

Institution: University of Cambridge

Unit of Assessment: 10 – Mathematical Sciences

1. Unit context and structure, research and impact strategy

Cambridge Mathematics is a broad community of mathematical scientists, consistently ranked in the top 5 of QS world subject rankings throughout this REF period (the only non-US institution to achieve this). Since REF2014, significant strategic development of our research agenda has been accompanied by major new investment in people. Highlights include:

1. Research Excellence

Recognition of the research achievements of our staff at the highest levels, including eight elections to the Royal Society, one to the US National Academy of Sciences, a knighthood, two OBEs and more than 70 medals and prizes including a Fields Medal.

2. Investing in academic appointments and training of postgraduate students

New appointments to 44 permanent academic positions (12 senior chairs), with 18 being newly created posts. Our academic and postdoctoral researcher headcount has increased from 205 in 2014 to 254 in 2020 and postgraduate numbers expanded from 220 to >325, with substantial development of research in mathematics of information, statistics and soft matter.

3. Addressing equality, diversity and inclusion within the Faculty

Ten women have been appointed to permanent academic positions, with the current number of women more than double 2014 levels (from six to 13 including two new Lecturers arriving in 2020/21). We are proud to have staff and students from over 80 countries and have hosted Race Awareness, Black History Month, LGBT+ History Month, Women in Maths, Respect at Work and Unconscious Bias events.

4. Increasing research income

Grant income increased from £46M to over £142M, including 21 ERC grants held over this REF period (three Advanced, six Consolidator and 12 Starting Grants). Six new Research Centres have been launched (Cantab Capital Institute for the Mathematics of Information, Centre for Mathematical Imaging in Healthcare, Edwards Centre for Soft Matter, Winton Centre for Risk and Evidence Communication, Cambridge Centre for Data-Driven Discovery and, new for 2020, Cambridge Centre for AI in Medicine) supported by £19M external funding.

5. Maximising impact from research

Appointment of Mathematics Knowledge Transfer and Research Facilitators, who have transformed our relationship with industry (developing links with more than 170 companies since 2014 including AstraZeneca, GSK and Aviva).

6. Enabling interdisciplinary research

Expanding emphasis on interdisciplinary research, with four new academic positions created in 2017 jointly with other physical science departments and increased collaboration within the University and with industry.

Faculty overview

The Faculty of Mathematics in Cambridge comprises two closely-linked departments: the Department of Applied Mathematics and Theoretical Physics (DAMTP) and the Department of Pure Mathematics and Mathematical Statistics (DPMMS), with the Statistical Laboratory as a sub-department of DPMMS.



Centre for Mathematical Sciences aerial view

Our community includes 120 academic and teaching staff, 134 Research Fellows and postdocs, 328 PhD students and 78 professional and support staff, working across the whole breadth of mathematics and its applications. The Departments are housed together with the Isaac Newton Institute for Mathematical Sciences (INI) and the Betty and Gordon Moore Library (BGML), a research resource containing the University Library's holdings in mathematical sciences, in the purpose-built Centre for Mathematical Sciences (CMS).

A distinctive feature of Cambridge Mathematics is that an exceptionally broad range of substantial groups, from theoretical physics to statistics to experimental fluid mechanics, exists within the same structure, making us well-placed to respond to mathematical challenges.

Together the departments actively seek to sustain breadth in research across a wide range of pure and applied mathematics, in theoretical physics and in probability and statistics. We aim to contribute to the most compelling areas of fundamental research, whilst extending our strong tradition in application areas. Our priorities are to reinforce and refresh areas of existing expertise, retaining international leadership of fast evolving fields as well as exploiting new areas of applications and fresh directions. We actively promote a stimulating research environment where researchers and students alike benefit from, and contribute to, a busy and broad programme of research seminars (more than 20 per week in term time, significantly enriched by our proximity to programmes run by the INI). We aim to compete for talent on the world stage and appoint individuals of the highest quality to academic posts. Since the last REF almost half of our permanent appointments have been from overseas institutions.

