# Isaac Newton Institute
for Mathematical Sciences

**Annual Report**
2017–18

## 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 Turing 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.

## Turing Gateway to Mathematics

The Turing Gateway to Mathematics (TGM) 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 TGM 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.

It has been another busy year for the Newton Institute, with some 2,500 participants passing through our doors to take part in a wide variety of activities, ranging from four- or six-month research stays on our longer programmes, through attendance at over 20 week-long workshops to a plethora of one or multi-day meetings. A highlight in 2017 was the unusual and noteworthy workshop on *'Form in Art, Toys and Games'*, whose theme encompassed both the emergence of form in art, including the mathematical and physical aspects of artistic processes and techniques, and the properties and role of form in finished artworks. A number of renowned artists lectured and exhibited their works during the week.

One of the first activities I attended to as Director was the preparation of the case for renewal of our core grant from the UK research councils. I am delighted that, as a consequence of the EPSRC Review of UK Mathematical Sciences Infrastructure published in 2015 and as evinced by our successful grant submission in 2017, the Institute is seen in a favourable light by EPSRC and the other research Councils. Hence, from the 1st March 2018 we commenced a six-year grant which provides a significant enhancement to our core funding. This gives far greater financial stability and allows for both the necessary forward planning and consideration of new initiatives/responses to changing demands.

There are a number of matters that we will need to address in coming years. The first is the continuation of our activities on equality, diversity and inclusivity. The number of female participants has risen sharply across all our activities, and we have put in place new funding and enabling mechanisms to remove barriers for those with child, health or other care needs to take part in our programmes and workshops. We have also instigated a new fund to encourage participation from excellent researchers from developing countries. By leading on equality and widening participation,



*The number of female participants has risen sharply across all our activities*
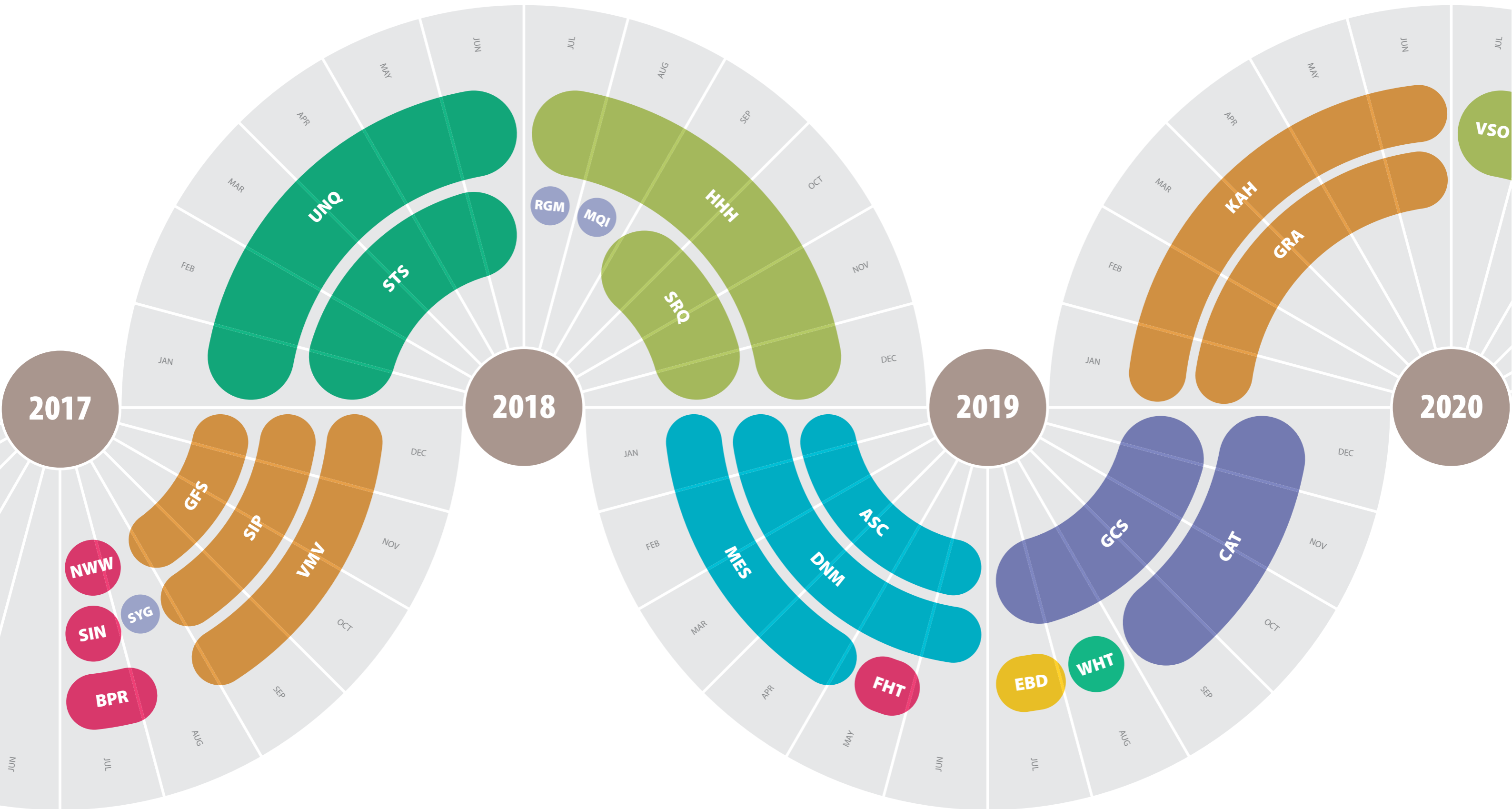
the Institute can not only improve the quality and outcomes of our research events but, through the sheer number of our attendees, also help change the culture both nationally and internationally.

Our governance structure also needs to be brought up to date; we need to increase the number of representatives from outside Cambridge on the Institute's Management Committee and ensure that, in general, we are more open to feedback and steer from the community. In the latter regard we are strengthening our Network of Correspondents, which now also acts for our sister institute, the International Centre for Mathematical Sciences, in Edinburgh. We have also made changes to our

other committees, including those of the Turing Gateway, to make them more reflective and strategic.

Finally, I must remark that the continuing success of the Institute is down to the commitment of so many people. First are the dedicated and hard-working members staff; it is pleasing to report that we have had few changes to personnel over the last year, and so we can continue to improve our services and refine the processes towards an ever-improving participant experience. Second, I personally express my deep gratitude to those who offer benefaction to the Institute, without whom the work undertaken here would not be possible. Third are the research programme organisers, who we rely on in so many ways, especially the setting of the scientific agenda of their respective programmes, ensuring the attendance of the appropriate international and home participants, and acting as social secretaries! Fourth are the organisers of all other events such as workshops, meetings, lectures, Turing Gateway workshops, and last are our committee members, referees and all others we call upon to scrutinise specific activities and advise us on our portfolio. Thanks go out to all who have offered their generous support over the past year.

