Isaac Newton Institute for Mathematical Sciences

Annual Report 2023-2024

UNIVERSITY OF CAMBRIDGE

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 transformational 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 early career researchers, by widening access, and by addressing equity, diversity and inclusion within the mathematical sciences. 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, INI 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

It is a pleasure to be writing about our thriving programme of activity at INI. The second half of 2023 saw three parallel programmes (one at the Møller Centre) and the first half of 2024, in addition to our usual two parallel programmes, saw the delivery and preparations for this summer's six satellite programmes. In total 29 one-week long workshops and many more shorter events were organised and supported. Once again, we counted more than 3000 visitors. Many thanks and congratulations go to our wonderful staff!

And it was worth the effort! The surprising synergies between the three programmes in the second half of 2023 and mutual interests of participants produced an exciting, vibrant and stimulating atmosphere. It brought communities together who would not normally have met and allowed them to discover that they are working on similar mathematical questions while addressing outwardly different problems. The feature article in this report, written by our colleagues of Plus Magazine, elaborates on this. In different ways our quite bespoke satellite programmes in Aberystwyth, the Isle of Skye and the Alan Turing Institute were highly successful. They each brought out the unique strengths of these locations. Aberystwyth was able to attract the international community and put a spotlight on its maths department; the Scottish topology and algebra community built on its experience to organise remote meetings on the Isle of Skye away from any disruption; and at INI we hope to build on our collaboration with the Alan Turing Institute to attract international visitors working on theoretical aspects of data science and AI.

I invite you to read the scientific reports from our programmes and trust that their richness will be evident. Here I restrict myself to mentioning but a few additional highlights:

- In autumn 2023, the Newton Gateway celebrated its 10th anniversary, a perfect moment to reflect on its recent successes and how much the knowledge exchange landscape for the mathematical sciences has changed since its inception.
- Chiming with our own efforts to increase interaction with developing countries, we were delighted to be able to support a joint research school with the University of Ibadan, Nigeria, as part of one of our programmes. We have produced a short podcast about the experience to encourage similar collaborations in future.
- We were privileged to host a star-studded meeting to honour Tim Gowers. Tim's broad interests and unique style as well as the impact of his work were on display.

Very sadly, we had to say good-bye to our beloved Sam Skehel who held the administrative reins of the Institute from 2015 to 2023. After several years of illness, Sam died in January this year. An obituary is included in this report. She will be much missed.

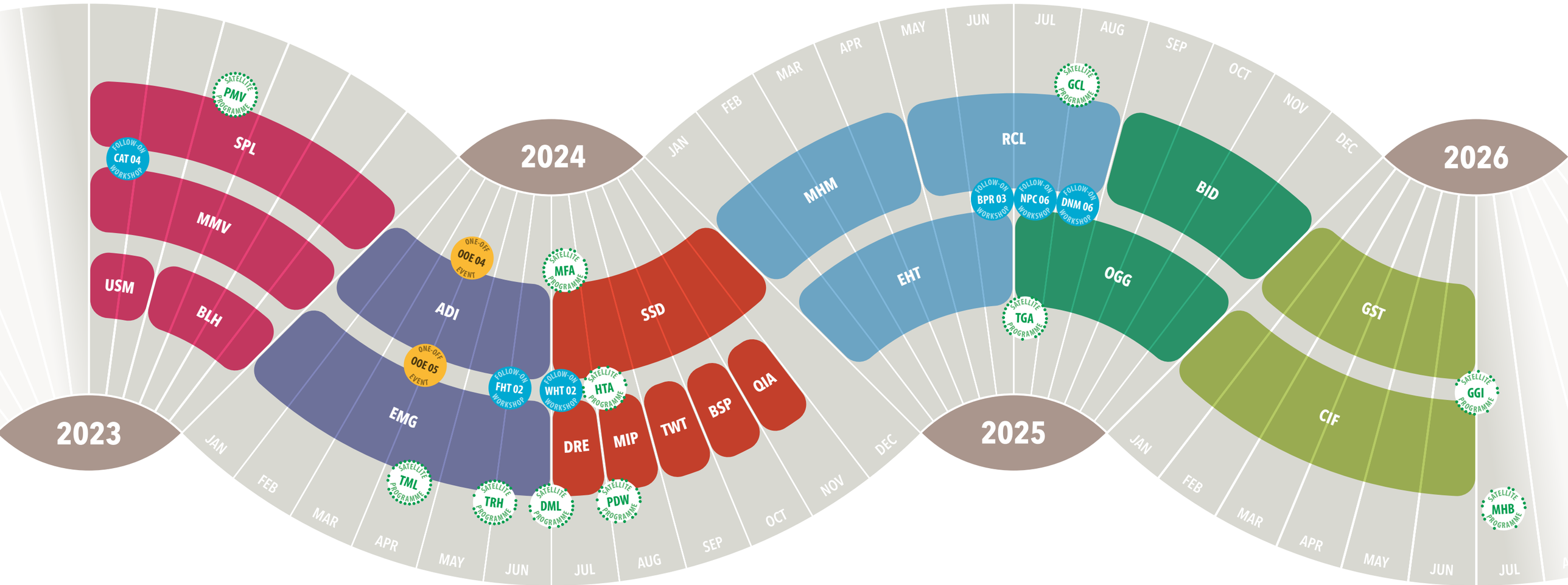
The Institute continues to support the Academy for the Mathematical Sciences (AcadMathSci) and the Knowledge Exchange Hub employing a combined staff force of six. Both have independent governance structures and the Academy has by now its own legal identity as a charity. The hope is that both will also achieve financial independence in the next year. Last November the Government set up a call for funding of £6m over a three-year period to which the Academy submitted a bid in June. In the meantime, EPSRC earmarked a pot of £2m to be spent over four years to which the KE Hub (only) has been invited to apply.

From the Director's point of view, a most important part of the year was the renewal of our recurrent grant from the EPSRC. This provides the core funding for our programmes, without which we would not be able to employ our staff and provide housing for long-term visitors. We estimate that this core funding attracts further funding of equal value, including most significantly funds for our extensive fellowships programme – a most effective and welcome tool to attract key participants staying for a significant length of time on our programmes. We are pleased that our Simons Fellowship programme has been renewed. Additional funds from the Simons Foundation for early career researchers from developing countries enabled us to launch the new Ramanujan Fellowship programme. Unfortunately, support through our Solidarity programme (run jointly with the LMS) is still much in demand from refugees, and a generous second donation from XTX Markets allows us to continue this worthwhile scheme. The gratitude of the recipients is enormous both for the support we could offer and the welcome they have received in maths departments throughout the country.

If writing grant proposals was my priority in the latter half of last summer, moving our building project forward quickly filled up any available time. Satisfyingly, the University's Planning and Resource Committee approved our extension project for Registration last December. Hand in hand with the development of our plans, we have also stepped up our fundraising campaign (see the latter pages of this report). The enthusiastic support from the new Vice Chancellor, Professor Deborah Prentice, and Sir Stephen Timms MP, both of whom visited INI earlier this year, as well as an early substantial pledge have been heartwarming and give us reasons to be optimistic. However, we are only at the beginning of our fundraising campaign. We anticipate that funds will have to come from many sources and I personally would be grateful for any and all support.

Ulrike Tillmann

Programme Schematic



SPL New statistical physics in living matter: non equilibrium states under adaptive control

CAT 04 Complex analysis: techniques, applications and computations - perspectives in 2023

MMV Mathematics of movement: an interdisciplinary approach to mutual challenges in animal ecology and cell biology

USM Uncertainty quantification and stochastic modelling of materials

PMV GeomPack: geometry and packing in material structure and biology

BLH Black holes: bridges between number theory and holographic quantum information

ADI Anti-diffusive dynamics: from sub-cellular to astrophysical scales

EMG New equivariant methods in algebraic and differential geometry

TML Heavy tails in machine learning

OOE 05 Space, Scale and Scaling in Art

OOE 04 Structure and Randomness - a celebration of the mathematics of Timothy Gowers

TRH Topology, representation theory and higher structures

FHT 02 Fickle Heart: The intersection of UQ, AI and Digital Twins

DML Diffusions in machine learning: foundations, generative models and non-convex optimisation

WHT 02 WHT Follow on: the applications, generalisation and implementation of the Wiener-Hopf Method

MFA The mathematics of multiphase flows with applications

SSD Stochastic systems for anomalous diffusion

DRE Discretization and recovery in high-dimensional spaces

HTA Hypergraphs: Theory and Applications

PDW Emergent phenomena in nonlinear dispersive waves

MIP Modelling and inference for pandemic preparedness

TWT Twistor theory

BSP Big Specification

QIA Quantum information, quantum groups and operator algebras

EHT Equivariant homotopy theory in context

MHM Modern History of Mathematics

RCL Representing, calibrating and leveraging prediction uncertainty from statistics to machine learning

BPR 03 Big proof: formalizing mathematics at scale

TGA Topological groupoids and their C*-algebras

NPC 06 Non-positive curvature and applications

DNM 06 Recent challenges in the mathematical design of new materials

GCL Geometric and categorical Lie theory

OGG Operators, Graphs, Groups

BID Quantum field theory with boundaries, impurities, and defects

GST Geometric spectral theory and applications

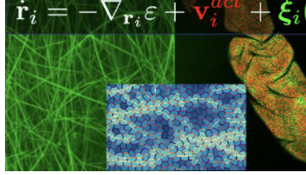
CIF Causal inference: From theory to practice and back again

GGI Algebras, Groups, Geometry, Invariants and Related Topics

MHB Maths of Human Behaviour: modelling sociality, mobility and protectionism

New statistical physics in living matter: non equilibrium states under adaptive control

July – December 2023



Life is an active, emergent process far from equilibrium and involving spatiotemporal organization across scales. Recent advances in the non-equilibrium statistical mechanics of active matter, along with such new experimental techniques as super-resolution microscopy and computational methods as machine learning, have opened new approaches for research on living systems. The programme focused on identifying mathematical techniques from non-equilibrium statistical mechanics that can be applied to biology at cellular and tissue scales, as well as new mathematical problems inspired by biology at this scale, forging new collaborations across disciplines.