Achievement of Strategic Aims:

1.1 Research Excellence

Key achievements in the REF period are highlighted by research groups and themes, which can span both Departments.

DPMMS

The Department has had an active recruitment programme over the period and numbers of academic and research staff have risen from 80 in 2013 to 107 currently. Recognition over the REF period has included ten invited speakers across the 2014 and 2018 ICMs, the awards of a Fields medal to *Birkar*¹ and the COPSS Presidents' Award to *Samworth*, both in 2018. Grant income has been considerably strengthened (including 12 ERC awards). Thriving research groups in the areas of Mathematics of Information and General Relativity and PDEs reach across both Departments. New Research Centres in the Faculty have been launched following large industry and external grants and, alongside a strong connection with the Alan Turing Institute (ATI), these support collaboration within

and outside the University. Research in the Department can be loosely organised into seven main themes.

¹Names in italics correspond to researchers submitted for this REF

Algebraic Geometry: *The REF 2014 priority was to make a lectureship appointment in this area.*

The REF 2014 priority was realised in the strategic appointment of *Ranganathan* (tropical geometry) in 2018. His appointment builds on the current strengths of the group. *Birkar*, promoted to Professor in 2015, was recognised as a world leader in the Minimal Model Program with the Fields Medal in 2018 and elected FRS in 2019 (£1.1M Royal Society Professorship). Gross, appointed as a Professor in 2013, is a leader in mirror symmetry (Clay Research Award in 2016, FRS in 2017, EPSRC Programme grant). Both *Ranganathan* and *Gross* have close connections to symplectic topology (*Smith and Keating*). *Grojnowski* (geometric representation theory) completes the group.



Birkar with Fields Medal (Rio 2018)

Analysis and PDEs: *In 2014 we aimed to extend existing expertise in PDEs and Geometric Analysis by making further appointments in Analysis, including to Lowndean and Herchel Smith Chairs*

The appointment of *Dafermos* (Lowndean Chair 2015; EPSRC Programme grant with Warwick), *Raphael* (Herchel Smith Chair 2019) and *Warnick* in 2017 as an interdisciplinary Lecturer between DAMTP and DPMMS fulfilled the 2014 REF strategic priority. They join the other main members of the group who came to Cambridge as early-career Lecturers or Readers and are now Professors and world leaders in their sub-areas; *Mouhot* (ERC Starter and Consolidator Grants worth EUR2.7M) and *Wickramasekera*. Alongside *Zsak*, *Becker-Kahn* (2019/20) and *Gajic* (Research Fellow), the group closely interacts with others across the Faculty: differential geometry, probability, general relativity, and applied analysis via joint seminars, co-supervision of PhD students and the Centres for Doctoral Training. The 2019 appointment of *Titi* to a senior Chair in DAMTP in the area of applied analysis has further enhanced the strong interplay between the two departments.

Combinatorics: *A key REF 2014 objective was to enhance our expertise in this area and to strengthen connections to other research areas.*

In 2018, *Wolf* (additive combinatorics, model theory) joined the strong combinatorics group involving *Gowers* (additive combinatorics), *Leader* (Ramsay theory, combinatorics) and *Thomason* (extremal theory); Bollobás (Emeritus), who has had an immense impact in the area, remains as active as ever. Beyond the established strength in the analytic side of combinatorics, the REF period has seen the emergence of a new internationally leading group around *Varju* (ergodic theory and group theory), appointed in 2016 (promoted to Reader in 2019 and Professor in 2020; £1.9M Royal Society URF & ERC Starting Grant) and *Breuillard* (group theory and geometry; £1M ERC Consolidator Grant), appointed as Sadleirian Professor of Pure Mathematics in 2018. In these appointments, along with the upcoming appointment of *Sahasrabudhe*, we have achieved the objectives of enhancing the area and building stronger links with combinatorics across mathematics. The number of Research Fellows/College Teaching Officer (including *Button*, *Rappoport* and *Wilkes*), postdocs and PhD students has increased to more than 30.