David Abrahams,
Director, Isaac Newton Institute

# Programme Schematic

**2017**

**2018**

**2019**

**2020**

UNQ
STS
GFS
SIP
VMV
NWW
SIN
SYG
BPR

RGM
MQI
HHH
SRQ
MES
DNM
ASC
FHT

GCS
CAT
EBD
WHT

KAH
GRA
VSO

| | | | |
|---|---|---|---|
| **BPR** Big proof | **SIP** Mathematics of sea ice phenomena | **RGM** Random geometry: follow-on workshop | **DNM** The mathematical design of new materials |
| **SIN** Scalable inference; statistical, algorithmic, computational aspects | **GFS** Growth, form and self organisation | **MQI** Mathematical challenges in quantum information: Beyond I.I.D. in information theory: follow-on workshop | **ASC** Approximation, sampling and compression in data science |
| **NWW** Nonlinear water waves | **VMV** Variational methods and effective algorithms for imaging and vision | **HHH** Homotopy harnessing higher structures | **MES** The mathematics of energy systems |
| **SYG** Symplectic geometry: celebrating the work of Simon Donaldson: follow-on workshop | **UNQ** Uncertainty quantification for complex systems: theory and methodologies | **SRQ** Scaling limits, rough paths, quantum field theory | **FHT** The fickle heart |
| | **STS** Statistical scalability | | |

| | | |
|---|---|---|
| **GCS** Geometry, compatibility and structure preservation in computational differential equations | **KAH** K-theory, algebraic cycles and motivic homotopy theory | |
| **EBD** Mathematical and statistical challenges in landscape decision making | **GRA** Groups, representations and applications: new perspectives | |
| **WHT** Bringing pure & applied analysis together via the Wiener-Hopf technique, its generalisations and applications | **VSO** Verified software | |
| **CAT** Complex analysis: techniques, applications and computations | | |

# Nonlinear Water Waves



# PROGRAMME HIGHLIGHTS

The theory of water waves dates back to the nineteenth century, and has deep and fascinating connections to many scientific research areas. Moreover, the complexity and variety of water-wave phenomena require innovative tools ranging from physical approaches to abstract mathematical considerations.

The theory of water waves has a long history dating back to the nineteenth century and has numerous real world applications including ship hydrodynamics, weather predictions, climate change and resilience of oil-platforms at sea. For waves of large amplitude nonlinearity is an essential feature and one cannot rely on traditional linear approaches.

The purpose of this programme was to bring together mathematical analysts, applied mathematicians and engineers to focus on recent developments in this multidisciplinary field and to anticipate and nurture breakthroughs in promising new research directions. Participants took advantage of this rare opportunity to compare theoretical predictions with both numerical simulations and experimental data in a number of different hydrodynamical contexts and progress was made in the following areas:

- high-precision numerical simulations for travelling waves in flows with constant non-zero vorticity over a flat bed;

> *...applications of the research include ship hydrodynamics, weather predictions, climate change and platforms at sea*

- the study of the pressure field beneath a surface wave;
- the long-time existence of solutions of small amplitude for surface waves in deep water;
- the Stokes drift phenomenon;
- the propagation of irrotational water waves over variable bottom topography;
- the Coriolis effect due to the Earth's rotation on tsunami waves;
- nonlinear studies of geophysical flows (waves and currents);
- computations of solitary hydroelastic waves;
- the statistical description of random surface wave interaction on deep water.

An exciting output, and a good indication of the volume of activity that took place, is the collection of contributions by the participants in the special issue of the Philosophical Transactions of the Royal Society A: Mathematical, Physical & Engineering Sciences, devoted to the programme (Volume 376, Issue 2111, January 2018).

ORGANISERS
Adrian Constantin
*(KCL, Vienna)*,
Joachim Escher
*(Hannover)*,
Hisashi Okamoto
*(Gakushuin)*

GENDER BALANCE
(F : M, %)

| 10 | 90 |
|----|----|

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

| 19 | 81 |
|----|----|

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

| 4 | 48 | 48 |
|---|----|----|

# Growth, Form, and Self-Organisation

ORGANISERS
Arezki Boudaoud *(Lyon)*,
Robert Dudley *(Berkley)*,
Andrzej Herczyński
*(Boston)*,
Darryl Holm *(Imperial)*,
Eric Lauga *(Cambridge)*,
Jean-Luc Thiffeault
*(Wisconsin-Madison)*

This programme was timed to coincide with the 100th anniversary of the publication of Sir D'Arcy Wentworth Thompson's 1917 book *On Growth and Form* which effectively started the field of physics of living systems. The aim was to bring into focus various contemporary strands of inquiry inspired by Thompson's ideas through the stimulation of new interactions and collaborations between applied mathematicians, biologists, physicists, and other experts.

The programme was notably broad, with seminar topics ranging from cell migration to the shape and function of the nasal cavity, and from fluid dynamical particle-wave duality to swimming and evolution of microorganisms. A highlight was the engaging talk by Professor Alain Goriely *(Oxford)* entitled *On Growth and Form and Mathematics: Reading d'Arcy Thompson 100 Years On.* The structured activities (two seminars per week, four workshops, including a satellite in Dundee, the Rothschild Lecture, an Outreach Day, and a one-day Commemorative Symposium held as a tribute to the late Konrad Bajer, a Polish physicist who played a critical role in early planning of the programme) and the countless informal discussions and intense debates contributed to a fertile, enriching, and invigorating programme.

> *... countless informal discussions and intense debates contributed to a fertile, enriching, and invigorating programme.*

The first workshop on *Form and deformation in solid and fluid mechanics* brought together a strikingly diverse group of scientists unified by their interest in applying modern theoretical methods in solid and fluid mechanics to a variety of problems in nature and bioengineering. Topics addressed included: pattern formation; morphogenesis; cellular mechanics; and biological shape and function. The workshop on *Shape Analysis and Computational Anatomy* showcased recent advances in mathematical aspects of this topic and their implications for computational anatomy including general approaches to shape differentiation, variation, and development, and as tools for analyzing MRI or CT images.

The satellite workshop *Growth, form and self-organisation in living systems*, held at the University of Dundee where Thompson spent half of his career, explored the intersection of the physical, biological, and morphological aspects of form in living organisms and highlighted recent advances, challenges and new mathematical approaches.

Alongside the programme, and extending its interdisciplinary character, the Institute hosted a month long art exhibition *Form in Art: Art of Form.* On view were 14 artworks by ten acclaimed contemporary painters and sculptors whose work engages science in some manner. With 23 talks given by scientists and 9 by the artists, the aim of the final workshop, *Form in Art, Toys, and Games*, timed to coincide with this exhibition, was to establish a community of scientists interested in the physics of art. The outreach forum on the last day included talks on form and deformation in art, toys and games.

By all accounts this was a highly successful programme with new research links established, collaborations begun, and initiatives developed during informal exchanges. For instance, the satellite workshop resulted in a number of new links between overseas participants and researchers from Dundee, and a fruitful collaboration between American scientists Mimi Koehl *(Berkeley)* and Lisa Fauci *(Tulane)* began when the two met in their shared INI apartment.

ROTHSCHILD FELLOWSHIP
Professor A Goriely

SIMONS FELLOWSHIPS
Professor M Ben Amar,
Professor A Boudaoud,
Professor P Degond,
Professor C Eloy,
Professor L Fauci,
Professor M Koehl,
Dr N Ribe,
Professor J Wang,
Professor R Zenit

GENDER BALANCE
(F : M, %)

| 20 | 80 |
|----|----|

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

| 27 | 73 |
|----|----|

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

| 0 | 38 | 57 | 5 |
|---|----|----|----|

# Mathematics of sea ice phenomena



ORGANISERS
Daniel Feltham *(Reading),*
Alexander Korobkin
*(East Anglia),*
Emilian Parau
*(East Anglia),*
Frank Smith *(UCL),*
Vernon Squire *(Otago)*

This four-month programme focused on sea-ice mechanics and thermodynamics, and ice interactions with fluids and solids. Spanning several areas of physics and mathematics, the complex behaviour of sea ice presents fundamental challenges over a large range of scales, with substantial contemporary implications in the natural sciences and engineering. A primary goal was to draw together researchers from different fields to work in groups on modern problems of ice dynamics and thermodynamics, to formulate new problems and models and to discuss strategies for their solutions. New ice-related problems were often inspired by recent research on climate change and global models of ocean-ice-atmosphere interactions.