Biological systems constantly dissipate energy, do work, and undergo complex motions, i.e., they operate far from thermal equilibrium. The frameworks of equilibrium thermodynamics and statistical mechanics that are so successful for soft materials (of which biological systems are made) is therefore often not applicable to living systems. The New Statistical Physics of Living Systems programme aimed at bringing together different scientific communities to address the challenge of developing new theoretical frameworks. This programme included communities working on (i) non-equilibrium statistical mechanics and simplified models, (ii) theoretical soft and active biological matter, (iii) experimental biophysics, and (iv) machine learning.

The programme focused on biologically diverse phenomena occurring at different spatial and temporal scales. These included new types of non-equilibrium phase transitions in epithelial sheets and tissues, the coupled mechanochemistry of motor proteins and filamentous assemblies, membraneless cellular organelles formed by phase separation, and self-assembly processes such as those found in the replication cycle of viruses. The first broad workshop aimed at bridging non-equilibrium statistical physics and biophysics. This was followed by a second workshop on active matter from single cells to cell layers, tissues and development at different scales, from cytoskeletal filaments to tissues and organoids. It included a special session in memory of Prof. Alex J. Levine, one of the instigators of the programme, who sadly passed away before it started. The third workshop focused on cellular organelles that are formed and maintained via phase separation processes, followed by a week-long mini workshop on gene regulation and cell fate decisions that brought in experimental biologists to interact with the program participants. A fourth satellite workshop was held at Edinburgh University, focusing on the non-equilibrium physics of biological self-assembly.

The program was complemented by an Open for Business Day focusing on the mechanics of cell walls across bacteria, plants, and fungi, as well as antimicrobial resistance. There was an EDI session discussing issues facing researchers from marginalized communities. In addition, we had a special one-day workshop commemorating the life and science of Prof. T. C. B. McLeish, FRS, an eminent member of the UK Biological Physics community.

The programme provided a welcome boost to research efforts, new collaborations, and mentoring of junior researchers in the field. The majority of participants initiated new collaborations, began research in new directions, and learned of new applications. Immediate achievements include new results on fluctuations of non-equilibrium systems, active matter, wound healing dynamics, filamentous assemblies, and fluctuating membranes and vesicles that are either motivated or testable by experiments. Plans are currently in place for follow-up activities in the form of short workshops at international venues across Europe, Asia, Africa, and the Americas to build a strong community working in this area.

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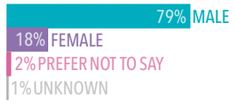

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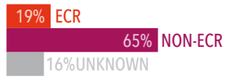

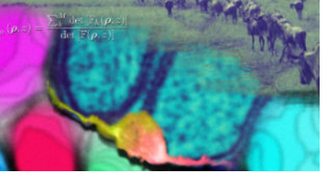

The mathematics of movement: an interdisciplinary approach to mutual challenges in animal ecology and cell biology

July – December 2023

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25% FEMALE
1% PREFER NOT TO SAY

GEOGRAPHIC DISTRIBUTION

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61% NON-ECR
14% UNKNOWN

Newton's legacy has inspired generations of mathematicians to study movement in all its shapes and forms producing advances in classical mechanics, partial differential equations, probability theory and stochastic calculus, to name but a few. Over three centuries, the influx of interdisciplinary problems has created a set of concepts, tools and techniques collectively termed the mathematics of movement. While this influx has realised a high level of mathematical sophistication, it has created cultural and technical barriers between movement modellers in different disciplines. The programme aimed to overcome these barriers and develop new mathematical paradigms to model motion across the life sciences.

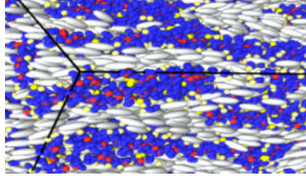
In the last twenty years, advances in animal tracking technologies and tissue imaging tools, have led to a dramatic upsurge in the analysis and quantification of the movement of organisms and their environments, with an unprecedented increase in the number, quality and types of movement data being studied. Spatio-temporal trajectories of biological entities are now routinely accompanied by a plethora of auxiliary information, e.g. weather conditions and onboard devices such as accelerometers and physiological sensors when tracking animals, and real-time changes in cell shape, cell cycle, and molecular transcriptional activities when imaging cell displacements and intracellular trafficking.

While the higher resolution of empirical observations has been beneficial to tackle unsolved problems common to animal ecology and cell biology, the increased mathematical sophistication required to analyse these novel datasets has created a series of conceptual and semantic barriers between the two disciplines. Theoretical scientists studying motion across the life sciences have been largely moving along parallel paths, with little exchange of ideas, tools and techniques. Given the vast knowledge on the methodologies to model and analyse movement, and the novel challenges that the data revolution has brought, the time was ripe for the communities working in animal ecology and cell biology to come together during the Mathematics of Movement programme. By cross-fertilising ideas between pure and applied math areas, the programme has been a successful intra and inter-disciplinary endeavour.

Among the many highlights of the programme, it is worth mentioning the one-week Summer School which took place near the beginning of the programme and was instrumental in familiarising all participants with the vast number of challenges in the two disciplines. Two weeks later, Iain Couzin, the Rothschild fellow, presented the influential Lecture on The Geometry of Decision-Making, just before the first workshop on Collective Behaviour, a vast area of research in the life sciences that also encompasses computer science, physics, engineering, and robotics. The second workshop, on Measures and Representations of Interactions, played a significant part in identifying common ground and key differences on how animals and cells interact with the surrounding environment and among themselves. When such interactions lead to the transmission of a pathogen between individuals, an infectious disease may spread within a population. This aspect was the focus of a one-day Open for Business event on Connecting Micro to Macro in Epidemiological Models, that involved active participation from academics and members of the government health sector. The Kirk distinguished lecture by Ruth Baker on Data-Driven Modelling of Collective Cell Motility, attracted a great deal of attention from programme participants as well as all attendees of the last workshop on Modelling non-Markovian Movement Processes. While the latter remains a challenging topic, during the workshop important recent advances from both fields were presented.

Uncertainty Quantification and Stochastic Modelling of Materials

July – September 2023



The Uncertainty Quantification and Stochastic Modelling of Materials programme was set at the interface between fundamental and applied continuum mechanics, statistics and probabilities. Its aim was to bring together international experts and early career researchers working on methodological advances and applications of uncertainty quantification and the stochastic modelling of soft engineering and biological materials. This is an emerging field that is expected to advance fast in the next decade and beyond. Because of the great novelty of the scientific ideas, the programme contributed to establishing a strong academic interdisciplinary community interested in applied probability, stochastic methods, materials science, biomedical engineering and soft matter.

There are many challenges associated with the mathematical modelling of soft materials where there are no established models. There are, however, several popular models that have been proposed and applied over the years. Traditionally, deterministic methods have been employed where material parameters are single-valued constants and physical quantities such as critical stresses and strains are scalar-valued functions of these parameters. By contrast, in stochastic modelling, parameters are described by probability density functions and quantities of interest are characterised as random fields. At the fundamental level, the aim is to derive universal theories that are valid for whole classes of materials.

Computationally, the scope is to devise multiscale models that are robust with respect to stochastic variations in microscopic components. More than that, as we fully enter the era of big data, the aspiration is to create intelligent systems that can account for all properties of a material, i.e., quantitative parameters (shear modulus, Poisson ratio, refractive index, electric permittivity, etc.) and also quantitative descriptions (softness, transparency, self-organization, self-healing, etc.), and generate new sustainable materials. Cutting-edge applications include mathematical modelling in medicine (traumatic brain injury, neurodegenerative or cardiovascular diseases, medical implants) and engineering design (haptic devises, Braille displays, protective equipment in sports and everyday life).

The programme started with a week-long summer school where experts in uncertainty quantification and stochastic modelling introduced their fields to an interdisciplinary audience. It later hosted a workshop on advanced mathematical modelling in biomechanics. These events were complemented by two public lectures by Distinguished Visiting Fellows Prof. Martin Ostoja-Starzewski (Rothschild Fellow) on "Tensor Random Fields in Mechanics" and Prof. Apala Majumdar (Kirk Fellow) on "Liquid Crystals: Where Mathematics Meets Physics and Applications", as well as a seminar series where participants at different stages of their career showcased their own work. The programme further featured a day celebrating "Equality in Physical Sciences", with a lecture on challenges and opportunities by Prof. Helen Gleeson OBE, followed by discussions on professional development for women and other under-represented groups.

Cross-disciplinary scientific interactions naturally extended to exchanges between the programme participants and those from the two concurrent programmes, namely: "New Statistical Physics in Living Matter" and "Mathematics of Movement". Synergies between the three programmes were also discussed. Therefore, the Isaac Newton Institute offered the perfect environment for establishing many interdisciplinary scientific links in order to further the field of mathematics and widen its range of applications.

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ECR STATUS

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51% NON-ECR
14% UNKNOWN

Black holes: bridges between number theory and holographic quantum information

September – December 2023

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78% MALE
21% FEMALE
1% PREFER NOT TO SAY

GEOGRAPHIC DISTRIBUTION

25% UK
75% NON-UK

ECR STATUS

36% ECR
56% NON-ECR
8% UNKNOWN

Obtaining a theoretical understanding of black holes constitutes a very challenging research endeavour that is central to any mathematically consistent theory of quantum gravity. Recent advances of our understanding of black holes in string theory have revealed fascinating connections of black holes with number theory and quantum information theory. The goal of this four-month long programme was to bring together mathematicians, mathematical physicists, string theorists and quantum information researchers to stimulate fertile interactions, with the objective of using black hole entropy as a central nexus to advance our understanding of the holographic formulation of quantum information in quantum gravity.

One of the central questions in quantum gravity is to understand the information content of black holes. This effort has generated two parallel streams of research in quantum gravity which, in the last decade, have experienced unprecedented conceptual and computational leaps. These two parallel research programs (one based on number theory and the other based on holographic quantum information) have operated in their own independent domains, and interface between them has been minimal. They have, however, one common focal point, namely understanding quantum information encoded in black hole entropy.

The aim of the programme was to establish bridges between these two parallel streams of research in quantum gravity. It was divided into three modules, each featuring a series of preparatory review lectures by experts introducing the state of the art. The first module explored emergent synergies between number theory, machine learning and quantum black holes, while the second probed the utility of machine learning toolkits to integrability techniques in gravity and featured an introductory hands-on machine learning bootcamp.

The last module was dedicated to the very recently surfaced exciting cutting-edge possibilities of using quantum information theory as an ontological framework to build up a holographic quantum field theoretic description of quantum gravity. This was punctuated by robust and vigorous cross-questioning as well as the emergence of audacious approaches to quantum gravity.