Differential Geometry & Topology: *Reinforcing breadth and consolidating connections to adjacent areas (algebra, algebraic geometry, geometric analysis) were key strategic goals.*

The appointment of *Keating* (symplectic topology) in 2016 has reinforced the group which now has expertise across a wide range of subjects successfully interacting with other areas including analysis, algebraic geometry and number theory. The core group members are *Kovalev* (Riemannian geometry), *Paternain* (geometric inverse problems), *Randal-Williams* (algebraic topology, promoted to Reader in 2017 and Professor in 2020, EUR1M ERC Starting Grant/Leverhulme Prize),

Rasmussen (low-dimensional topology, promoted to Professor in 2018), *Smith* (symplectic topology, £1M EPSRC Fellowship), and *Wilton* (geometric group theory, promoted to Reader in 2017) as well as four new College Teaching Officers (*Khukhro* in 2018; *J. Smith*, *Bradford*, *Chiodo* in 2019) and Research Fellows (including *S. Rasmussen*, *Dervan* (RSURF 2020), *Eskenazis*, *Heuer*).

Number Theory and Algebra: *Rebuilding this area via new appointments was a key aim over this REF period.*

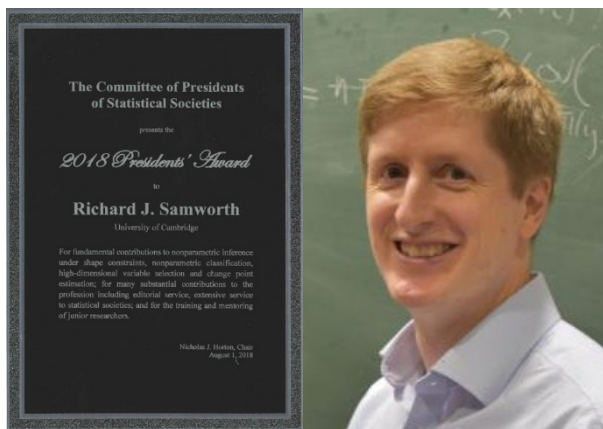
Three new appointments in this area have been made since 2014; *Krieger* (arithmetic dynamics, appointed as the new Corfield Lecturer in 2016), and from 2020/21 *Fintzen* (local Langlands and representation theory, RSURF 2020 and ERC Starting Grant) and *Zhou* (arithmetic geometry, Shimura varieties, and geometric representation theory). They join *Thorne* (Langlands programme, arithmetic invariant theory; ERC Starting Grant), promoted to Professor in 2018 and elected FRS in 2020 (the youngest on appointment of all living Fellows), who is already a world leader, *Fisher* (computational number theory) and *Scholl* (arithmetic algebraic geometry and automorphic forms). In cognate areas, *Gowers*, *Breuilard* and *Grojnowski* are engaged with the group. There are also senior College staff active in different areas of representation theory and group theory (*Camina*, *Martin*, *Lawther* and *Wadsley*) as well as Research Fellows (*Law* and *Walker*).

Probability, Applied Probability and Information Theory: *The priority was to sustain growth in this area both in scale and depth, in its range of applications and connectivity with other parts of mathematics.*

Over the course of the REF period, we have been able to make very strong appointments at Lecturer and Reader level (*Miller*, *Sousi*, *Bauerschmidt* who have all since been promoted to Professor and Readers respectively). The recent appointment of *Kontoyiannis* to the Churchill Professorship, and a new Lecturer (*Jog* from Jan 2021), will see the emergence of a new group in Information Theory and related areas, having strong links to both the probability and the statistics groups. Research in the probability group addresses two related central themes: (i) the geometry of random structures, (ii) rigorous scaling limits in statistical mechanics. The REF period has seen major successes in both themes. Research has been funded by an EPSRC Programme Grant on Random Geometry (£1.5M; *Grimmett*, *Berestycki*, *Norris*), two current ERC Starting Grants (EUR2.5M; *Miller*, *Bauerschmidt*), and an EPSRC New Investigator Award (*Sousi*), supporting a series of postdocs and an Isaac Newton Institute Programme on Random Geometry. We have also benefitted from the award of three Research Fellowships (*Hutchcroft*, *Gwynne*, *Qian*) and participation in the EPSRC CDT in Analysis and the CMI CDT in Mathematics of Information. The appointment of a new Professor of Mathematical Statistics, following *Grimmett*, is a major opportunity.