The programme was organised around four thematic foci: Multi-Scale Modelling of Ice Characteristics and Behaviour; Ice-Fluid Interaction; Ice-Structure Interaction; and Ice Fracture and Cracks. Each of the foci was explored in its own, week-long workshop. These workshops attracted the leading researchers from across the world, along with early career researchers, and stakeholders. Overviews of the state-of-the-art, recent research results, industrial and other stakeholder needs were presented, with scheduled and impromptu discussions between all parties.

Special teaching events were held to introduce and explain complex mathematical techniques related to ice research. In addition to the workshops, three one-day industrial satellite events took place: Future developments in climate sea ice modelling; Ice-structure interaction; and Mathematics of sea ice (the latter two in collaboration with the British Antarctic Survey). These brought in users of sea ice mathematical models, and stakeholders interested in industrial and climate-related applications and led to discussions of future development priorities.

Among the mathematical topics discussed were: models and analysis of ocean waves and swell propagating in ice fields and altering its morphology; linear and nonlinear hydroelastic waves; sea ice growth, ablation and morphology, including phase transitions, mushy layer dynamics and heterogeneity; melt ponds; ice dynamics; ice mechanics including relationships between internal ice forces and the deformation of ice covers, ice friction, crushing, and anisotropic mechanics; granular flows of ice and discrete element models; and other types of ice such as glacial ice and river ice. Attention was paid to models of sea ice in global and regional environmental systems, including representation of processes controlling the exchange of momentum, heat and mass with the atmosphere and ocean. In particular, the breakup of sea ice floes and aggregates of floes, especially in the context of global warming, was the subject of intense discussion.

Attention was paid to industrial problems including icing, thermally induced loads from ice and frozen soils, and mechanical loads on offshore and coastal structures from contact interaction. Important yet poorly understood problems were identified, including icing of ships, and energy loss mechanisms for waves in different types of sea ice cover.

> *Special teaching events were held to introduce and explain complex mathematical techniques related to ice research.*

ROTHSCHILD FELLOWSHIP
Dr E Hunke

SIMONS FELLOWSHIPS
Dr L Bennetts,
Professor D Feltham,
Professor A Herman,
Professor H Kalisch,
Dr T Khabakhpasheva,
Professor A Korobkin,
Dr M Meylan,
Dr E Parau,
Professor P Plotnikov,
Professor V Squire

GENDER BALANCE
(F : M, %)

| 20 | 80 |
|----|----|

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

| 45 | 55 |
|----|----|

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

| 16 | 35 | 48 | 1 |
|----|----|----|----|

# Variational methods and effective algorithms for imaging and vision

ORGANISERS
Ke Chen *(Liverpool)*,
Andrew Fitzgibbon
*(Microsoft)*,
Michael Hintermüller
*(Berlin)*,
Carola-Bibiane Schönlieb
*(Cambridge)*,
Xue-Cheng Tai
*(Hong Kong)*

Mathematical imaging, image processing and computer vision have become central for obtaining information in various subfields within medicine, the sciences, and technology. The computation, visualisation and the automatic processing of digital images from sources ranging from consumers' digital cameras to industrial installations, as well as from visualizing (material or tissue) properties which are accessible only indirectly through measurements, are ubiquitous in both imaging and vision communities. Yet these two strongly-related multidisciplinary communities often run their own networking activities.

This programme brought together researchers and practitioners from both the imaging and vision communities to review and work on state of the art models, methods, algorithms and applications. Participants from both communities found these interactions, collaborations and networking opportunities both useful and fruitful.

The dominating themes that emerged through the programme were nonlinear optimization and, more surprisingly, machine and learning frameworks which coupled with imaging and vision research proved to be highly successful. Both themes are closely related to Big Data. Additionally, participants coming from fields like statistics, inverse problems, partial differential equations and numerical analysis, are getting increasingly interested in understanding the mathematics behind convolutional neural networks, and recent progress surrounding deep neural networks, also for several image analysis and processing problems, had a clear impact on the programme.

*The workshops attracted more than one hundred international experts from mathematics, engineering and computer science, and a large number of early career researchers in these fields.*

The programme included three main academic workshops that highlighted recent research in: convex and non-convex large-scale optimisation in imaging; model- and data-driven imaging including current mathematical approaches for machine learning in imaging; and shape spaces and geometric flows. These workshops attracted more than one hundred international experts from mathematics, engineering and computer science, and a large number of early career researchers in these fields.

Early career participants profited from three short courses given by internationally renowned experts: Martin Burger *(Münster)* gave a course on biomedical imaging; Martin Holler *(Graz)* on higher-order total variation regularisation; and Mila Nikolova *(ENS de Cachan)* on non-convex minimizers.

Several user-engagement days were run with industry and academic experts from imaging-rich application domains such as biomedicine, archaeology, satellite imaging, and earth sciences taking part. Among these were a workshop co-organised with the Turing Gateway to Mathematics, a satellite-workshop on imaging in the life sciences at the University of Warwick, an IMA conference on inverse problems and three Schlumberger satellite workshops at Schlumberger Gould Research that explored the synergies between research in Schlumberger and research topics in the programme. Our Rothschild public lecture given by Professor Joachim Weickert *(Saarlandes)* on Image Compression with Differential Equations attracted a large audience.

During the programme, several participants gave lectures in other UK Universities including UCL, Imperial, Oxford, Liverpool, Bath, Nottingham, Bournemouth, Edinburgh and some participants have started new collaborations. Various follow up activites are planned including a special journal issue dedicated to the programme topics; a proceedings book to celebrate the research achievements made during the programme; and a forthcoming conference to further increase the impact and to follow up on new projects ideas.

ROTHSCHILD FELLOWSHIP
Professor J Weickert

MICROSOFT FELLOWSHIP
Professor M Nikolova

SIMONS FELLOWSHIPS
Professor S Arridge,
Professor Y Boykov,
Professor M Burger,
Professor A Chambolle,
Professor M Hintermuller,
Professor M Nikolova,
Professor T Pock,
Professor X Tai,
Professor O Veksler

GENDER BALANCE
(F : M, %)

| 21 | 79 |
|----|-----|

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

| 39 | 61 |
|----|-----|

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

| 20 | 58 | 21 | 1 |
|----|----|----|---|

# Statistical Scalability

The important role of statistics within Big Data has been clear for some time. However, the current tendency has been to focus purely on algorithmic scalability, such as how to develop versions of existing statistical algorithms that scale better with the amount of data. The focus of this programme was to go beyond this narrow view, and to bring together researchers working across methodological, algorithmic, theoretical and application challenges, as it is only by working across this interface that we can hope to develop the robust, scalable methods that are needed.

The six-month programme involved well over 300 participants, coming from diverse areas such as statistics, machine learning and theoretical computer science. Activity was structured around 4 workshops, each with different themes and 2 *"Open-for-Business"* days. Outside these we ran a twice weekly seminar series, followed by informal discussions over coffee and cake.

The practical importance of, and potential for impact of, the research during the programme can be seen by the involvement from industry in the open for business days. These involved companies and applications spanning pharmaceuticals, telecommunications, energy, genomics, the environment and security. The talks

introduced challenges and opportunities such as how to use data to better inform drug development and personalised medicine, or to diagnose faults and security threats on IP networks.

Key scientific challenges addressed during the programme included, amongst many others: how to reliably quantify uncertainty in big data applications where we have often carried out exploratory data analysis which has informed model choice; understanding the impact of unavoidable model misspecification on statistical procedures, and developing new approaches that are robust to such error; developing greater insight into the fundamental trade-offs between computational versus statistical efficiency across an increasing range of statistical problems; and how to adapt statistical methods to streaming applications, where we need to be able to update our inferences as data arises at high frequency.