The Rothschild lecture, given by Robert de Mello Koch and entitled "From Black Holes to Holographic Spacetime", surveyed some of these recent developments and attracted wide interest. Another equally successful programme highlight was a one day Open for Business event, "Machine Learning: Portents and Possibilities", which brought together thinkers and practitioners across a wide range of thought streams spanning industry representatives, string theorists, mathematicians, biologists and ethicists to have free flowing conversations on the possibilities and burgeoning challenges of having machine learning reshape the landscape and methodology of human knowledge and the intentionality and consequences thereof. There was also a lively EDI workshop on "Examining, discussing, and promoting EDI initiatives in the mathematical sciences".

To sum up, this programme was successful in terms of kick-starting fertile cross-pollinations across classic and emergent streams of research. Some striking examples include forthcoming papers by groups of programme participants on the application of machine learning techniques to determine integrability in gravitational systems and very exciting reformulations of automorphic forms that act as generators of the statistical microstate degeneracy of a class of supersymmetric black holes in superstring theories, in terms of quantum information theory applied to the dual holographic QFT.

The organisers will build on this experience and organise follow-up events to capitalize on these newly evidenced interconnections and support the momentum buildup of research at the ever deeping intersection of number theory, superstring theory and quantum information theory, with the nascent but fast evolving tool of machine learning.

New equivariant methods in algebraic and differential geometry

January – June 2024

Many of the most powerful tools in geometry exploit the existence of symmetry. While this is an old idea, several recent developments in algebraic geometry – where the objects of interest are determined by polynomial equations – have introduced new, more broadly applicable techniques, with the promise of applications to various central goals of the field. This has led to a surge of interest in "equivariant" techniques in general, namely those that employ symmetry, and further suggests that equivariant techniques should be powerful beyond questions of classical interest.

Our programme "New equivariant methods in algebraic and differential geometry" brought together experts and early career researchers across various different subfields of mathematics whose areas employ equivariant techniques. This led to a broad programme with an emphasis on new collaborations, both within subfields of mathematics and between different subfields. While the majority of our participants were algebraic geometers, there were also many differential geometers, algebraists, geometric analysts and computational geometers, leading to a wealth of new activity between these fields.

The origin of our programme was the recent development of "non-reductive GIT" by two organisers (Gergely Berczi, Frances Kirwan), which greatly expands the applicability of equivariant techniques in algebraic geometry, by allowing many more general classes of symmetry than had previously been possible. Having already produced several breakthroughs in the field, our strong expectation is that these key new tools can be applied in many more directions. One of our main goals was therefore to explain and advertise these new ideas to the next generation, in particular through a series of lectures by Frances Kirwan given in February.

We began our programme with a winter school for early career researchers, held jointly between the Isaac Newton Institute and the University of Ibadan, Nigeria. The courses taught in Cambridge were livestreamed in Ibadan and vice versa, greatly expanding the reach of the school. We then held four further week-long workshops on an array of topics: applied geometry, hyperbolicity, K-stability and moduli theory. Aside from these, we encouraged new collaborations by fostering an active culture in the programme and by holding several more informal seminars, with the facilities enabling a remarkable degree of new collaboration between the participants.

Programme highlights were the Rothschild Public Lecture of Michael Thaddeus and the Kirk Public Lecture of Barbara Fantechi. Our Kirk Fellow also gave an illuminating talk at a well-attended diversity event "Mathematical Paths" organised together with the concurrent programme Anti-diffusive dynamics: from sub-cellular to astrophysical scales. The inspiration for our programme, derived from moduli theory, is also highlighted in Plus Magazine. Additionally, we are planning a book bringing together much of the recently developed theory of non-reductive GIT.

We have already observed early indicators of the programme's genuine success, evidenced by several new collaborations among our participants. We hope and expect these initiatives will inspire further collaborations.

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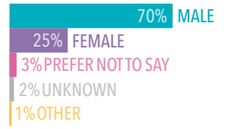

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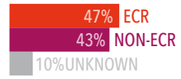

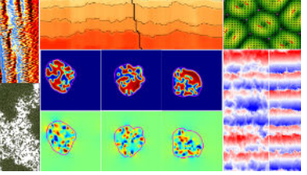

Anti-diffusive dynamics: from sub-cellular to astrophysical scales

January – June 2024

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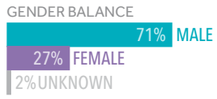

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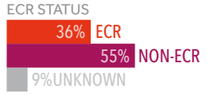

"Anti-diffusion" refers to that remarkable class of processes in which particles, fluid elements, etc. tend to migrate up-gradient, contrary to expected diffusive relaxation. "Anti-diffusive" includes what are known as "negative viscosity phenomena", and refers to similar dynamics, in a broader range of contexts. This programme did indeed study anti-diffusion from sub-cellular to astrophysical scales, with specific phenomena discussed ranging from biophysical transport and response in micro-vascular flows and the flocking of bacteria as an active fluid phenomenon, through to planetary and exoplanetary super-rotation and the dynamics of the Jovian and Saturnian atmospheres, including the origin of their famous bands and jets.

A particularly dramatic and fascinating anti-diffusion phenomenon is layering or staircase formation, in which turbulent stirring leads to the formation of mixed regions, interspersed by layers of steepened gradients; the latter may be thought of as transport barriers. The phenomena of layering are often said to result from inhomogeneous mixing, which should be contrasted to gradient relaxation, the usual outcome of mixing processes. Indeed, layering as the outcome of stirring is quite contrary to intuitive expectations based on homogenization.

The programme included five workshops: (i) Layering – a Structure Formation mechanism in Oceans, Atmospheres, Active Fluids and Plasmas, which surveyed the fields of the programme at the outset; (ii) Layering in Magnetized Plasmas, held at the University of York, which focused on applications to fusion physics and the implications of anti-diffusion for future magnetic confinement devices (this workshop included an Open for Business Day); (iii) Mathematical and Computational Modelling of Anti-Diffusive Phenomena, which addressed theoretical and computational approaches to problems of layering and anti-diffusion; (iv) Climate Applications of Layering, which explored layering in the context of climate physics, including multi-phase flows ('real world' questions concerning staircases were discussed extensively); and (v) Anti-Diffusion in Multiphase and Active Flows, which explored anti-diffusive phenomena such as coarsening and spinodal decomposition, active fluid dynamics, flocking and clustering, and environmental applications of multiphase flows. Taken together, these five workshops and the associated programme constituted the broadest and most comprehensive study of anti-diffusive phenomena ever undertaken.

The Rothschild Lecture on Inertia, Turbulence and the Concentration Field in Active Fluids, was given by Professor Sriram Ramaswamy. The Kirk Lecture on Evading Newton's Third Law and Setting Patterns in Motion, was presented by Professor M. Cristina Marchetti. The Heilbronn Colloquium (delivered at the University of Bristol) by Professor Anna Frishman, was entitled Universality of Satellite Formation During Breakup of a Fluid Bridge. In addition, there were typically 3–5 seminars and working group meetings during most weeks of the programme.

Discussions throughout the programme were extremely wide-ranging, reflecting the broad range of topics covered. However, one thread that ran throughout was the question of whether there is some (small) set of common mechanisms that underlie the wide range of layering phenomena. A few possibilities emerged. One is bistable mixing – i.e. from transport processes involving two mixing scales, one of which is emergent, dependent upon gradient and turbulence intensity. Such processes typically exhibit nonlinear flux-gradient curves, with at least two stable branches. Another idea is phase separation, as in spinodal decomposition phenomena. Here, the mechanism of motility-induced phase separation is of particular interest. A third mechanism for inhomogeneous mixing is homogenization within non-overlapping cells or phase space islands. Here also, the interplay between two scales – the island or cell width and the distance between resonances – is critical. If the latter exceeds the former, the mixing is inhomogeneous.

With sadness, we mourned Robert (Bob) Dewar, who died suddenly during the programme. Bob was a giant in theoretical plasma physics, with significant contributions in both magnetic fusion research and astrophysics.

GeomPack: Geometry and packing in material structure and biology

August – September 2023 | Aberystwyth University

ORGANISERS:

Simon Cox
(Aberystwyth University)
Adil Mughal
(Aberystwyth University)

GENDER BALANCE
90% MALE
10% FEMALE

GEOGRAPHIC DISTRIBUTION
31% UK
69% NON-UK

ECR STATUS
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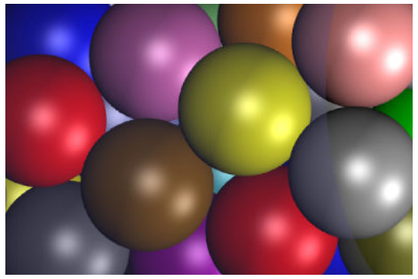
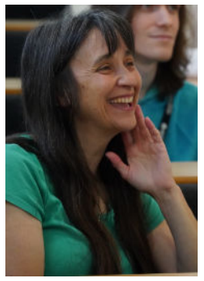
62% NON-ECR
17% UNKNOWN





The satellite programme on Geometry and packing in material structure and biology (GeomPack) at Aberystwyth University, convened experts in computational, combinatorial, and discrete geometry, physicists, and virologists. The month-long programme highlighted the mathematical challenges and the practical applications of packing problems in fields such as virology and soft-matter physics. GeomPack crowned a year of celebrations marking 150 years of Mathematics at Aberystwyth University.

Notable attendees included Thomas Hales, known for resolving the Kepler conjecture, and Chaim Goodman-Strauss from the National Museum of Mathematics in New York. Goodman-Strauss discussed the Einstein tile, a geometrical breakthrough allowing for a non-repeating tessellation of the plane with a single tile.

Reidun Twarock's evening lecture at the Aberystwyth Science Café, linking packing problems to viral self-assembly, underscored the relevance of this topic in the current global health context to a broader audience, blending mathematics and biology. Structural colour (Manoharan, Schroeder-Turk) also emerged as a theme: how nature uses packings of, for example, spheres, or minimal surfaces such as the gyroid, to generate colour.

Presentations from photographer Kym Cox and graphic artist Mark Eaglen, taking inspiration from packings of bubbles and the scutoid cell, provided a very different, and very welcome, view of how geometry appeals to other communities.

