care scheme **www.newton.ac.uk/information/childcare** continues to provide financial and practical support for those with caring needs or responsibilities.

Institute Activities (continued)

In the academic year 2018-2019 there were 12 successful applications to the Provision of Care scheme. Collectively they received a total of £43k. Of the 12 funded participants in academic year 2018-2019, the nine female applicants received over 92% of the allocated funds.

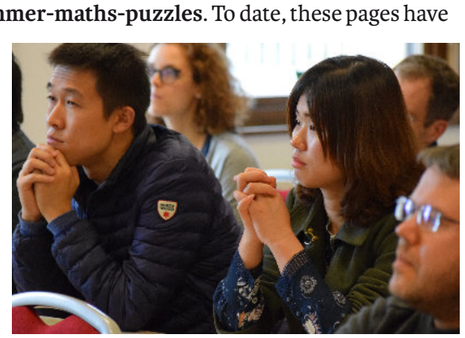
A scheme for removing barriers to participation for participants from DAC-listed countries **www.newton.ac.uk/outreach/DAC** was introduced in 2019 and thus far 13 individuals of 10 different nationalities based in eight different countries including Ghana, India, Mexico, Nepal and Pakistan have received a total of almost £9k to assist with travel, accommodation, visa and local expenses. Feedback indicates the life-changing impact that support from these schemes can provide.

The international mix of participants remains high with approximately a third of all programme participants coming from the UK, a third coming from the rest of Europe and the remaining third coming from the rest of the world. The proportion of UK-based participants is slightly higher for workshops. Programme and workshop participants were of 120 different nationalities and came from over 650 different institutions in 75 different countries spanning all continents. We have begun collecting information on ethnicity but this data is currently still sparse.

Communications and Public Engagement

In the past year the Institute's monthly online "e-bulletin" newsletter subscriber base has grown in size to a high of just under 1,400. Combined with other distribution lists, a total of over 17,000 e-bulletins were delivered during that 12-month period. Engagement with the e-bulletin has seen a significant rise over the reporting year.

The Institute's website, **www.newton.ac.uk**, continues its robust performance, averaging 18,000 users per month. A particularly popular attraction was the 'Summer Maths Puzzles' project where, throughout August, a different mathematical puzzle was published each weekday to encourage public engagement with mathematics during the school summer holidays , see: **www.newton.ac.uk/news/summer-maths-puzzles**. To date, these pages have received over 15,000 unique page views by over 4,500 distinct users. In terms of demographics: 34% of the users visiting the puzzle pages were from the US, 26% from the UK, with the other major groups (in gradually descending order from 6-1% each) being from India, Germany, France, Canada, Australia, China, Japan and the Netherlands. Hundreds of solutions to these puzzles were submitted by email, with the puzzle solvers ranging from families and school children to established academics.