It was also beneficial that the other concurrent INI programme, on *'Uncertainty quantification for complex systems: theory and methodologies'*, was on a loosely cognate area, and there was plenty of fruitful interaction between the programmes.

> *The six-month programme involved well over 300 participants, coming from diverse areas such as statistics, machine learning and theoretical computer science*

**ORGANISERS**
John Aston *(Cambridge)*,
Idris Eckley *(Lancaster)*,
Paul Fearnhead
*(Lancaster)*,
Po-Ling Loh
*(Wisconsin-Madison)*,
Robert Nowak
*(Wisconsin-Madison,
Toyota)*
Richard Samworth
*(Cambridge)*

We are living in the information age, with modern technology allowing us to collect and store data on unprecedented scales. From the use of Oyster card data to improve London's transport network, to the Square Kilometre Array astrophysics project that has the potential to transform our understanding of the universe, `Big Data' has the potential to inform and enrich many aspects of our lives. To fully realise this potential requires new statistical and algorithmic ideas that enable us to reliably extract useful information from Big Data.

**ROTHSCHILD FELLOWSHIP**
Professor P Bühlmann

**SIMONS FELLOWSHIPS**
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Professor E George,
Mr Q Han,
Professor C Kirch,
Dr T Krivobokova,
Dr P Loh,
Dr X Qiao,
Professor J Wellner,
Dr Y Yu

**GENDER BALANCE**
(F : M, %)

| 29 | 71 |
|---|---|

**GEOGRAPHIC DISTRIBUTION**
(UK : NON-UK, %)

| 41 | 59 |
|---|---|

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

| 14 | 70 | 16 |
|---|---|---|

# Uncertainty Quantification

ORGANISERS
Catherine Powell
*(Manchester)*,
Max Gunzburger
*(Florida)*,
Peter Challenor *(Exeter)*,
Henry Wynn *(LSE)*

In areas as diverse as climate, manufacturing, energy, life sciences, finance and geoscience, mathematical models and their discretizations into computer models are routinely used to make forecasts, inform decisions and formulate policies. How accurate are the predictions made using such models? This crucial question lies at the heart of uncertainty quantification (UQ).

When we use models to simulate real-world processes, the quantities we compute always have uncertainty in them due to model error, uncertain model inputs, errors associated with the use of numerical algorithms and measurement errors (in data). Thus, UQ is an essential component of model-based science and associated decision making. Moreover, modern society is challenging scientists with the scale and complexity of the models needed to solve real-world problems and the amount of data available to aid the modelling process.

UQ is a rapidly evolving and highly interdisciplinary field combining applied mathematics, statistics, numerical analysis, computational science, probability, data science, applications and more. Since applied mathematicians and statisticians have different approaches to modelling and approach UQ in different ways, there has historically been a barrier to interactions between these two particular groups. Hence, the main aim of the programme was to bring them together to formulate a common foundation for UQ and establish connections that will lead to future advances in UQ theory and methodologies.

> *UQ is a rapidly evolving and highly interdisciplinary field.*

Activities were organised around the themes of Surrogate Modelling, Multilevel & Multifidelity Methods, Dimension Reduction Methods and Inverse Problems. Workshops were held in January, February, March and April and were all well attended. The Rothschild Lecture was delivered by Professor Andrew Stuart *(Caltech)* on the pioneering work of Rudolph Kalman in blending data and mathematical models.

There were also two *"Open-for-Business"* events. Three programme participants gave talks at the LMS Women in Mathematics Days and the programme also hosted the Models to Decisions Network's annual conference on *Decision Making Under Uncertainty*.

Outside workshop weeks, seminars and discussion groups took place. Highlights of the scientific discussions included

- Design: connections between experimental design and the design of reduced bases for PDEs with parameter-dependent inputs; space-filling designs versus sparse grids and their suitability for different UQ tasks.
- Multilevel & Multifidelity methods: connections between multilevel and multifidelity Monte Carlo methods and multilevel Gaussian process emulation.
- Surrogate Modelling: connections between stochastic collocation methods, stochastic Galerkin methods and Gaussian process emulation; connections between Gaussian process emulation and radial basis function approximation; reconciling deterministic and probabilistic statements about accuracy of surrogate models.

Important questions for future collaborations include: How can we develop a rigorous mathematical framework for model error? How can we design surrogate models with guaranteed error control that satisfy important physical constraints? How can we better fuse data, models and algorithms in UQ studies and provide rigorous underpinning mathematics?

ROTHSCHILD FELLOWSHIP
Professor A Stuart

SIMONS FELLOWSHIPS
Professor P Challenor,
Dr M Dashti,
Professor S Guillas,
Professor M Gunzburger,
Dr L Lee,
Dr C Powell,
Professor C Schillings,
Professor R De Vore,
Professor D Woods,
Professor H Wynn

GENDER BALANCE
(F : M, %)

| 21 | 79 |
|----|----|

GEOGRAPHIC DISTRIBUTION
(UK : NON-UK, %)

| 39 | 61 |
|----|----|

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

| 13 | 62 | 22 | 3 |
|----|----|----|----|

# Follow-on workshops

## Symplectic geometry: celebrating the work of Simon Donaldson: follow-on workshop (14-18 August 2017)

The concept of a symplectic structure arose in the study of classical mechanical systems, such as a planet orbiting the sun, where one needs two pieces of information (such as position and velocity at any time) in order to determine the trajectory. Thus, symplectic geometry lives on even dimensional spaces, and measures the sizes of 2-dimensional objects rather than the 1-dimensional lengths and angles of Euclidean and Riemannian geometry. In the late 80s and early 90s Gromov and Floer introduced pseudo-holomorphic curve techniques into the subject. They showed that solving the Cauchy-Riemann equations in symplectic manifolds gives a powerful new way to study them. By the time of the 1994 Newton Institute programme "Symplectic Geometry", it was clear these methods would revolutionise the area. Floer homology and Gromov-Witten invariants had been defined in some special cases; the link to gauge theory and low-dimensional topology had been envisaged (through the Atiyah-Floer conjecture); Taubes had achieved breakthroughs in the classification

of symplectic 4-manifolds; and Donaldson had started his programme of showing the powerful algebro-geometric techniques of ample linear systems could be adapted to the symplectic context. Consequences and applications were developed during the programme and published in the subsequent INI proceedings. This 2017 follow-on workshop proved highly successful. Gromov and Floer's techniques now form the foundation of the subject. They have been joined more recently by ideas from homological algebra and mirror symmetry. The result is a very active field with exciting new applications, as explained by an array of top international speakers. The building was full to capacity with those excited to hear of the remarkable recent progress. Early career researchers benefitted greatly from the presence of more senior participants from the original 1994 programme, such as Gromov (IHES, Paris), Dusa McDuff (Columbia) and Sir Simon Donaldson (Imperial and Simons Center) – whose 60th birthday was also celebrated.