With more than half of the participants from overseas, the programme stimulated many new collaborations and has also led to a developing collaboration with industry. Livestreaming talks and sharing the recordings on YouTube has also helped to strengthen the packing community. Online seminars will continue, plans are underway to host a follow-up meeting outside the UK, and further funding for scientific exchanges is being sought, all with the aim of sustaining and expanding the collaborative network fostered at GeomPack.

Heavy Tails in Machine Learning

April 2024 | Alan Turing Institute

ORGANISERS:

O. Deniz Akyildiz
(Imperial College London)
Anita Behme
(Technische Universität Dresden)
Emilie Chouzenoux
(Université Paris Saclay)
Jorge Gonzalez-Cazares
(National Autonomous University of Mexico (UNAM), IIMAS)
Aleksandar Mijatovic
(University of Warwick; The Alan Turing Institute)

GENDER BALANCE
79% MALE
17% FEMALE
2% PREFER NOT TO SAY
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GEOGRAPHIC DISTRIBUTION
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60% NON-UK

ECR STATUS
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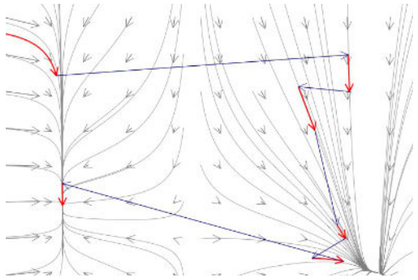
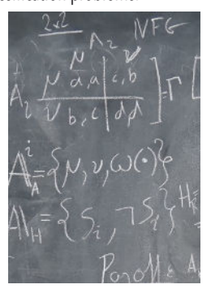


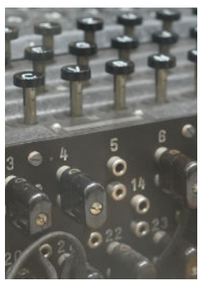
The Heavy Tails in Machine Learning research programme sought to enhance our understanding of heavy-tailed distributions in machine learning, focusing on their impact on model performance and optimization strategies. A series of events delved into critical aspects of this emerging field. The opening workshop set the foundation by bringing together experts to discuss the role of heavy tails in stochastic processes and their occurrence, whether naturally or artificially, in areas such as stochastic gradient methods and cluster distributions in classification problems.

Subsequent workshops, including the closing workshop and the Open for Business Day, explored the practical implications of heavy tails in deep learning and their relevance to differential privacy.



This programme effectively bridged mathematics, statistics, and computer science, fostering collaborations that led to innovative methods for managing heavy-tailed data. These collaborations resulted in significant advances, particularly in understanding chaos propagation and the compressibility of large neural networks, please see the long report on the INI webpage for more details.

The programme also spurred future research directions, underscoring the importance of heavy tails in generalization errors, the convergence of stochastic optimizers, and their applications beyond academia in sectors like finance and telecommunications. By facilitating unlikely collaborations and producing influential publications, the programme advanced the field significantly, establishing a foundation for ongoing research efforts. These efforts are anticipated to have enduring impacts across disciplines, addressing broadly relevant topics related to heavy-tailed phenomena in machine learning.



Topology, representation theory and higher structures

May – June 2024 | Gaelic College, Sabhal Mòr Ostaig

ORGANISERS:

Tara Brendle
(University of Glasgow)
Ran Levi
(University of Aberdeen)
Ehud Meir
(University of Aberdeen)
Simona Paoli
(University of Aberdeen)
Ana Ros Camacho
(Cardiff University)
Markus Upmeier
(University of Aberdeen)

GENDER BALANCE

65% MALE
26% FEMALE
2% PREFER NOT TO SAY
5% UNKNOWN
1% OTHER

GEOGRAPHIC DISTRIBUTION

46% UK
54% NON-UK

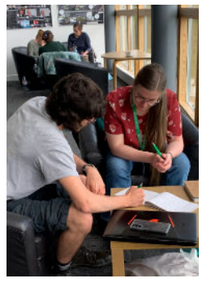
ECR STATUS

26% ECR
32% NON-ECR
42% UNKNOWN

The four-week programme "Topology, representation theory and higher structures" took place at the Sabhal Mòr Ostaig (Skye, Scotland). The programme was designed to bring together researchers at various career stages in homotopy theory, geometry, representation theory, quantum algebra, and higher categories.

Recent decades have seen a surge of multidisciplinary mathematical activity across these four areas. The programme aimed to capitalise on this transformative interdisciplinary activity via two weeks of collaborative research with a small number of talks, followed by a one-week workshop aimed at early-career researchers, with expository talks in each of the four themes as well as contributed talks, and with the final week featuring an international conference with ten plenary talks as well as additional contributed talks.

By facilitating collaboration among these diverse fields, the programme aimed to push the boundaries of current knowledge and foster the development of new approaches. Specific topics of focus included the classification of tensor categories, the K(π,1) conjecture, realisation problems, representation stability, and applications of higher category theory to areas such as unstable homotopy theory and manifold topology.



The college environment with all meals provided on-site, together with cultural activities such as a guest lecture on whisky-tasting and a live ceilidh band, naturally facilitated inclusivity and mixing across different research areas, levels of academic seniority, and other characteristics, as well as helping to support participants with caring responsibilities. Nearly a third of participants reported a new collaboration resulting from participation in the programme, a positive indicator of its success.

Diffusions in machine learning: Foundations, generative models and non-convex optimisation

June – July 2024 | Alan Turing Institute

ORGANISERS:

O. Deniz Akyildiz
(Imperial College London)
Gersende Fort
(Université de Toulouse)
Sotirios Sabanis
(University of Edinburgh)
Ying Zhang
(Hong Kong University of Science and Technology (Guangzhou))

GENDER BALANCE

72% MALE
26% FEMALE
2% PREFER NOT TO SAY

GEOGRAPHIC DISTRIBUTION

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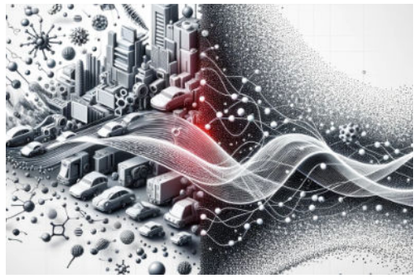
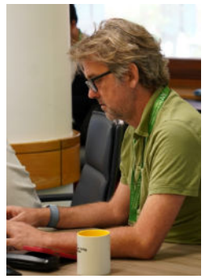




Diffusion models have swiftly become indispensable tools in machine learning, serving as a cornerstone in generative models, sampling algorithms, and as continuous-time models in stochastic optimization methods.

Our Programme "Diffusions in Machine Learning: Foundations, generative models and nonconvex optimisation" brought together a diverse group of experts and early-career researchers from various subfields within mathematical sciences, engineering, computer science and the social sciences. This diversity facilitated a broad and dynamic programme, with a strong emphasis on fostering new collaborations both within individual disciplines and across different fields.

The programme was inspired by recent developments in diffusion-based stochastic optimizers for artificial neural networks, pioneered by organizers Sotirios Sabanis and Ying Zhang, along with their collaborators. These advancements, combined with the rapid progress in diffusion-based generative models, have unlocked new potential for this technology, making it more versatile and applicable across a wider range of fields than ever before.

We launched our program with a summer school which experienced overwhelming demand, underscoring the significant demand and the critical importance of such

initiatives within the academic community. Key highlights of the programme included the hackathon week held at the University of Edinburgh supported by the Centre for Investing Innovation, where participants engaged in industry-inspired challenges provided by Amazon. Additionally, the Open for Business day featured a distinguished lineup of speakers, including Arnaud Doucet (Google DeepMind/Oxford University), Andrew Stuart (California Institute of Technology) and Eric Moulines (Ecole Polytechnique/French Academy of Sciences). The program culminated in an international conference in London, that showcased a rich diversity of perspectives.

Looking ahead, the outcomes of this programme are poised to drive forward the frontier of research and innovation in machine learning. We are confident that the interdisciplinary collaborations formed during this programme will lead to lasting contributions in both academic research and practical applications, positioning diffusion models at the forefront of AI and machine learning for years to come.

Recurring themes: A year of surprising connections

Over the past three years, plus.maths.org *editors Marianne Freiberger and Rachel Thomas have had a unique interaction with the Isaac Newton Institute, bringing with them extensive experience in communicating mathematical concepts to non-expert audiences. Here they reflect on some of the recurring themes.*

If there's one thing we've learned as maths communicators working with the INI and the Newton Gateway it's this: progress in the mathematical sciences thrives when new connections are discovered. We're far from unique in this insight, in fact we're in good company. As Albert Einstein said, "Growth comes through analogy; through seeing how things connect." What is very nearly unique, however, is the role the INI and the Newton Gateway play in affording researchers the time and space to develop connections between seemingly different fields so that cross-fertilisation can flourish.

Our collaboration with the INI and Newton Gateway began in early 2021. It now comprises over 180 articles and 31 podcasts published on plus.maths.org, covering over 60 research programmes, workshops and events. Our aim is to bring the fascinating work that happens here to non-expert audiences – from students and teachers to policy makers and press, people working in industry or researchers in other fields, or indeed anyone curious about what happens at the cutting edge of mathematical science.

Linking applications to address global problems

The last year has delivered some excellent examples of just how fruitful the crossing of boundaries can be. At first sight cancer cells have little to do with fish, but one thing the organisms do have in common is that they move around. Since similar mathematical models can be used to describe all kinds of movement this opens up astonishing opportunities for cross-fertilisation. The Mathematics of Movement programme (MMV) brought together animal ecologists and cell biologists to exploit both mathematical and technological synergies in an unprecedented manner.

"Over time both research communities have become specialised in their mathematical modelling, and yet we are looking at very similar, if not identical, structures and quantities to represent movement," co-organiser Luca Giuggioli told us in an enthusiastic interview. "During the programme there were lots of exchanges about methodologies to look at similar processes, but also at very different ones to exploit each other's expertise."