Statistics: *REF2014 aims were strategic expansion including appointment to Chair of Statistical Science and development of this area, both in theory and applications.*

Over the REF period, the statistics group has made a number of powerful appointments including *Aston* (applied statistics, particularly in neuro-imaging and linguistics), *Samworth* (high-dimensional statistics and nonparametric statistics, appointed Chair of Statistical Science in 2017, winner of COPSS Presidents' Award in 2018), *Berthet* (theoretical statistics, 2014-2019), *Bacallado* in 2015 (Bayesian statistics) and *Zhao* (causal inference) in 2019. From 2021, the appointment of *Loh* (high-dimensional statistics) will add to the strength and profile of the statistics group joining *Nickl* (uncertainty quantification, promoted to Professor in 2016), *Shah* (large-scale data analysis, promoted to Reader in 2019) and *Coca* (nonparametric inference in 2018).



Samworth COPSS Presidents' Award

Spiegelhalter (retired in 2018).

The group has been awarded a Programme Grant (*Aston/Samworth/Shah*), two Fellowships (*Aston and Samworth*) and a New Investigator Award (*Shah*) from the EPSRC alongside an ERC Consolidator grant (*Nickl*) totalling £4.1M.

Long-term collaborations with other Departments include the appointment of *Mandel* (ERC Consolidator Grant), an Astrostatistics Interdisciplinary Lecturer with the Institute of Astronomy in 2017, links to the Applied Computational Analysis group in DAMTP (*Aston and Nickl* with *Schönlieb* and *Fawzi*) and research with Psychology as an integral part of the Winton Centre for Risk and Evidence Communication led by

DAMTP

Research in DAMTP is centred on the major themes of applied and computational analysis (including the mathematics of information, AI and machine learning, often, though not exclusively, with applications in health care), continuum mechanics and soft matter (with wide applications in the life sciences, the environment and industry) and theoretical physics (gravitation, high energy physics, astrophysics, cosmology). Strength in these broad themes has continued, with significant evolution and development which has been driven by 18 new hires (eight of which are to newly-created positions and another five of which are long-term proleptic replacements of colleagues still in post) since the last REF. Research in DAMTP is loosely structured around eight research themes, in many cases with substantial overlap and with some colleagues being affiliated with more than one theme.

Applied & Computational Analysis (ACA): *The priority since 2014 has been to grow substantially in this area, and to extend the volume and reach of our interdisciplinary engagement.*

Strategic academic appointments and promotions growing this area include *Schönlieb* (promoted to Professor in 2018), *Titi* (appointed in 2018 from Texas A&M), *van der Schaar* (appointed in 2018 from Oxford, joint with Engineering and Public Health), *Shadrin* (promoted to Reader in 2018), *Fawzi* (appointed 2016 from MIT), *Hansen* (URF and promoted to Reader in 2017), *Fokas* (EPSRC Established Career Fellowship). The group also includes a number of independent researchers; *Ashton* (College Lecturer), *Liang* (Leverhulme Early Career Fellow), *Roman* (Senior Research Associate, SRA) and *Kreusser* (College Research Fellow).

The focus of the ACA group is in applied and computational PDEs, inverse problems, applied harmonic and functional analysis, machine learning, approximation theory and optimisation, with a diverse range of interdisciplinary research projects in the areas of biomedical imaging, AI in healthcare, remote sensing and cultural heritage. ACA has connections to many other groups including fluid mechanics, mathematical biology, quantum information as well as analysis, probability and statistics.