## Random geometry: follow-on workshop (9-20 July 2018)

Working at the interface between probability, geometry and analysis, and with motivations coming from theoretical physics and in particular the work on Liouville quantum gravity, the 2015 Random Geometry programme brought together specialists in these and other connected areas, including the Fields medalist Wendelin Werner *(ETH Zürich)*. They studied random geometries that appear

random at every scale (fractal) alongside other types of random geometries that somehow "average out" at large scales. Many of the objects considered (random surfaces, random curves, random graphs, etc.) had very counterintuitive properties thereby driving the theory far beyond traditional boundaries and leading to the development of radically new concepts and intuitions. With much to capitalise on, in

July 2018 a follow-on workshop to the programme, including a combination of intensive mini-courses and seminars, allowed high-level researchers at all careers stages and from across all disciplines involved, to catch up on developments and to plan future research directions for the subject. For example, Loève Prize winner Sourav Chatterjee *(Stanford)*, who had participated in the original programme via video conference, came in person to present a mini-course on the Yang-Mills problem, one of the Clay Institute's famous million dollar problems. This was particularly beneficial for the many participants actively exploring analogies between the string trajectories of Chatterjee's theory and the corresponding trajectories developed in
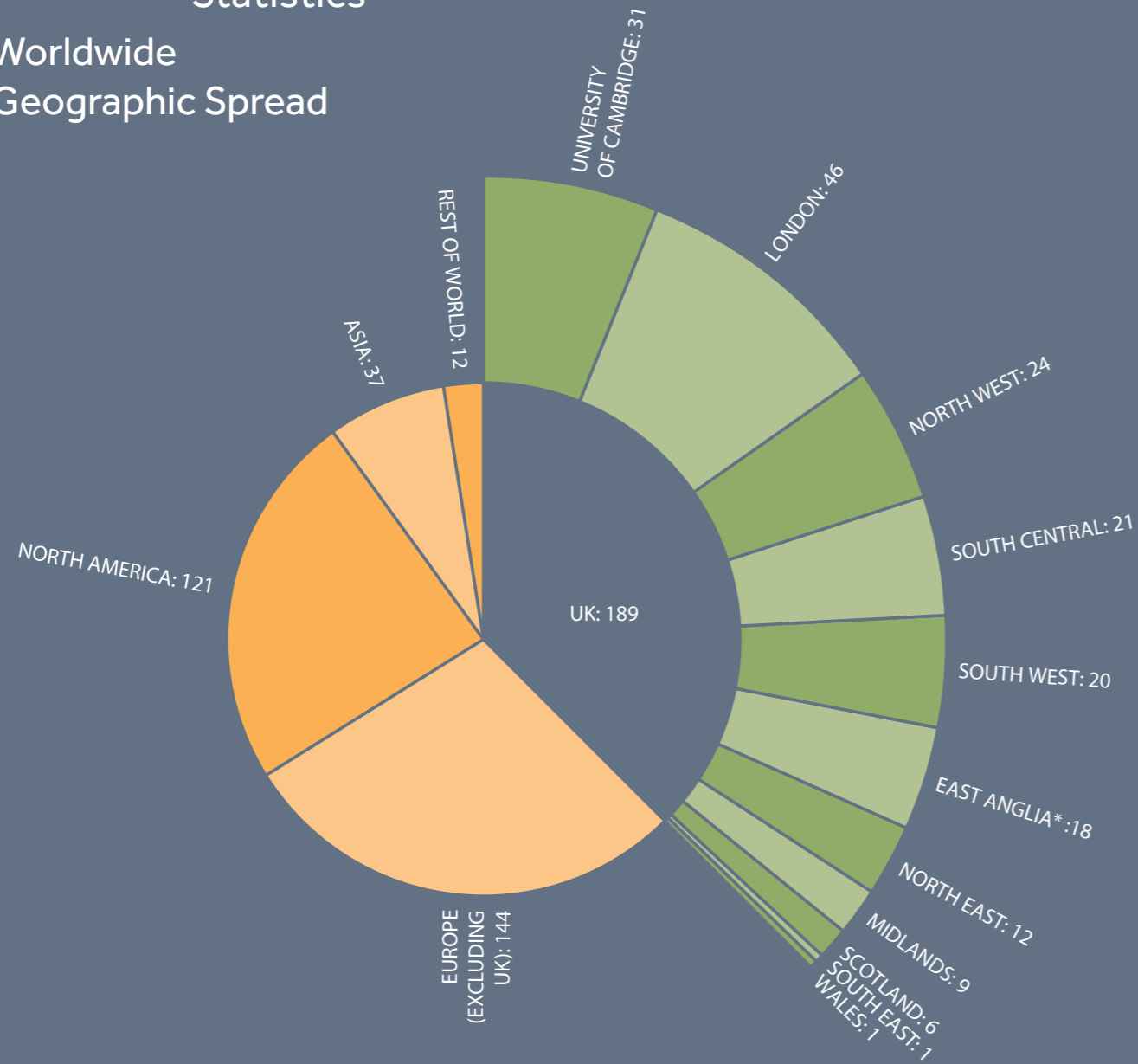
Liouville quantum gravity. Many of the researchers who were at very early stages in their career (students and postdocs) in 2015 had substantial achievements to present at the follow-on workshop and Wendelin Werner said of the programme, *"The Random Geometry semester has had a transformative effect on this research area. Many research directions of today find their roots in the interactions and discussions that took place then. One big success has been the way in which it enabled the younger participants (PhD students and postdocs) to define their own research agendas. At the follow up event it was truly remarkable to see the talks and witness the achievements of this impressive group."*

## Mathematical challenges in quantum information: Beyond I.I.D. in information theory: follow-on workshop (23-27 July 2018)

This MQI follow-on workshop, held in July 2018, was attended by both quantum information theorists as well as some classical information theorists. This led to fruitful scientific exchanges between the two communities. There were excellent talks on various key research topics, including data compression, entropies, uncertainty relations, resource theories (of coherence, and thermodynamics), quantum channels, and quantum dynamical semigroups. There was a special session in memory of Denes Petz, the esteemed mathematician who made numerous, invaluable contributions to the field of quantum information theory, and who sadly passed away earlier this year. Talks in this session covered his salient contributions, as well as recent research by others which has
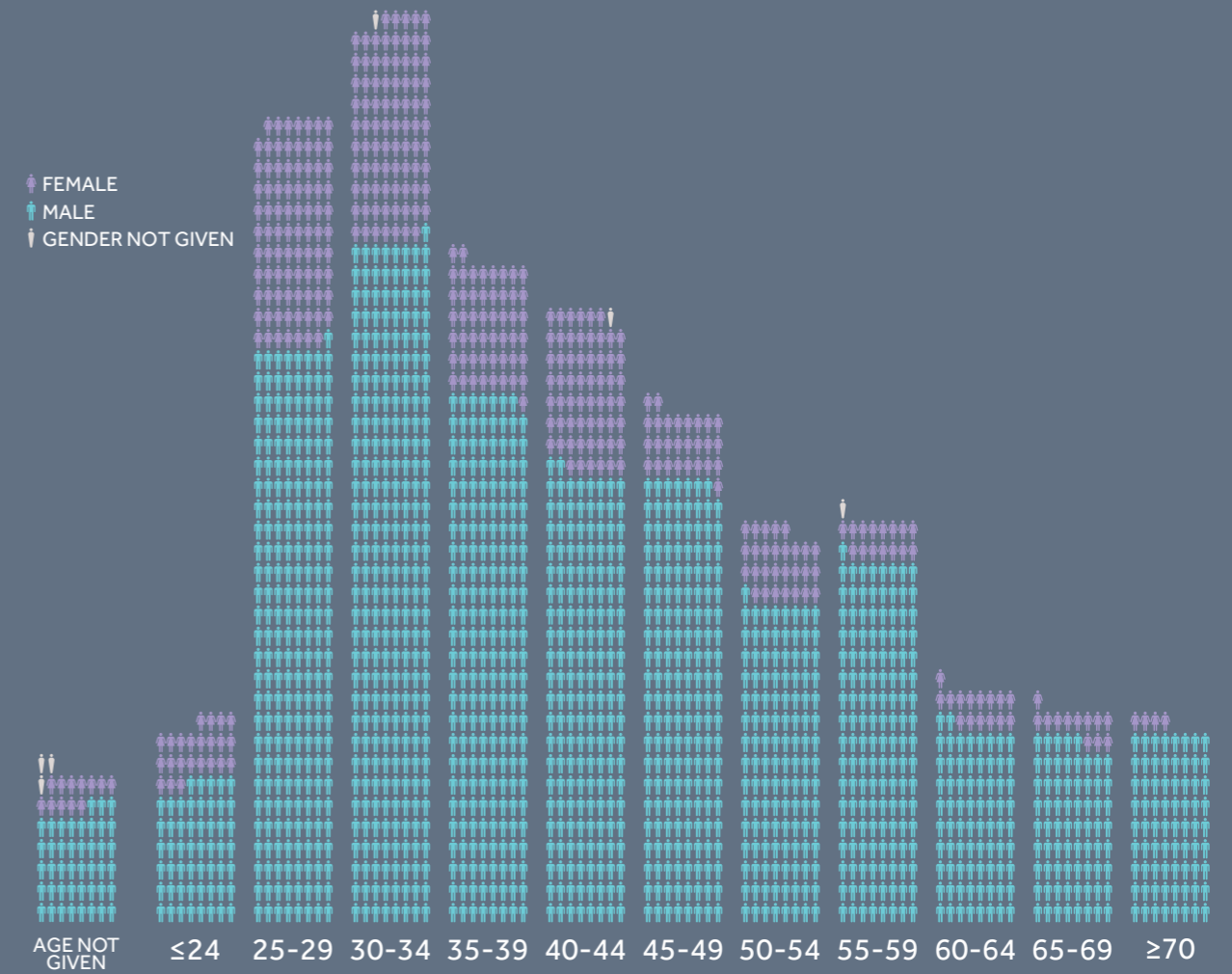
been influenced by his work. There was a lively poster session in which many of the younger participants presented their results. The Open Problems Session was particularly interesting and has already led to some new results (see e.g. arXiv:1810.09791, "A proof of the Shepp-Olkin entropy monotonicity conjecture" by workshop participant Oliver Johnson *(Bristol)* and his former Postdoc Erwan Hillion *(Aix Marseille Université)* in which a conjecture mentioned in this session was proved). There have also been other papers posted on the arXiv in the last few months, which arose out of discussions between participants at the workshop. Overall the workshop resulted in rejuvenating the field of "information theory beyond I.I.D." and can be considered to have been a huge success.
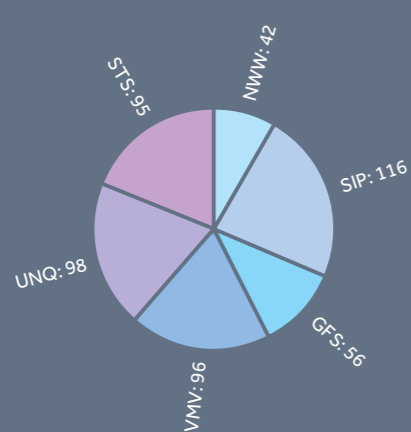
# Statistics