Areas as diverse as cancer research and the conservation of endangered species stand to benefit. Our favourite example of an idea sparked by the programme involves fooling cancer cells to move in a particular direction using a robotic "leader cell" – it was inspired by shoals of fish and flocks of birds, which can be similarly directed by robots. Birds also made an appearance in the programme Anti-diffusive dynamics: from sub-cellular to astrophysical scales (ADI), which made a connection between systems of different kinds and at different scales. We are used to the idea of diffusion, particularly in turbulent systems, which results in spreading of substances or structures. But in some cases a remarkable process can happen alongside this that results in a sharpening, rather than a spreading, of structures. This phenomenon of anti-diffusion is thought to play a role in a wide range of fields: from understanding the banded structures we see on Jupiter to possible containment methods of plasma fusion reactors. The programme was unique for bringing together expertise from three very different areas: fluid dynamics, plasma fusion, and active matter – where the matter in question comes with an energy source, such as subcellular bacteria and flocking birds.

"What the INI is fantastic for is bringing together people who wouldn't normally meet at conferences," said co-organiser David Hughes. "You are exposed to problems that you wouldn't normally see, and you see overlaps in different areas."

The power of mathematics to link up applications lies in its ability to describe the processes at play abstractly, freeing them from particular contexts. This also applied to the programmes Uncertainty quantification and stochastic modelling of materials (USM) and New statistical physics in living matter: non equilibrium states under adaptive control (SPL) which both explored properties of materials, from brain tissue and cytoskeletons to 3D printing composites.

Linking pure mathematics and theoretical physics

The programmes mentioned here help find solutions for some of the world's most pressing problems, but INI activities focus equally on less applied areas such as pure mathematics and theoretical physics. Here too there are astonishing synergies. This was exemplified by the programme Black holes: bridges between number theory and holographic quantum information (BLH). As we learnt, not only does mathematics enable progress in physics, but also ideas from physics, in particular string theory, drive forward pure mathematics, in particular number theory.

What we have touched on in this article are just some of our favourite highlights of last year's activities at the INI and Newton Gateway. Surprising connections are a theme that runs through all the programmes, workshops and activities we attended – rivalled only by participants' and organisers' enthusiasm at being given the opportunity to develop and exploit these connections to benefit science, mathematics, and humanity as a whole.

Structure and Randomness

A celebration of the mathematics of Timothy Gowers

Report by Rachel Thomas, Editor of plus.maths.org

Eminent mathematicians from around the world gathered at the INI in April 2024 to celebrate both the mathematics and the 60th birthday of Professor Sir Tim Gowers FRS. Reflecting Gowers' wide interests, talks ranged from Banach space theory to combinatorics and additive number theory, and from theoretical computer science to pedagogy.

Gowers' contributions to these areas has been recognised by many prizes, including the Fields medal in 1998. Over 125 of the leading mathematicians in these areas joined the hybrid workshop from around the world, with speakers including Abel Laureates Endre Szemeredi and Avi Widgerson, and fellow Fields Laureate Terence Tao. Tao's session was one of many that were so popular that some of the audience had to stand at the back of the seminar room. Many of the speakers began their talks with fond memories of working with Gowers, and a continuing theme in the whole workshop was the importance of collaboration to mathematicians both now and in the future. Most of the speakers had co-authored papers and books with Gowers and had stories of working with him directly. But Gowers has also been pivotal in developing some very new ways for mathematicians to work together.

"Tim is willing to muse, to throw ideas out there about possible ways to do mathematics, to collaborate or come up with ideas," said Tao in the introduction to his talk. Gowers and Tao were very early adopters of new technologies to work differently. Gowers followed Tao in setting up a blog in 2007 – offering more immediate access to their work and also an insight into life as a research mathematician. Another example is the Polymath project set up by Gowers, which allows mathematicians to collaborate by posting their thoughts about a problem online or commenting on the thoughts of others.

Tao's talk highlighted very recent work with Gowers and others, which spans both the traditional way of doing maths and a new and revolutionary approach using computers to harness the power of human collaboration. Tao spoke about his recent work with Gowers, along with Ben Green, from the University of Oxford and one of the organisers of the workshop, and Frederick Manners from the University of California, San Diego. Together they proved Marton's PFR conjecture, a result in additive combinatorics, that built on work of Imre Ruzsa, another speaker at the workshop. In 2023 Gowers, Green, Manners and Tao proved this result for a specific kind of group where addition operates on strings of binary numbers, but at the workshop Tao announced that they had gone even further. Just the week before the workshop Gowers, Green, Manners and Tao had published a full proof of Marton's PFR conjecture, this time not restricted to a certain type of group.

The work also illustrates another new approach to doing mathematics. Just days after they shared their traditional proof of the result for binary strings in November 2023, Tao announced that he and two students at the University of Cambridge (Yaël Dillies and Bhavik Mehta) had begun a collaborative project to formalise the proof. Formalising proofs in this way is a very modern way of doing mathematics, says Tao. "It's a weird mix of human mathematics, computer programming and proof checking." And a key aspect is that it encourages collaborations between people from many different parts of mathematics. Twenty people joined the project, many of whom were present at the INI workshop, and they completed the project within weeks.

Tao says one of the key benefits of formalising a proof in this way is that it opens the proof up to many contributors, even if they are only able to work on one small corner of the

proof. "The thing is it's very parallelisable, people volunteer to take on any piece," says Tao. "You don't need to do it in a linear order. And you don't need to understand the entire proof to formalise a little piece." This meant people who were not experts in the area but who were interested could just work on small parts of the proof. "People dropped in and did one little step and dropped out. It was a lot of fun – I'd wake up every morning and a bit more of the graph was completed!"

The importance of collaboration and Gowers' imaginative approach to it was emphasised in many talks. In Tao's introduction to his talk, he said: "A lot of mathematicians are trained to only talk about what we can prove – to be very cautious about speculating. But Tim is willing to be more bold. What if we all try to collaborate online? What if we write an encyclopaedia of all mathematics, and so on. We need more people like that."

The encyclopaedia Tao was referring to was The Princeton Companion to Mathematics, edited by Gowers along with June Barrow-Green and Imre Leader, who were both speakers at the workshop. Barrow-Green is a historian of mathematics, and spoke about a surprising collaboration between epidemiologist Ronald Ross and mathematician Hilda Hudson in the early twentieth century. Hudson, the first woman to give a lecture at an International Congress of Mathematicians (Cambridge, 1912), provided the mathematical skills that Ross lacked in order to help found the mathematical theory of epidemics. This includes an early version of the famous SIR model that takes account of immunity in the spread of disease.

Another highlight from the workshop was Avi Widgerson's talk about a number of open questions from different parts of mathematics. These questions might seem relatively simple, but Widgerson explained why their solution would have profound implications for complexity theory. Widgerson was recognised early on in his career for his contributions to theoretical computer science with the Nevanlinna Prize in 1994, and for his lifelong contribution by an Abel Prize in 2021. It was during the workshop at the INI that Widgerson discovered he had been awarded the 2023 Turing Award.

At the beginning of his talk Widgerson celebrated the fact that he was in the presence of hundreds of the greatest problem solvers. "Being here is phenomenal," he said. "I invite you to the fun and games – I've been playing it for over 40 years!" It was clear from the experiences being shared in the workshop that Gowers and his colleagues have much to celebrate from a life in mathematics.

Joint INI-Ibadan School on Equivariant Methods in Geometry

8 – 12 January 2024

Report by Victoria Hoskins

Dominic Bunnett and Victoria Hoskins have produced a guide to organising joint INI schools with African universities. The guide can be found on the "Equivariant methods in geometry" INI website page.

One novel aspect of the INI programme "New equivariant methods in algebraic and differential geometry" was that the opening school was run jointly between the INI and the University of Ibadan. The goal of the school on "Equivariant methods in geometry" was to provide various introductory lectures on different aspects of the programme for young researchers. As organisers, we decided that this would be a fantastic opportunity to include mathematicians in the global south. Fortunately there was a natural choice of partner: Praise Adeyemo working at the University of Ibadan was already in contact with various European algebraic geometers and was excited about such a joint venture.

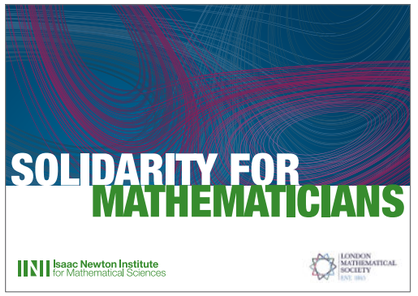
For the successful running of the school, Dominic Bunnett and Joshua Jackson travelled to Ibadan to give courses, as well as help with the organisation and offer guidance to students attending in Ibadan. Their travel was funded by the Clay Mathematics Institute, and the INI sent stationary and funds for running the school in Ibadan. We coordinated the schedules so that in both Ibadan and Cambridge, a maximum of one talk a day would be followed online: Josh's Ibadan-based course on geometric invariant theory was broadcast in Cambridge, and two Cambridge-based courses were also followed in Ibadan. Dominic and Praise both gave more foundational courses tailored to the backgrounds of the students in Ibadan, whereas in Cambridge there were a few more advanced courses that were not followed in Ibadan. Frances Kirwan also sent some signed books as prizes for the student talks and mini-projects in Ibadan, and we were delighted when Praise sent back some presents for the organisers at the INI.

Overall this joint school was a great success and we hope it may be repeated in the future.

Key Updates

INI-LMS Solidarity for Mathematicians Programme

Set up in March 2022 in collaboration with the LMS, the Solidarity programme for refugees received a further substantial donation from XTX Markets of £600k, thus doubling the funds available for this initiative. This allowed us to admit eight new participants to the scheme and offer extensions to a further six already on the scheme but who had not yet found employment. On the other hand, five people left the scheme over the course of the year of whom two found permanent academic jobs in China and the US, one was offered a fully funded PhD position in Scotland, and one found a job in industry.



To enhance their experience on the Solidarity programme, we offered participants support to attend the IMA event for new lecturers at INI and a Sanctuary Seekers STEM Seminar in Oxford. Participants, who are given the option to join the LMS for free while on the Solidarity programme, were also invited to the AGM and dinner of the LMS. At INI we extended our Talks Elsewhere scheme to the Solidarity programme and no less than 15 talks were delivered throughout the UK. It is a delight to be able to report that, given the circumstances, many of our participants have been extraordinarily productive with a total of 28 papers published and a further 10 preprints, one book and one monograph produced.

We would like to thank at this point the hosts and our partner universities for their continued and crucial support for the scheme, which sadly is still needed.