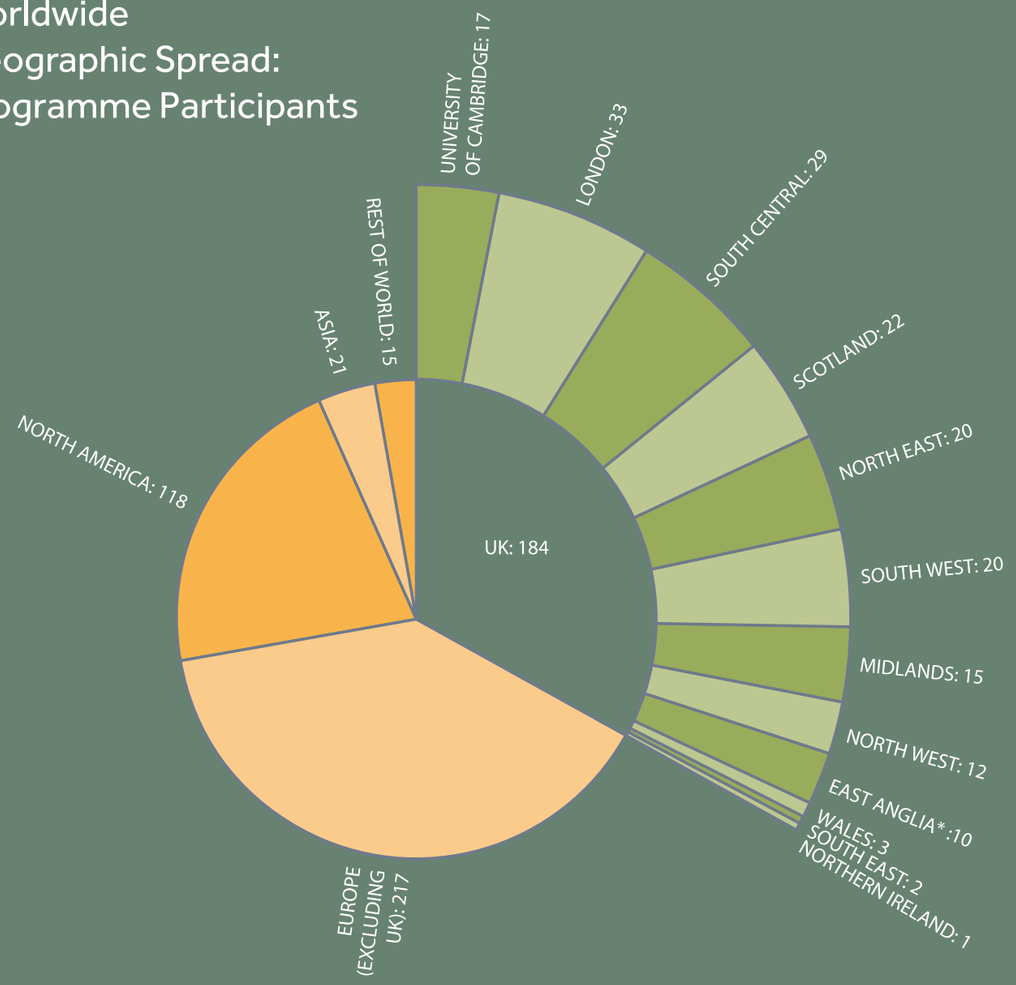


INI's social media streams, via Facebook, Instagram and Twitter, are continuing to grow in reach. This is most pronounced in the latter which now boasts over 5,500 followers. Each month there are up to 170,00 impressions, up to 3,000 profile visits, and "@NewtonInstitute" is referenced up to 150 times in other users' content.

The team at INI has produced 23 programme organiser video interviews since August 2017 with a further 4 videos on other relevant subjects and topics such as Rothschild and Kirk Fellowship talks, childcare support, and funding for participants from DAC-listed countries. This growing repository of video content is hosted concurrently on INI's new YouTube channel, **www.newton.ac.uk/youtube**, and the University's Streaming Media Service.