## Worldwide Geographic Spread

UNIVERSITY OF CAMBRIDGE: 31
LONDON: 46
NORTH WEST: 24
SOUTH CENTRAL: 21
SOUTH WEST: 20
EAST ANGLIA* :18
NORTH EAST: 12
MIDLANDS: 9
SCOTLAND: 6
SOUTH EAST: 1
WALES: 1
UK: 189

REST OF WORLD: 12
ASIA: 37
NORTH AMERICA: 121
EUROPE (EXCLUDING UK): 144

## Gender and Age

FEMALE
MALE
GENDER NOT GIVEN

AGE NOT GIVEN | ≤24 | 25-29 | 30-34 | 35-39 | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | ≥70

*Excluding University of Cambridge

**503** PROGRAMME PARTICIPANTS

STS: 95
NWW: 42
SIP: 116
GFS: 56
VMV: 96
UNQ: 98

**16975** PROGRAMME PARTICIPANT DAYS

STS: 4251
NWW: 526
SIP: 3344
GFS: 1910
VMV: 4005
UNQ: 2939

**1499** WORKSHOP PARTICIPANTS

MQI: 60
SYG: 97
RGM: 63
GFS: 169
NWW: 50
SIP: 283
VMV: 266
STS: 240
UNQ: 271

**8020** WORKSHOP PARTICIPANT DAYS

MQI: 353
SYG: 543
RGM: 674
GFS: 813
NWW: 229
SIP: 1430
VMV: 1281
STS: 1246
UNQ: 1451
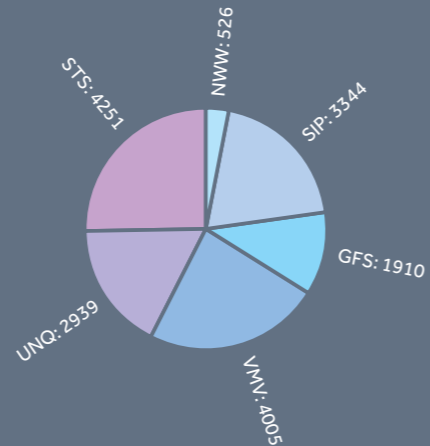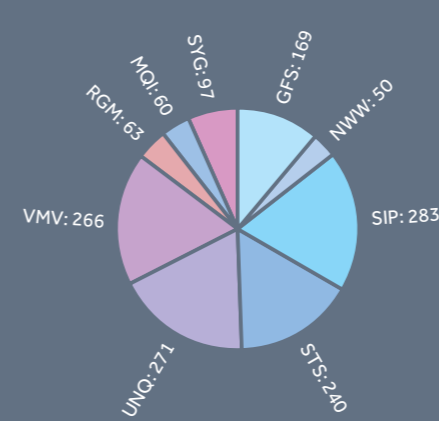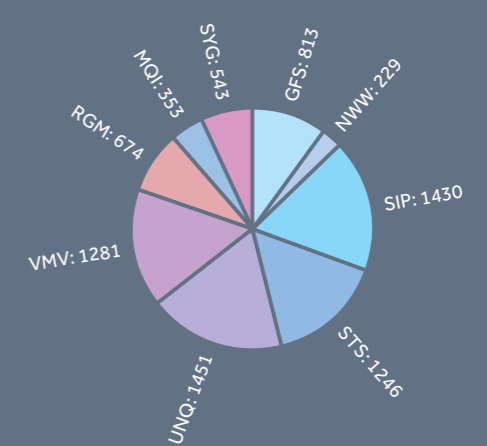
With the continued trial of running three programmes in parallel and with 26 weeks of workshops including 4 weeks of follow-on workshops and 3 satellites, 2017-18 has been a busy year for the Institute.

The Institute remains committed to **nurturing the next generation** of mathematical scientists and, of the programme participants who indicated their work status, 8% were research students and 14% were post-doctoral researchers. Similarly, for workshop participants, 18% were research students and 14% were post-doctoral researchers: by a different metric, 35% of all programme participants and 40% of all workshop participants were aged 35 or under. As well as having unsurpassed networking and collaboration opportunities and access to leaders in their field, early career researchers are encouraged to fully participate in Institute programmes and 8% of seminar speakers were research students and a further 7% were post-doctoral researchers.



Engagement with the **UK mathematical sciences** community remains of paramount importance to the Institute and 38% of both programme and workshop participants were from the UK, representing 69 different universities, institutions, companies and government departments. The **Talks Elsewhere** scheme proved as popular as ever with 48 talks given by 28 different people at 20 different institutions across the UK, and **satellite workshops** were held in Dundee, Warwick and The Lake District. Additionally, in response to the long-standing low participation rates from Northern Ireland, the Director and Deputy Director of INI, along with the Scientific Director and Centre Manager of ICMS, made a visit to Queen's University, Belfast.