INI-Simons Postdoctoral Fellowships

The INI-Simons Postdoctoral Fellowships scheme continued to thrive this year, appointing four new fellows in January 2023. This brings the total number of recipients to seventeen since the scheme's inception in 2021. This year's fellows include SJ Kole, William Duncan Martinson, Theodoros Papazachariou, Paul Pruzina, Samuel Stark, and Watse Sybesma. Each fellow was affiliated with a programme at the INI, spending four to six months at the Institute before completing their 12-month fellowship at another UK mathematics department.

The programme has laid a strong foundation for the fellows' future successes, leading to successful grant applications, tenured lectureships, and further postdoctoral and research positions.

Network Support for the Mathematical Sciences

The INI Network scheme continues to thrive and now supports over 40 networks through-out the country on topics from the whole breadth of the mathematical sciences for example on prostrate cancer, constructing a virtual eye, modelling ocean wave energy, exploring the mathematics of sea ice and mass extinction, as well as organising resources for diversity in mathematics. The programme offers a snapshot of the vibrancy of the mathematical sciences across the UK, and of its broad reach across all aspects of the sciences.

The INI scheme provides a small funding package to enable networks of researchers to continue and intensify their work, or to allow new networks to be formed. Networks typically run for around two years and offer fertile ground for connecting mathematicians in informal or more formal groups and meetings. Funded since the inception of the scheme from the additional funding awarded to the mathematical sciences in 2020, we are pleased that the scheme will be supported jointly from 2025 by the Heilbronn Institute for Mathematical Research.

Key Updates

Equality, Diversity and Inclusion

INI has historically helped to develop the next generation of mathematical scientists by encouraging participation of early career researchers, by addressing the gender gap and by widening participation. Key ongoing activities have included the Kirk Distinguished Visiting Fellow scheme, which showcases the work of very senior female academics and members of other under-represented groups; funding schemes for child-care and participants from developing countries to help remove barriers to participation; and the Living Proof podcast which shares the "stories" of its visitors to enable a greater understanding and appreciation of the work and lives of mathematicians more broadly. INI was also proud to support the Black Heroes of Mathematics conference again this year, as well as the Retreat for Women in Applied Mathematics held at ICMS.

Building on this legacy, in October 2023, we published a renewed five-year EDI action plan for 2023-2028. The new EDI action plan is central to INI's mission, broadening the focus beyond gender and incorporating the University's new Code of Behaviour and Dignity at Work policy. It also includes planned engagement across the mathematics community to share learning and develop best practice. All INI programmes now have a designated budget for EDI events, with recent events including a workshop entitled *"Examining, discussing, and promoting EDI initiatives in the mathematical sciences"*; and a *"Mathematical Paths: How do you become a mathematician?"* event jointly organised by two programmes, with speakers Barbara Fantechi (SISSA) and Rachael Warrington (Smith Institute). There have been new efforts to support Early Career Researchers and participation from underrepresented groups. In particular, Ramanujan Fellowships, funded by the Simons Foundation, offer the opportunity for promising early career researchers living and working in low- and middle-income countries to attend an INI programme for one to three months.

The first Solve for X modelling camp for the Martingale scholars from lower socio-economic backgrounds was organised by INI and the Newton Gateway in June 2024.

Social Media, Podcasts and Video Interviews

There was another substantial increase in our social media engagement this year. A significant achievement is that both our main YouTube channel and the Seminar Room 1 channel have exceeded 3,000 subscribers. Seminar Room 1 now has enhanced live streaming and video production capabilities, featuring state-of-the-art AV equipment, following a renovation in December 2023, and we can now capture audience and speaker audio flawlessly, alongside stunning visuals.

Our video interview series featuring Rothschild and Kirk Distinguished Visiting Fellows and programme organisers has been expanded to include INI satellite programme organisers, with the Communications Team travelling to the satellite locations to carry out interviews. Twelve distinguished fellow and eight organiser interviews were recorded in this period. Our most popular interview to date with Sir Andrew Wiles, featured in the last annual report, garnered an impressive further 70,000 views from July 2023 to July 2024.

The Institute's Living Proof podcast series has seen a rise in listeners, accumulating over 2,500 downloads during this reporting period. Podcasts from within the past year include the *"Meet the Simons Postdoctoral Fellows"* mini-series, *"Voices from Ukraine: Olena Domanska of the Solidarity for Mathematicians programme"*, *"Linking Cambridge with Africa: how to co-host an international research workshop"* and *"Meeting the three mathematics medalists from the STEM for Britain awards 2024"*.

One of the highlights of this year's outreach activities was the hugely popular INI annual public lecture, *"The Force Awakens: Quantum Collisions"*, given by Ben Allanach in March as part of the Cambridge Festival, involving even a musical performance by Ben.

The Newton Gateway to Mathematics

The Open for Business events, developed and delivered by the Newton Gateway to Mathematics as an integral part of INI programmes, continue to be highly valued by programme organisers, as is evident in the programme summaries in this annual report. In November 2023, the Newton Gateway to Mathematics hosted its 10th anniversary celebration with a vibrant afternoon of talks highlighting the full breadth of Gateway activities. The Newton Gateway has continued to work with UKHSA on internship placements for doctoral students in the mathematical sciences and with UKRI's Analysis for Innovator programme which provides UK businesses access to cutting-edge research expertise resulting in many R&D projects. More information about the Gateway's activities this year can be found in their annual report, which is attached to this INI report.

Other Key Updates

INI has always taken its national role seriously. With that in mind, satellite workshops and programmes were conceived. We have already reported on the four satellite programmes and two satellite workshops as part of INI programmes during 2023-24 and are pleased to say that one of each is planned to take place in Northern Ireland in 2025, a long awaited (and worked for) first!

INI also continues to host small one-off and bespoke events, such as the conference in honour of Sir Timothy Gowers that has a longer feature article in this report. We also held a workshop connected to art, *"Space, Scale and Scaling in Art"*, that brought together physicists, mathematicians, neuro-scientists, art historians, and artists. The 2023 Santa Fe School took place at INI in August on the topic of *"Intelligence & Representation: Models of the world in natural and artificial systems."* This was a very interdisciplinary two-week summer school, aimed at expanding the minds of the students. In addition to the participants chosen by the Santa Fe Institute, six UK students attended the school (for free).

Two follow-on workshops were held: "Complex analysis: techniques, applications and computations – perspectives in 2023" and "Fickle Heart: The intersection of UQ, AI and Digital Twins". Follow-on workshops can be useful for consolidating learnings from an INI programme and reviewing how the field has evolved since and the current hot topics. They are usually held at least a year after the original INI programme.

On a more modest scale, **Talks Elsewhere** remains a popular scheme with 104 talks delivered by INI visitors throughout the UK. As in previous years, INI supported the **IMA workshop for new lecturers** held at INI and administrated the **HoDMS conference**. As in previous years, INI has provided the publicity for the **STEM for Britain** event and sponsored the Bronze award in the mathematical sciences. The **network of Correspondents** met in January for a small but delightful gathering at ICMS in Edinburgh. Correspondents remain a direct link of the two institutes to some 70 UK universities.

Enhancing the National Infrastructure

Over two years ago, two new organisations were set up, the Knowledge Exchange Hub and the Academy for the Mathematical Sciences. Both grew out of recommendations in the 2018 Bond Review, *The Era of Mathematics*, that had been fleshed out in two green papers commissioned by the Council for Mathematical Sciences (CMS). After extensive consultations in the first part of 2022 confirmed strong community support for both, the CMS set-up the Academy and INI initiated the KE Hub. INI has provided core financial and administrative support to the two initiatives. Both have now independent governance structures and the Academy is its own legal entity. We are delighted that both have also good prospects to gain financial independence.

These initiatives, as many other activities mentioned in this report, have been made possible through the INI's grant from the EPSRC Additional Funding for Mathematical Sciences. We include reports from both organisations below.

Knowledge Exchange Hub for Mathematical Sciences

KE Hub

The UK Knowledge Exchange Hub for Mathematical Sciences (KE Hub) was set up in July 2022 with generous support from the INI, with the aim of:

- Scaling up KE activity in the UK;
- Connecting researchers, practitioners, and end-users;
- Supporting existing KE activity in the community;
- Delivering activities; and
- Coordinating support for mathematical science KE projects from beginning to end.

KE Hub activity is led by the Scientific Director, Professor Chris Breward, and KE Manager, Rachael Harris, and is supported by an Executive Team including representatives from the Newton Gateway, ICMS and Innovate UK Business Connect, as well as 8 Super Champions (Professor Chris Budd (Bath), Professor Alan Champneys (Bristol), Dr Shirley Coleman (Newcastle), Dr Joanna Jordan (Independent), Professor William Lee, Dr Alberto Paganini (Leicester), Dr Lars Schewe (Edinburgh), Professor Diwei Zhou (Loughborough)). Strategic advice and guidance is provided by an Advisory Board, comprising senior leaders from academia and business, industry, and government.

Over the past year, the KE Hub has grown three networks – one each for KE Champions from university departments, KE Professionals, and Business Industry, and Government (B.I.G) Partners. Mathematical science departments from across the UK have nominated KE Champions who led their department's engagement with the KE Hub. To date, KE Champions from 60 departments representing 53 universities have joined and have benefitted from regular meetings to share opportunities and good practice. Knowledge Exchange Professionals have been encouraged to join the KE Professionals Forum. So far, 53 KE Professionals have joined and meet monthly to explore specific challenges and share best practice. In addition, the KE Hub continued to welcome representatives from outside academia to join its Business, Industry, and Government (B.I.G) Partnership; 62 organisations have joined to date. The B.I.G partners have the opportunity to participate in key KE Hub activities with universities such as triaging workshops assessing specific industry challenges . These one-hour online sessions launched in March 2024 with support from ICMS and run fortnightly. In each workshop, a B.I.G partner presents a challenge where the mathematical sciences might help to an audience of academics drawn from mathematical scientists at partner universities. A number of questions are posed with the aim to build a team, drawn from those present, to take forward a collaboration to address the challenge. 10 workshops took place between March and July and the programme is full through to the end of 2024. The KE Hub has delivered eight KE-related training courses, benefiting 78 mathematical scientists from 39 universities, and a well received "Knowledge Exchange for Pure Mathematicians" event, reaching 88 attendees from across the country.

In December 2023, the KE Hub held its official launch event at Aston University, attended by over 80 representatives from the 3 KE Hub networks as well as other key representatives from the UK mathematical sciences landscape. Quick-fire presentations were utilised to drive one-to-one networking with B.I.G. partners and there was plenty of time for discussing potential collaborations and exploring funding possibilities.