ACA contributes strongly to research programmes spanning both departments, which include the Cambridge Centre for Analysis (an EPSRC CDT, led by *Norris* and *Peake*), the EPSRC Centre for Medical Imaging in Healthcare (led jointly by *Aston* and *Schönlieb*) and the Cantab Capital Centre for the Mathematics of Information (CCIMI, led by *Schönlieb*) and its associated CDT programme (CMI, co-led by *Nickl* and *Schönlieb*).

The CCIMI, founded by a benefaction of £5M from Cantab Capital Partners LLP in 2016, provides the coherent setting for both departments' efforts to place mathematics at the heart of work in big data. The new Cambridge Centre for Data-Driven Discovery (C2D3), an interdisciplinary hub to bring together researchers from across Cambridge, with Aviva as a founding partner (£2.5M investment)

moved to CMS in 2019, with *Schönlieb* as co-Chair. DAMTP also hosts the Cambridge Centre for AI in Medicine (CCAIM) (directed by *van der Schaar*) supported by AstraZeneca and GSK with a £7M investment (2020-2024).



Four new Research Centres launched with £15M Industrial and EPSRC grant funding, placing the Faculty at the heart of image and data analysis as well as AI and machine learning within Cambridge

Astrophysics: *Since 2014 our goal has been to consolidate strength in this area, focusing efforts in expertise in accretion discs and planet formation, and to further develop collaboration with other groups within and outside DAMTP.*

Rafikov (recruited from Princeton 2015, promoted to Reader in 2018), along with *Latter* and *Ogilvie*, leads analytical and computational studies of astrophysical fluid dynamics, magnetohydrodynamics and gravitational dynamics applied to accretion discs, planet formation and exoplanets. The group includes five STFC-funded research associates and two Research Fellows, with ongoing strength in atomic and solar physics (led by *Del Zanna* and *Loi*, with continued engagement of *Mason* OBE and *Proctor* FRS).

Within DAMTP the group has significantly strengthened scientific overlap with other groups, including Fluids (especially since the arrival of *Kerswell* FRS in 2017) and Relativity and Gravitation (e.g. in black-hole astrophysics and gravitational waves). Beyond DAMTP, there are major connections with the Institute of Astronomy and Cavendish Astrophysics, which, together with DAMTP, have founded the Cambridge Exoplanet Research Centre, forming a world-class grouping with expertise in observation, instrumentation, theory and modelling. The Kavli Institute, another interdisciplinary initiative between DAMTP, Astronomy and Physics, also supports activity in this area.

Fluids: *This continues to be a defining activity of DAMTP. The group's overarching strategy has been to diversify its expertise both in reach and methodology as well as strengthening links to related groups.*

A number of new appointments have been made that diversify and strengthen activity both in and surrounding the core fluids group; *Kerswell* FRS (from Bristol in 2017 to the GI Taylor Professorship, a key aim from the last REF), bringing new expertise in high-Re fluid dynamics and *Bruna* (from Oxford in 2019) as a Lecturer who works in stochastic particle systems, a new direction for the group reaching across to the Soft Matter group.

The ACA appointments of *Titi* (applied analysis of Navier-Stokes equations) and *van der Schaar* (machine learning), and the Soft Matter appointments of *Cates* FRS (statistical mechanics in complex fluids and active matter) and *Adhikari* (low-Re flows) bring fresh expertise to enhance the group. Independent researchers include *Ayton* (EPSRC Early Career Fellow), *Le Fauve* and *Ming* (Leverhulme Fellows), *Kowal and Peng* (College Research Fellows), *Oliveira* (Herchel Smith Fellow) and SRAs (*Etzold*, *Spivak*, *Rath-Spivak*).