The Institute's **Network of Correspondents** has been refreshed and reinvigorated and has extended its remit to sharing information about the International Centre for Mathematical Sciences (ICMS), Edinburgh, as well as INI. Correspondents Day, held in January, was attended by 50 Correspondents who learned much from the keynote talk by Dr Andrew Bourne, Associate Director of EPSRC, on *The mathematical landscape in the UK*,



and from the talk by Professor Liz Mansfield, President of the IMA, on *Diversity in the mathematical sciences*. Feedback from the breakout discussions on this topic was illuminating and instrumental in informing INI and ICMS's policy in this area. We are grateful to Correspondents for the important role that they play in disseminating information about Institute activities and, at the time of writing, are advertising for a new Chair of Correspondents to replace Professor Ulrike Tillmann, Oxford, who kindly stepped in as interim Chair.

Three past programmes (*Symplectic Geometry* (1994), *Mathematical Challenges in Quantum Information* (2013), and *Random Geometry* (2015)), held **follow-on workshops** at the Institute this year. The Symplectic Geometry workshop was a celebration of the work of Fields Medalist, Sir Simon Donaldson FRS to mark his 60th birthday and the 95 participants included 30 members of Simon's mathematical family tree including (going up the tree) his two PhD supervisors, Nigel Hitchen and founding Director of INI, Sir Michael Atiyah. A case study based on the Random Geometry follow-on workshop and showing the impact of follow-on workshops in sustaining momentum gained during a programme can be found here: *www.newton.ac.uk/news/case-studies/random-geometry*.
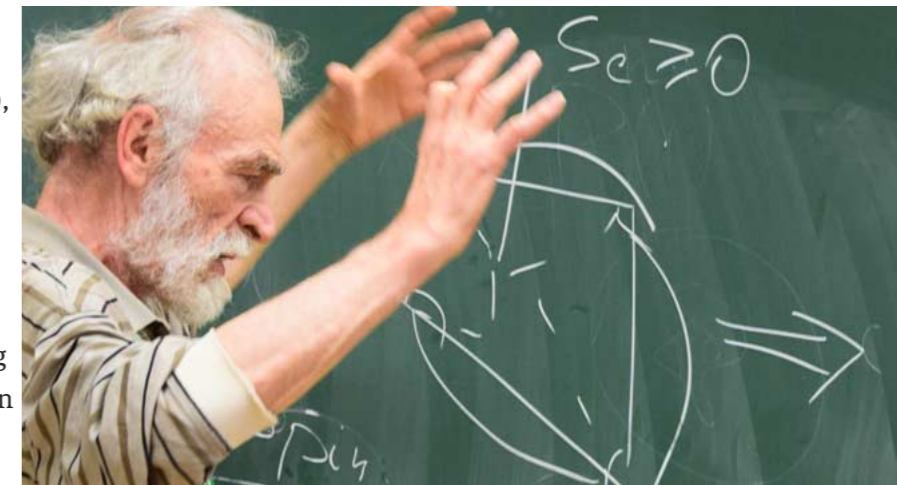
The Institute continues to build its bank of online resources and this year 716 seminars (92% of all seminars) given by 655 different participants were added to the **online seminar archive**: *www.newton.ac.uk/webseminars*.  Additionally, 32 preprints were added to the series taking the total in the **online preprint archive to 1343**: *www.newton.ac.uk/documents/preprints*.

The Institute has also begun a series of **short video interviews with programmes organisers**.  As an accessible introduction to the challenges that their fields face and to the hopes and aspirations for what might be achieved during their programmes, we recommend these highly: *www.newton.ac.uk/news/video-interviews*.  Finally, a time-lapse video of the main blackboard in the mezzanine area during the Anniversary year has been produced and can be found here: *www.newton.ac.uk/news/timelapse*.
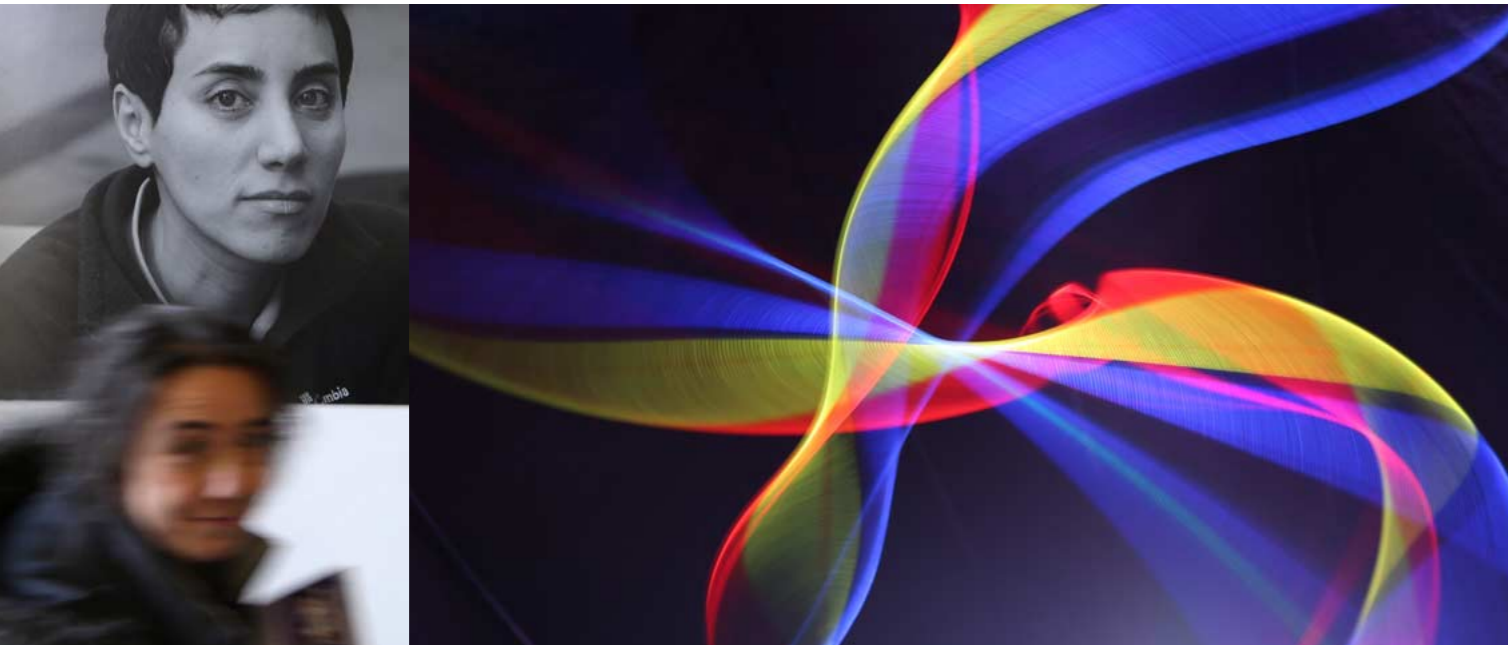


Mindful of the importance of **outreach and engagement**, the Institute was part of a *"Mathematics in the Real World"* stand at the **New Scientist Live** exhibition at the Excel Arena in London: to those of us there it felt as though most of the 30,000 attendees visited our stand! Additionally, the Institute hosted an **art exhibition**, *Form in Art: Art of Form*, as



part of its *Growth, Form and Self-Organisation* programme, and science author, public speaker and TV personality, Dr Emily Grossman gave an excellent talk on *Lies, Damned Lies, and Newspapers: The use and abuse of statistics in the media* for the Institute's contribution to the **2018 Cambridge Science Festival**.  With a great turnout despite the snowy conditions, Emily's highly amusing talk included a number of illustrative examples of "embarrassing moments" where she herself has been caught out by the statistics.