As part of its remit to support existing KE activity in the UK, the KE Hub has provided funding to enable the success of the European Study Group with Industry (ESGI) 180, including subsidies to facilitate two small businesses to present a challenge, and follow-on travel funding to enable researchers to travel to partner organisations to present their findings and to discuss follow on activities. The KE Hub has also provided underpinning funds and administrative support for V-KEMS (Virtual Forum for Knowledge Exchange in Mathematical Sciences) to develop and deliver 3 Virtual Study Groups in UK.

The KE Hub Management Team have benefited greatly from supererogatory advice, support, and guidance from INI during this crucial set-up period.

Enhancing the national infrastructure

Academy for the Mathematical Sciences (AcadMathSci)

The 2018 Bond Review, The Era of Mathematics, emphasised the need for a unified, authoritative voice for the mathematical sciences. To advance this, in Autumn 2022, the Council for the Mathematical Sciences (CMS) appointed an Executive Committee, chaired by retired senior civil servant Nigel Campbell, and established an Advisory Board. The Isaac Newton Institute (INI) generously agreed to incubate the Academy for a two-year setup phase, with INI Deputy Director Dr. Christie Marr seconded as Executive Director.

This academic year has seen significant progress in establishing the Academy for the Mathematical Sciences (AcadMathSci), with the goal of becoming the UK's fifth government-funded National Academy. In September, the Academy achieved charitable incorporated organisation (CIO) status with the mission to "benefit society through the power of the mathematical sciences." The founding trustees are Nigel Campbell, Professor Rachel Bearon, Ruth Kaufman OBE, Professor Terry Lyons FRS FRSE FLSW, Lynne McClure OBE, and Simon Yun-Farmbrough.

In May, Professor Alison Etheridge OBE FRS was appointed as the first President, recognised both for her outstanding research credentials and for her exceptional record of leadership and service to the profession.

In the autumn, two Policy Analysts, Dr. Vinesh Maguire Rajpaul and Thomas Chi Wah Law, joined the Academy. Together, they have worked on several projects, including leading a joint initiative with CMS to produce a Maths Manifesto, advocating for the value of the mathematical sciences in the UK.

AcadMathSci played a key role in organising the first-ever Maths Summit at the Science Museum in March, bringing together leaders from academia, industry, education, and politics. Topics addressed included the importance of the mathematical sciences in research and innovation and its power to change society for the better.

In November, the government pledged "up to £6m of seed funding over three years" to establish a National Academy for mathematical sciences, contingent on a business case. In January, the Department for Science Innovation and Technology (DSIT) issued a Call for Evidence, followed by a Call for Applications in May. With the backing of INI, CMS, and the Learned Societies, AcadMathSci has engaged vigorously with this process: we submitted our application in June and await a decision.

With over 80 volunteers on the Executive Committee and Advisory Board including senior academics, educators and leaders in business and industry, a joint statement of support from CMS and its constituent learned societies, and an impressive list of named supporters, this project has gained significant momentum and earned the mandate of the community.

The Executive are greatly indebted to INI for its significant financial and infrastructure support during this setup phase.

Samantha Skehel (1967 – 2024)

INI Business and Operations Manager, 2015 – 2024

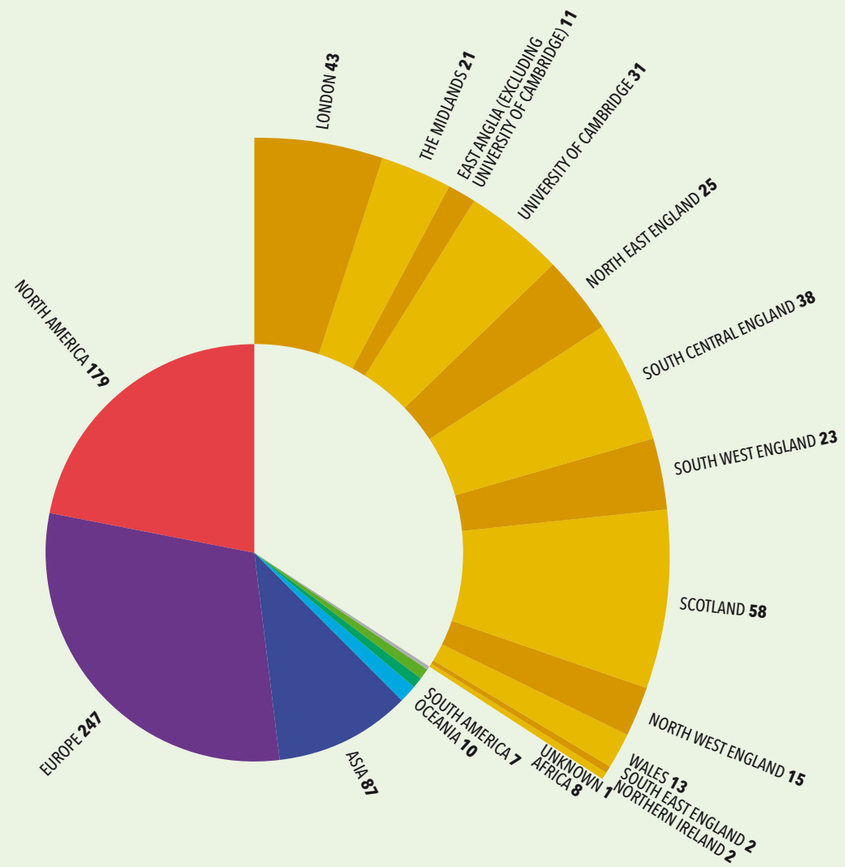
The staff and greater community of the Isaac Newton Institute were greatly saddened by the death of Samantha Skehel on 26 January 2024.

Sam joined the Isaac Newton Institute in June 2015. She oversaw and developed INI's administration, building a strong team to support the Institute's visitor research programmes. Sam was instrumental in shepherding through many major projects at INI most recently bringing her insight to the management of the many new projects and opportunities created as a result of the additional funding awarded to the mathematical sciences community in 2020.

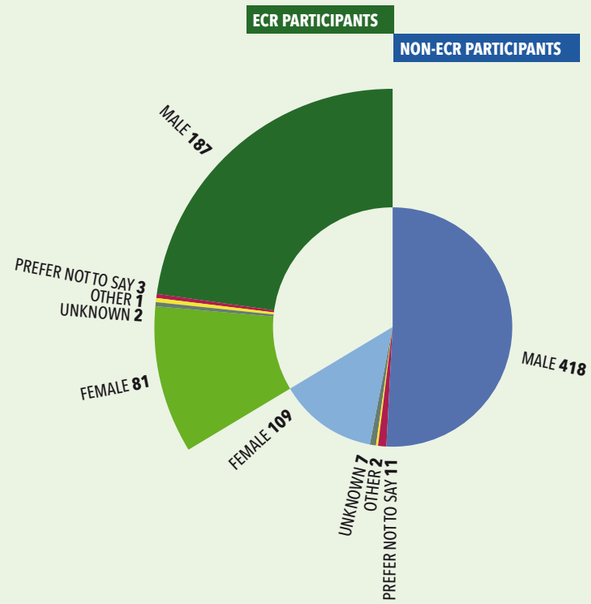
Before joining INI, Sam's career spanned multiple sectors – ranging from industry to charitable bodies, local government to higher education – and included organisations such as Cambridge's Laboratory of Molecular Biology, STARS Children's Bereavement Support Service, and Marks and Spencer. Within the University of Cambridge she took up two secondment opportunities, one to review the methods of providing internal audit, and the other as Audit and Regulatory Compliance Officer, co-ordinating Risk Management and providing administrative support for both Internal Audit and the Audit Committee. Sam held an undergraduate degree in English Literature and an MBA. Her passion outside of work was riding, and she owned two horses during her time at INI, most recently a mare called Goldie.

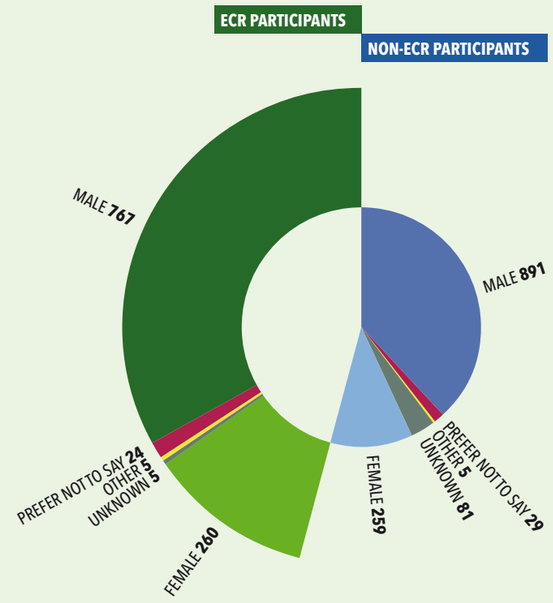
Alongside her always professional approach, Sam brought style, laughter and warmth to her work. She nurtured the careers of many colleagues at the INI and across her wide University network. Many of us, whether here at INI or in new ventures, will feel grateful for her support and guidance. Sam was immensely loyal to the Institute and its staff, and proud of the work she oversaw. Her effervescence and energy infused the working culture of the Institute, and her passing leaves an indelible mark. She is very much missed.