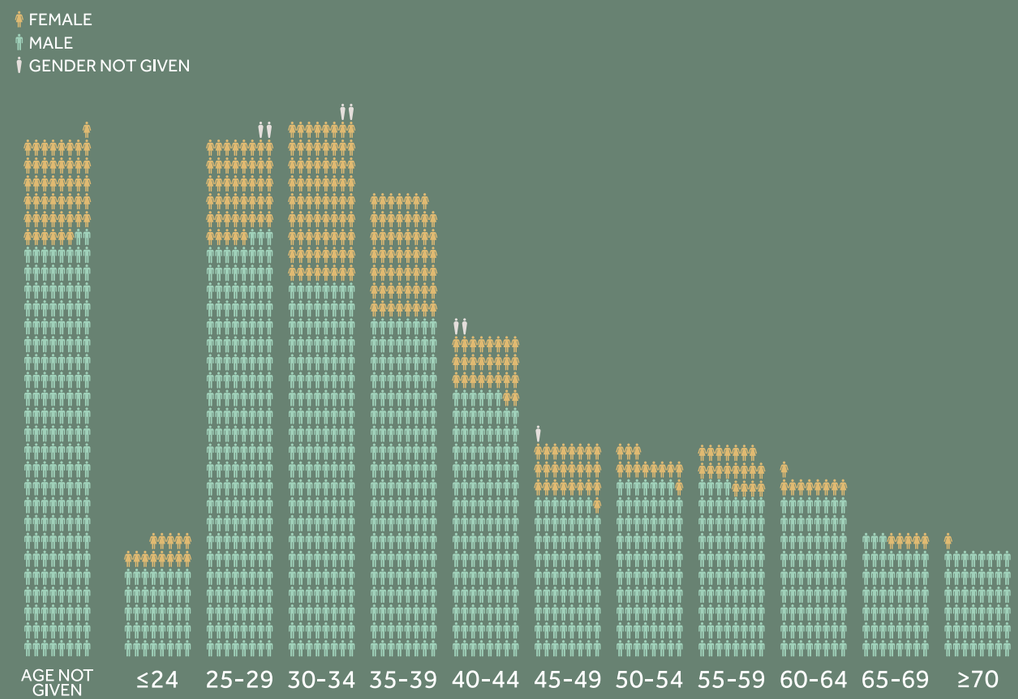
Outreach and public engagement has maintained its importance for the Institute, with two particular events deserving mention and celebration. The Institute's annual contribution to the Cambridge Science Festival in 2019 took the form of the talk: 'Making Alexa Smarter – AI at scale' by Dr Craig Saunders, Head of Applied Science at Amazon Alexa Knowledge. Dr Saunders' fascinating talk was delivered to a 120+ capacity crowd, with an overflow room used to accommodate the large number of those who attended. A particularly active question and answer session followed the presentation. Secondly, INI and the Newton Gateway to Mathematics once again took part in the New Scientist Live exposition at London's ExCel centre. Combined on a single stand alongside three other partners (the Operational Research Society, the Institute of Mathematics and its Applications and the International Centre for Mathematical Sciences), the Institute and Gateway embraced this unparalleled opportunity for public engagement to spread awareness of the UK's vibrant mathematics community and its own role within it. Between the five partners, close to 8,000 branded puzzle cubes were distributed to show visitors over its four-day run, whilst the 'Summer Maths Puzzles' (see above) initiative was used to further engage attendees in the pleasure of mathematical problem solving. Thanks in large part to 13 different volunteers from amongst INI and Gateway staff, the stand was expertly run and myriad conversations and engagements of potentially significant impact with visitors of all ages were enjoyed.