The Institute's **social media** presence continues to increase with: over 4000 followers on Twitter yielding roughly 1500 profile visits each month; almost 50,000 likes on Facebook yielding over 1000 engagements each month; and 126 followers on Instagram. Additionally, there are over 1200 subscribers to the Institute's monthly e-news bulletin: *www.newton.ac.uk/news/e-bulletin*.



With 3 Fields Medalists participating in Institute programmes and workshops in this reporting year alone, INI continues to deliver world class ground-breaking and innovative programmes in the mathematical sciences broadly interpreted. Of those workshop participants that responded to feedback questionnaires, 78% rated the scientific content of the workshop as excellent.  Further, of those programme participants responding to feedback questionnaires, 89% rated the scientific quality of the programme as "Excellent" (80% or above) and 94% said that participating in the programme opened up new research directions for them.
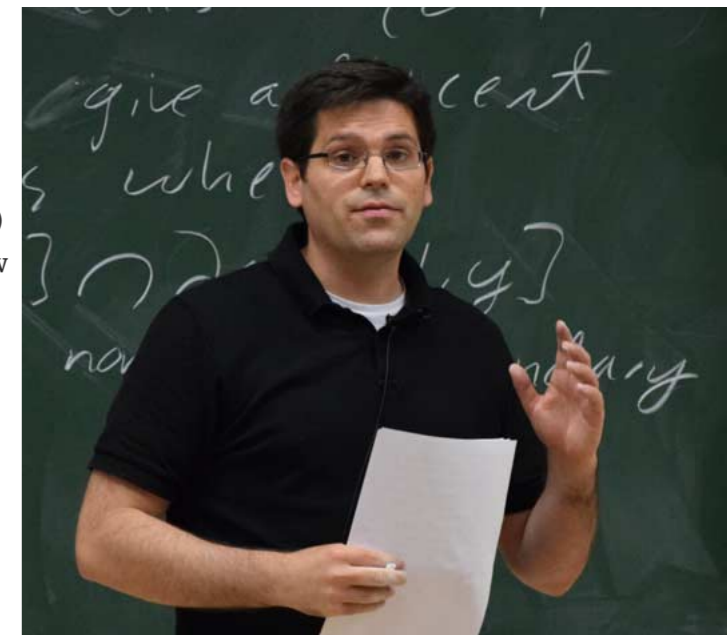
## Equality and Diversity and the Isaac Newton Institute

Working tirelessly to improve the gender imbalance within the mathematical sciences continues to be a focus for the Institute and we are delighted to report that over a five year period the absolute number of women participating in INI activities has almost doubled.

In particular, 21% of programme participants and 23% of programme participant-days were female. Similarly, 21% of workshop participants and 21% of workshop participant-days were female. It should be noted that rather than rejecting otherwise stellar programme proposals from fields with particularly low female participation rates, the Institute works with organisers of those programmes to improve diversity and equality of opportunity within their field. For further details, the Institute's 2018-2020 Equality and Diversity Action Plan can be found here: www.newton.ac.uk/outreach/women-in-mathematics.

October saw the 30th Black History Month and the second Black Mathematician Month, which is celebrated annually in countries including the US, Canada, Ireland and the Netherlands. The Institute supported Rafael Prieto Curiel (UCL), Co Founder and Director of Chalkdust Magazine, in the production of the article *Why we're adding Black Mathematician Month to our calendars* published in The Guardian*. The geographic and ethnic diversity of INI participants continues to be very broad with programme and workshop participants coming from 423 institutions spanning 48 countries and 6 continents, including 19 participants from home institutions in DAC-listed countries. Using nationality as a metric, in this reporting year there were participants of 67 different nationalities. Further, 247 participants, spanning 25 different nationalities, listed their nationality as that of a DAC-listed country.

Further details of the Institute's provision of care policy can be found here: www.newton.ac.uk/information/childcare. Additionally, details of its provision for supporting participants from DAC listed countries can be found here: www.newton.ac.uk/outreach/DAC

*www.theguardian.com/science/blog/2017/oct/02/why-were-adding-black-mathematician-month-to-our-calendars

## Accounts for August 2017 to July 2018

*Note: Figures for 2017-2018 include the Turing Gateway to mathematics (TGM)*

| | Notes | 2017-2018 | 2016-2017 |
|---|---|---|---|
| **Income** | | | |
| | | £000 | £000 |
| Research Grants and Contracts | 1 | 1,980 | 1,833 |
| Contribution from the University of Cambridge | 2 | 408 | 429 |
| Donations | 3 | 157 | 158 |
| Additional workshop income | | 123 | 138 |
| Additional income | 4 | 261 | 67 |
| Endowment and investment income | 5 | 428 | 389 |
| **Total income** | | **3,357** | **3,014** |
| **Expenditure** | | | |
| Staff costs | | 943 | 701 |
| Travel and subsistence | 6 | 1,248 | 1,194 |
| Other operating expenses | 7 | 358 | 164 |
| Overheads paid to the University | 8 | 448 | 507 |
| **Total expenditure** | | **2,997** | **2,566** |
| **Surplus/(deficit)** | | **360** | **448** |

## Notes to the Accounts

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

| | |
|---|---|
| Salaries | 570 |
| Participant costs (travel and subsistence) | 975 |
| Other costs | 8 |
| Estates and indirect income | 427 |
| **Total** | **1,980** |

### 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 | 35 |
| Cambridge Philosphical Society | 4 |
| Turner Kirk Charitable Trust | 106 |
| Heilbronn Institute for Mathematical Research | 8 |
| Donations, other | 4 |
| **Total** | **157** |

### Note 4 - Additional income

| | |
|---|---|
| Merchandise sales | 8 |
| Programme sponsorship | 146 |
| HEIF (TGM) | 55 |
| Housing | 48 |
| Other | 4 |
| **Total** | **261** |

### 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 | 1,236 |
| Staff travel & subsistence | 12 |
| **Total** | **1,248** |

### Note 7 - Other operating expenses

| | |
|---|---|
| Computing | 23 |
| Institute running costs | 56 |
| Catering | 28 |
| Net housing costs | 162 |
| Furniture | 20 |
| Professional & brought in services | 69 |
| **Total** | **358** |

### 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 2018 was as follows:

| Name | Institution | End of Service |
|---|---|---|
| Dr Ewan Kirk (Chair) | General Board | 31 Dec 2018 |
| Professor I. David Abrahams | Director, Isaac Newton Institute | 30 Sep 2021 |
| Dr Katie Blaney | EPSRC | |
| Dr Gabor Csanyi | Council of the School of Technology | 31 Dec 2018 |
| Professor Mark Gross | Faculty of Mathematics | 31 Dec 2018 |
| Professor Valerie Isham | Chair of the Scientific Steering Committee | 31 Dec 2020 |
| Professor Eric Lauga | Trinity College | 31 Dec 2018 |
| Professor Nick Manton | St John's College | 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 Nigel Peake | Head, DAMTP, University of Cambridge | |
| Professor Ulrike Tillman | London Mathematical Society | 31 Dec 2018 |



**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 2018 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 |
| Professor Wolfgang Dahmen | Aachen | 31 Dec 18 |
| Professor Paul Glendinning | Manchester | 31 Dec 19 |
| Professor Iain Gordon | Edinburgh | 31 Dec 19 |
| Professor Saul Jacka | Warwick | 31 Dec 18 |
| Professor Jon Keating | University of Bristol | 31 Dec 20 |
| Professor Dame Frances Kirwan | Oxford | 31 Dec 19 |
| Professor Marta Kwiatkowska | Oxford | 31 Dec 18 |
| Professor Simon Tavaré | Cambridge | 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 • Anonymous Donation

## How to Donate

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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 Glen Whitehead at University Development and Alumni Relations (+44 (0)1223 330112 / gw366@cam.ac.uk).