Research is carried out across the spectrum ranging from low-Re number micro-hydrodynamics (*Lauga & Lister*), stochastic particle dynamics (*Bruna*) and quantum fluids (*Berloff*); through high-Re number flows and turbulence (*Cowley*, *Kerswell* FRS, *Peake*); to environmental flows (*Caulfield*, *Dalziel*, *Haynes* FRS, *Linden* FRS & *Taylor*) and geophysics (*Neufeld & Worster*), and is supported by the GK Batchelor Laboratory (Director *Dalziel*) which can measure flows from nanometre through to metre scales.

There are seamless connections with surrounding groups specifically, ACA (*Titi*), Soft Matter (*Adhikari*, *Cates*), Mathematical Biology (*Goldstein*) and Astrophysics (*Latter*, *Ogilvie & Rafikov*)

which mean that as a whole, DAMTP has a group of over 100 researchers of fluid dynamics (staff and students). As well as establishing the Cambridge Fluids Network spanning Engineering, Chemical Engineering & Biotechnology, Chemistry, the Institute of Astronomy and the BP Institute, there is a well-established link with Schlumberger and developing links to DeepMind, Google and the St Barts Heart Centre.

The group has received over £11.8M in support during the assessment period (£6.7M EPSRC, EUR3M ERC, £1.3M NERC, £0.8M Royal Society) and participates in a number of CDTs: Cambridge Maths of Information (CMI), the 'C-Clear' NERC DTP and the AI for the Study of Environmental Risk UKRI DTP.

General Relativity and Gravitation: *The priority for this area was to sustain the ability to make pioneering advances across a broad range of cosmology and gravitational theory.*

Several appointments have been made at Lecturer level. In 2017: *Warnick* (from Imperial, jointly with DPMMS, hyperbolic PDEs in general relativity); *Sherwin* (from Berkeley, Cosmic Microwave Background, awarded ERC Starting Grant, 2019). In 2018: *Pajer* (Professor, University of Utrecht, the interface of cosmology, string theory and particle physics); and *Wall* (from Stanford, black hole thermodynamics and quantum gravity, winner of the Breakthrough New Horizons in Physics Prize, 2019). The group is currently seeking to make a world-class appointment to the inaugural Stephen Hawking Chair of Cosmology, funded by a gift of \$6M from the Avery-Tsui Foundation.

The group has expertise in black hole theory (*Dunajski, Reall, Santos, Wall, Warnick*), numerical relativity and gravitational waves (*Sperhake, Agathos, Noller*), and cosmological theory (*Challinor, Fergusson, Pajer, Shellard, Sherwin*). The group currently has five independent researchers, *Baldauf* (Stephen Hawking Fellow), *Macpherson* (Herchel Smith Fellow), *Noller* (Ernest Rutherford Fellow) and *Ganguly, Namikawa* (College Fellows).

The group's activities are closely intertwined with the Centre for Theoretical Cosmology (CTC), founded by Stephen Hawking in 2007, to bring together world-class researchers studying the extreme universe. CTC supports senior Research Fellows, hosts visitors, and organises topical workshops and major international conferences in theoretical cosmology and gravitation, including "Gravity and Black Holes" marking the 75th birthday of *Hawking* in 2017.

The group is very well connected with the DAMTP High Energy Physics group, with groups in Astronomy and Physics, and is a major participant in the Kavli Institute for Cosmology. The group maintains excellent supercomputing facilities through close industrial collaborations (Intel) with grants for their COSMOS supercomputer totalling over £3M since 2010, and in 2017 as launch partner with Hewlett Packard Enterprise (HPE) for their first Superdome Flex server.