Worldwide geographic spread of programme participants



Gender and ECR* Status

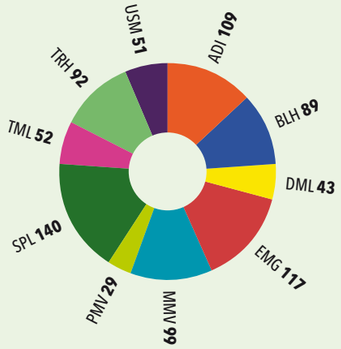




*ECR: early career researcher

PROGRAMME PARTICIPANTS | **WORKSHOP PARTICIPANTS**

Programme participant numbers



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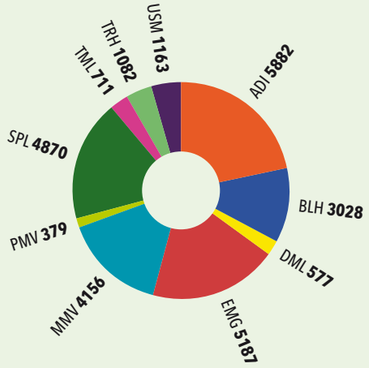
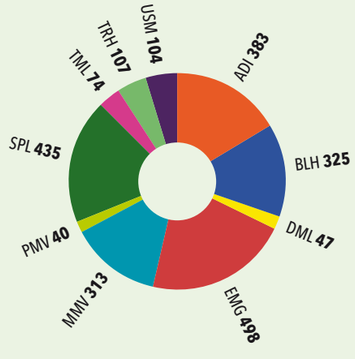
PROGRAMME PARTICIPANTS

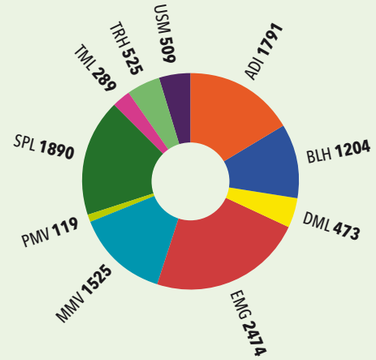


27035
PROGRAMME PARTICIPANT DAYS

Workshop participant numbers



2326
WORKSHOP PARTICIPANTS



10799
WORKSHOP PARTICIPANT DAYS

Governance: Advisory Council

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 fundraising 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 2024 was as follows:

Name	Institution	End of Service
Dr Ewan Kirk (Chair)	General Board	31-Dec-25
Professor Kerem Akartunali	University of Strathclyde	31-Dec-25
Dr Marianne Rolph	EPSRC	
Professor Colm-Cille Caulfield	Head, DAMTP, University of Cambridge	
Professor Mark Chaplain	St Andrews	31-Dec-24
Professor Darren Crowdy	Imperial College London	31-Dec-25
Professor Christl Donnelly	Imperial College London	31-Dec-26
Dr Milla Kibble (Secretary)	Deputy Director, Isaac Newton Institute	
Professor Niall MacKay	Chair of Correspondents, York	
Professor Ivan Smith	Head, DPMMS, University of Cambridge	
Professor Nigel Peake	Head, School of Physical Sciences	
Professor Ulrike Tillmann	Director, Isaac Newton Institute	
Professor Helen Wilson	Chair of the Scientific Steering Committee	31-Dec-26

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 2024 was as follows:

Name	Institution	End of Service
Professor Helen Wilson (Chair)	University College London	31-Dec-26
Professor Nick Barton	Institute of Science and Technology Austria	31-Dec-25
Professor Lucia Caporaso	Università degli Studi Roma Tre	31-Dec-27
Professor Mark Girolami	University of Cambridge	31-Dec-26
Professor Susanne Ditlevsen	Københavns Universitet	31-Dec-24
Professor Noah Linden	University of Bristol	31-Dec-26
Professor Sara Lombardo	Loughborough University	31-Dec-24
Professor Laure Sainte-Raymond	IHES	31-Dec-26
Professor Richard Samworth	University of Cambridge	31-Dec-27
Professor Ulrike Tillmann	Director, Isaac Newton Institute	
Professor Minhyong Kim	Scientific Director, ICMS	

Financial Information

Accounts for August 2023 to July 2024

For the Isaac Newton Institute and Newton Gateway to Mathematics

Income	*Notes*	2022-2023 £000	**2023-2024 £000**
Research Grants and Contracts	*1*	5,004	**4,441**
Contribution from the University of Cambridge	*2*	650	**540**
Donations	*3*	466	**530**
Additional workshop income		71	**129**
Additional income	*4*	480	**741**
Endowment and investment income		659	**720**
Total income		7,330	**7,101**
Expenditure			
Staff costs		1,866	**1,997**
Travel and subsistence	*5*	3,388	**2,854**
Other operating expenses	*6*	688	**958**
Overheads paid to the University	*7*	844	**764**
Total expenditure		6,786	**6,573**
Surplus / (deficit)		544	**528**

Notes to the Accounts

Note 1 – Research Contracts and Grants (EPSRC, Simons Foundation & Heilbronn Institute for Mathematical Research)

Salaries	1,546
Participant costs (travel and subsistence)	2,199
Estates and indirect income	696
Total	**4,441**

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

Miscellaneous donations	32
Donations, other	498
Total	**530**

Note 4 – Additional income

Merchandise sales	19
HEIF (Newton Gateway)	58
Newton Gateway income	610
Programme Sponsorship	25
London Mathematical Society	30
Total	**741**

Note 5 – Travel and Subsistence

Programme & workshop	2,854
Staff travel & subsistence	15
Total	**2,869**

Note 6 – Other operating expenses

Computing & Printing	199
Institute running costs	104
Catering	13
Furniture	5
Professional & brought in services	588
Miscellaneous	48
Total	**958**

Note 7 – Overheads paid to the University

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

Building Campaign:
Expanding the reach of mathematics

The Isaac Newton Institute brings together researchers from across the full breadth of the mathematical sciences and collaborative disciplines including physics, quantum technology, ICT, engineering, bio-medical sciences and much more. As such, INI is a unique part of the UK's infrastructure for the mathematical sciences and should be considered the mathematical equivalent of a national lab. Mathematics may not need big machinery but it does need space as provided by INI where researchers can gather in the stimulating environment created by the thematic programmes to discuss deep theories and methodologies, try new ideas collaboratively on the many blackboards, work intensively over weeks and even months to develop and fine-tune their work, undisturbed and undistracted, away from their usual obligations.

We have ambitious plans for a state-of-the-art lecture theatre embedded in a new visitor centre. Improving facilities will help maintain INI's ability to attract top researchers and hence its world-leading position. Crucially, the new visitor centre will enable INI to respond agilely and timely to new research developments. It will allow INI to respond to the ever-growing demands for thematic programmes fed by the increasing need for mathematics in so many scientific areas by running an additional parallel strand as recommended by international review panels.

The extension will create much-needed space while retaining the unique design and character of our treasured current building.

What this project would provide:

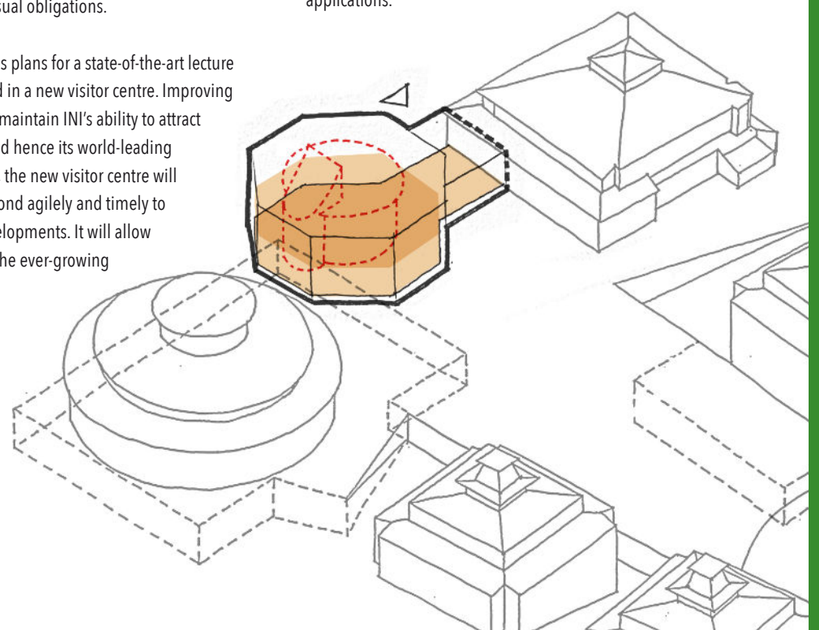
The Institute seeks to build an extension next to its existing building in harmony with the architecture of the Centre for Mathematical Sciences. Architectural plans already drawn up include:

- a new 150-seat raked lecture room, with state-of-the-art AV, webcasting and recording facilities
- a reception and exhibition area for 150 people outside the new lecture room
- new collaborative working spaces and additional spaces for long-term visitors
- much-needed office space to accommodate staff members

Such an increase in capacity will enable the Institute to comfortably host 3 programmes in parallel as standard, and will provide space to hold multiple workshops, meetings, exhibitions and seminars.

A study commissioned by the Institute has determined that the cost of realising this vision is £18.3 million over a 3-year timescale.

We are seeking philanthropic investment to meet this cost, securing for the future the Institute's place at the forefront of mathematical research and its game-changing applications.



Cumulative Financial Grants and Donations above £10,000

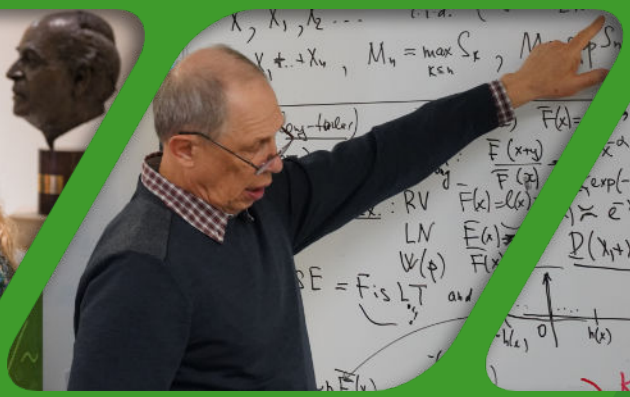
Elena Ambrosiadou • Michael Astor • Apple Computers Ltd. • Applied Probability Trust • Autonomy Systems Ltd. • Iain Bratchie • Bank of England • Benfield Greig • BNP Paribas • British Aerospace • British Gas • Howard & Veronika Covington • William Craig • Cambridge Philosophical Society • Clay Mathematics 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 • Gwyneth Moss • David Harding Foundation • Henderson Global Investors • Hewlett—Packard • Timothy Hennock• 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 • 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 • UKRI (EPSRC, BBSRC, ESRC, MRC, NERC, STFC) • 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 • XTX Markets • Anonymous Donations

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 Meaghan Annear at Cambridge University Development and Alumni Relations (+44 (0)1223 332288 / meaghan.annear@admin.cam.ac.uk).

UNIVERSITY OF CAMBRIDGE








Natural Environment Research Council

Biotechnology and Biological Sciences Research Council

Science and Technology Facilities Council

Economic and Social Research Council

Engineering and Physical Sciences Research Council

SIMONS FOUNDATION

LONDON MATHEMATICAL SOCIETY
EST. 1865