Worldwide Geographic Spread: Programme Participants

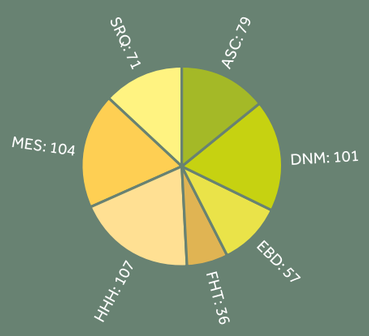


*Excluding University of Cambridge

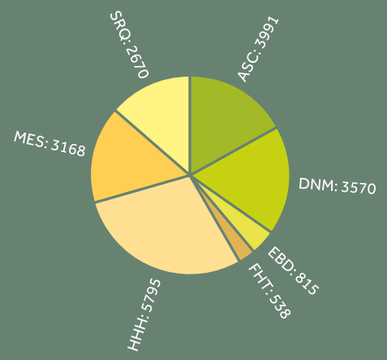
Gender and Age: Workshop Participants



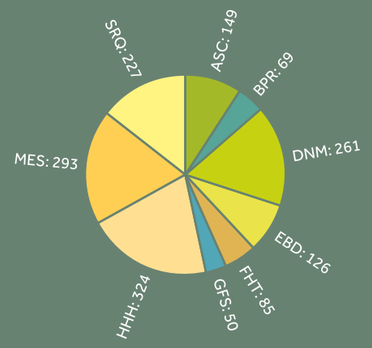
555
PROGRAMME PARTICIPANTS



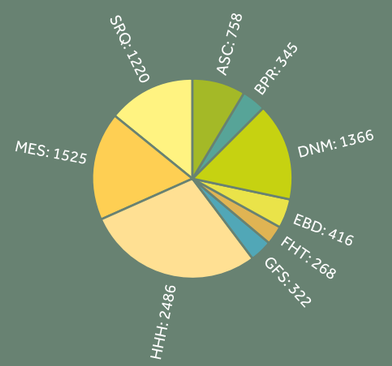
20547
PROGRAMME PARTICIPANT DAYS



1584
WORKSHOP PARTICIPANTS



8706
WORKSHOP PARTICIPANT DAYS



Accounts for August 2018 to July 2019

For the Isaac Newton Institute and Newton Gateway to Mathematics

Income	*Notes*	**2018-2019**	2017-2018
		£000	£000
Research Grants and Contracts	*1*	**2,068**	1,980
Contribution from the University of Cambridge	*2*	**485**	408
Donations	*3*	**500**	157
Additional workshop income		**117**	123
Additional income	*4*	**312**	261
Endowment and investment income	*5*	**483**	428
Total income		**3,965**	3,357
Expenditure			
Staff costs		**959**	943
Travel and subsistence	*6*	**1,487**	1,248
Other operating expenses	*7*	**446**	358
Overheads paid to the University	*8*	**491**	448
Total expenditure		**3383**	2,997
Surplus / (deficit)		**582**	360

Notes to the Accounts

Note 1 - Research Contracts and Grants (EPSRC & Simons Foundation)

Salaries	476
Participant costs (travel and subsistence)	1141
Other costs	-
Estates and indirect income	451
Total	**2068**

Note 2 - Contribution from the University of Cambridge

The University's financial contribution towards the Institute's running costs. In addition, the University provides the main and Gatehouse building, and pays for all services and rates.

Note 3 - Donations

London Mathematical Society	45
Cambridge Philosphical Society	4
Kirk Distinguished Visiting Fellows	250
Winton Philanthropies	200
Donations, other	1
Total	**500**

Note 4 - Additional income

Merchandise sales	9
Programme sponsorship	248
HEIF (NGM)	55
Total	**312**

Note 5 - Endowment &Investment income

Endowment & Investment income from Garfield Weston Foundation, Clive Humby and Edwina Dunn, Henderson Group, PF Charitable Trust, Rothschild and Turner Kirk Charitable Trust is now shown separately.

Note 6 - Participant costs

Programme & workshop	1,474
Staff travel & subsistence	13
Total	**1,487**

Note 7 - Other operating expenses

Computing	47
Institute running costs	124
Catering	31
Net housing costs	167
Furniture	13
Professional & brought in services	64
Total	**446**

Note 8 - Overheads paid to the University

Includes Estates and Indirect costs on grants and overheads on Trust Funds.

Governance: Advisory Council

Dr Ewan Kirk,
Chair of the Management Committee

Management Committee

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. Membership of the Management Committee at 31 July 2019 was as follows:

Name	Institution	End of Service
Dr Ewan Kirk (Chair)	General Board	31 Dec 2022
Professor I. David Abrahams	Director, Isaac Newton Institute	30 Sep 2021
Dr Katie Blaney	EPSRC	
Professor Nigel Cooper	Council of the School of Physical Sciences	31 Dec 2022
Dr Gabor Csanyi	Council of the School of Technology	31 Dec 2019
Professor Mark Gross	Faculty of Mathematics	31 Dec 2019
Professor Valerie Isham	Chair of the Scientific Steering Committee	31 Dec 2020
Professor Eric Lauga	Trinity College	31 Dec 2019
Professor Nick Manton	St John's College	31 Dec 2019
Dr Christie Marr (Secretary)	Deputy Director, Isaac Newton Institute	
Professor James Norris	Head, DPMMS, University of Cambridge	
Professor Nigel Peake	Head, DAMTP, University of Cambridge	
Professor Ulrike Tillmann	London Mathematical Society	31 Dec 2019

Professor Valerie Isham
Chair of the Scientific Steering Committee

Scientific Steering Committee

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. Membership of the Scientific Steering Committee at 31 July 2019 was as follows:

Name	Institution	End of Service
Professor Valerie Isham (Chair)	University College London	31 Dec 20
Professor I. David Abrahams	Director, Isaac Newton Institute	30 Sep 21
Professor Mark Chaplain	University of St Andrews	31 Dec 21
Vacancy		
Professor Paul Glendinning	Manchester	31 Dec 19
Professor Iain Gordon	Edinburgh	31 Dec 19
Professor Aleksandar Mijatovic	Warwick	31 Dec 22
Professor Jon Keating	University of Bristol	31 Dec 20
Professor Dame Frances Kirwan	Oxford	31 Dec 19
Professor Carola-Bibiane Schönlieb	Cambridge	31 Dec 22
Professor Robin Henderson	Newcastle	31 Dec 19
Professor Richard Taylor	Institute for Advanced Studies	31 Dec 20
Professor Susanna Terracini	Università degli Studi di Torino	31 Dec 20

Cumulative Financial Grants and Donations above £10,000

Elena Ambrosiadou • Michael Astor • Apple Computers Ltd. • Applied Probability Trust • Autonomy Systems Ltd. • Iain Bratchie • Bank of England • Benfield Greig • BNP Paribas • British Aerospace • British Gas • Howard & Veronika Covington • William Craig • Cambridge Philosophical Society • Clay Mathematics Institute • CNRS • Credit Suisse • Daiwa Anglo–Japanese Foundation • DERA • Deutsche Forschungsgemeinschaft • Emmanuel College • European Molecular Biology Organisation • European Science Foundation • European Union • Dill Faulkes Foundation • Garfield Weston Foundation • GLC Charitable Trust (Lawrence Staden) • Gonville and Caius College • David Harding Foundation • Henderson Global Investors • Hewlett–Packard • Clive Humby & Edwina Dunn • Institute of Physics • Jesus College • John Templeton Foundation • Dr EM Kirk & Dr PJ Turner • Leverhulme Trust • London Mathematical Society • Hamish Maxwell • Steve Mobbs • Magnox Electric • Medical Research Council • Met Office • Microsoft Corporation/ Microsoft Research • National Science Foundation • NATO • Nomura Corporation • Nuffield Foundation • Office of Naval Research • Old Mutual plc • Paul Zucherman Trust • PF Charitable Trust • Prudential Corporation plc • NM Rothschild and Sons • Research Councils UK (SERC/ EPSRC/ PPARC/ STFC/ NERC/ BBSRC/ ERSC) • Rolls Royce • Rosenbaum Foundation • Royal Commission for the Exhibition of 1851 • Schlumberger • Simons Foundation • St John's College • Sun Microsystems inc. • Thriplow Trust • Trinity College • Trinity College (Isaac Newton Trust) • TSUNAMI • Unilever • University of Cambridge • David & Elizabeth Wallace • Wellcome Trust • Winton Philanthropies • Anonymous Donation

How to Donate

You may donate to the Isaac Newton Institute online by credit or debit card through the University of Cambridge's secure site. US tax payers may donate to Cambridge in America, a 501(c)(3) tax-exempt organisation and qualify for an income tax deduction. Please state when making your gift that you would like your donation to support the Isaac Newton Institute for Mathematical Sciences. The University has charitable status and so donations made to it or its constituent parts, including the Institute, may attract tax relief. For UK tax payers this is available under Gift Aid.

All donors will be acknowledged formally in the Institute's Annual Report (unless anonymity is preferred). The Institute offers recognition in various ways, including naming opportunities. If you would like to discuss these or other aspects of supporting our work, please do not hesitate to contact the Director (+44 (0)1223 335980 / director@newton.ac.uk) or Josh Bowerman at Cambridge University Development and Alumni Relations (+44 (0)1223 330112 / gw366@cam.ac.uk).

UNIVERSITY OF CAMBRIDGE

EPSRC Pioneering research and skills

BBSRC bioscience for the future

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

NATURAL ENVIRONMENT RESEARCH COUNCIL

Science & Technology Facilities Council