High Energy Physics (HEP): *Maintaining the strength of this area and extending key STFC funding were priority objectives for this REF period*

Two appointments in particle phenomenology have been made: *Ubiali* (from Cambridge Physics in 2017, ERC Starting Grant, 2020) and *McCullough* (from CERN in 2018), and there is a further opportunity to recruit a new Professorship of Mathematical Physics (due to the retirement of *Davis*) to enhance the world-class strength in HEP research. Faculty members include *Allanach, Dorey, Dunajski* (since 2018 employed jointly as a University and College Lecturer, promoted to Reader in 2020), *Evans, Manton, Quevedo, Santos* (promoted to Reader in 2018), *Skinner, Stuart, Thomas* (promoted to Reader in 2020), *Tong* and *Wingate* (promoted to Reader in 2015). The group includes five independent researchers *Day, Hofmann, Melville, Reid-Edwards* (College Fellows) and *Chakraborty* (Leverhulme Early Career Fellow), seven postdocs funded on an STFC consolidated grant and a Simons Investigator Award, as well as 25 PhD students.

The HEP group pursues research in many areas of fundamental physics, unified under the umbrella of quantum field theory, including the search for new particles beyond the Standard Model, nuclear structure, condensed matter phenomena, cosmological particle physics, and quantum gravity.

HEP has strong overlap with the General Relativity and Cosmology Group, including with *Santos*, *Quevedo* and *Wall*. The group has substantial Consolidated Grants from STFC (£4.1M in the REF period) (*Allanach* is PI) which also supports the Cavendish HEP theory group, with whom they have strong links (including a joint seminar series and joint postdoc positions).

Mathematical Biology: *A REF 2014 objective was to consolidate the strength being built in this area.*

Simons (statistical mechanics of model stem cell development, Royal Society E.P. Abraham Professor) joined DAMTP in 2018 from Cambridge Physics to strengthen further activity in this group, which has many interconnections to other research in the mathematics of life both within DAMTP and the broader University. Permanent staff include *Goldstein* FRS (Schlumberger Professor of Complex Physical Systems) who conducts both theoretical and experimental research on problems of evolutionary biology and is well-connected with *Lauga's* theoretical modelling of the flow of complex fluids and small-scale hydrodynamics; *Eglen* (computational neuroscience, promoted to Reader in 2015 and Professor in 2020), *Gog* OBE (mathematics of infectious diseases, promoted to Professor in 2017, a key participant in the independent Scientific Pandemic Influenza-Modelling "SPI-M" group advising Government on the current pandemic). The group currently has three Research Fellows (*Gomez*, *Haas*, *Kissler*) and two SRAs (*Leptos*, *Pesci*).

Eglen (and *Micklem*) play a major role in the Cambridge Computational Biology Institute (CCBI) a cross-School initiative, hosted in DAMTP, to bring together the strengths of Cambridge in medicine, biology, mathematics and the physical sciences. *Eglen* is the Director of the MPhil in Computational Biology based in DAMTP (100 students over REF period). At doctoral level the group is part of the Wellcome Trust PhD programme in Mathematical Genomics and Medicine (run jointly with the Sanger Institute).

Soft Matter: *Making a world-class appointment to the Lucasian Professorship of Mathematics was a main 2014 REF objective. In achieving this we have fulfilled another strategic goal, which was to establish a major new presence in soft matter research.*

The arrival of *Cates* FRS as Lucasian Professor in 2015 (from Edinburgh) was followed by two new Lectureships - *Adhikari* in 2016 (from IIMS Chennai) and *Jack* in 2017 (from Bath), the latter a joint hire between DAMTP and Chemistry. The resulting new Soft Matter group hosts three self-funded Research Fellowships (*Fodor*, *Pietzonka*, *Scalliet*) with others postdocs and students funded via ERC Advanced, Royal Society Professorship and Unilever Grants.

Current research focuses on active matter, glassy/granular systems and biophysics, using stochastic thermodynamics, large deviation theory, and computer simulation methodologies. This group has significant connectivity with the fluids group (*Lauga* and *Bruna*), with mathematical biology (*Goldstein* and *Simons*), and across the University via the Edwards Centre for Soft Matter Research (a virtual laboratory founded by *Cates*).

Centre for Quantum Information and Foundations (CQIF) *A 2014 REF objective was to enrich this group via new appointments in this area of current very high scientific importance and technological impact.*

New appointments of *Datta* as a Lecturer in 2017 (promoted to Reader in 2018), and *Beri* (from Birmingham in 2017, promoted to Reader in 2020) complement and enhance activity of *Jozsa* FRS (Leigh Trapnell Professor of Quantum Physics) and *Kent*. *Beri's* joint appointment with Physics strengthens further the group's links with cognate theoretical and experimental work. The group currently hosts three Research Fellows (*Strelchuk* (RSURF), *Bausch* and *da Silva*).

Within this richly cross-disciplinary area, there is world class expertise in the mutually interacting principal sub-areas of quantum algorithms and computational complexity, quantum cryptography, quantum entropies and information theory, quantum foundations, and topological phases of matter.

1.2 Investing in academic appointments and training of postgraduate students

Permanent **academic appointments** have been an obvious priority and the Faculty has filled 12 high profile named Chairs and Professorships since the last REF:

- *Aston* (from Warwick) as Professor of Statistics in 2014, with key roles as co-director of two research centres between DAMTP and DPMMS prior to secondment to the Home Office as Chief Scientific Advisor in 2017. Elected to the Harding Professor of Statistics in Public Life from 2021.
- *Cates* FRS (from Edinburgh) as Lucasian Professor in 2015, building major new activity in soft matter, including the subsequent appointment of two new University Lecturers, *Adhikari* from Chennai and *Jack* from Bath.
- *Dafermos* who joined the DPMMS as a Lecturer in 2004 and was appointed in 2015 as the Lowndean Professor of Astronomy and Geometry (1749), provides a strong link to DAMTP with expertise in hyperbolic partial differential equations in general relativity.
- *Abrahams* (from Manchester) appointed to the posts of NM Rothschild & Sons Professor of Mathematical Sciences and Director of the Isaac Newton Institute for the Mathematical Sciences (INI) in 2016.
- *Kerswell* FRS (from Bristol) as GI Taylor Professor of Fluid Mechanics in 2017, bringing world-leading expertise in high Reynolds number flows and applications in geophysical and astrophysical flows.
- *Breuillard* (from University of Münster) in 2017 to Sadleirian Professorship in Pure Mathematics, is connecting combinatorics, geometry, ergodic theory and number theory.
- *Samworth*, the current Director of the Statistical Laboratory, to the Chair of Statistical Science in 2017.
- *van der Schaar* (from Oxford and UCLA) in 2018 as the new John Humphrey Plummer Professor of Machine Learning, Artificial Intelligence and Medicine, joint between DAMTP, Engineering and Public Health, developing a major new effort in applications of mathematics in healthcare.
- *Simons* (from Cambridge Physics) as Royal Society Research Professor in 2018, working jointly between DAMTP and the Cambridge Gurdon Institute on the mathematical and physical modelling of stem cell development.
- *Titi* (from Texas A&M) as Professor of Nonlinear Mathematical Sciences in 2018, strengthening our expertise in applied analysis and providing a further strategic link with DPMMS.
- *Raphael* (from Université de Nice Sophia-Antipolis) as Herchel Smith Professor of Pure Mathematics, a strategic appointment in mathematical analysis in 2019.
- *Kontoyiannis* in 2020 to the Churchill Professorship to develop a centre of excellence in information theory and machine learning, with links to DAMTP and Engineering.
- *Tillman* from 2021 as the next Director of the Isaac Newton Institute

Alongside these Professorships, 32 other academic appointments have been made since 2014 at Readership (1) and Lectureship (31) levels. Postgraduate research student numbers have increased from 220 in 2014 to >300 in 2020 due in part to increases in grant funding and leveraging of industrial collaborations.

1.3 Improving equality, diversity and inclusion (EDI) within the Faculty

Increasing the proportion of women at all levels from undergraduate to Professor is an ongoing challenge embraced by the Faculty. Significant progress has been made since 2014, particularly in academic roles, with ten women newly appointed in this period (nine at Lectureship level, including to a newly created Director of Taught Postgraduate Education position, and one at Professor). Women make up 29% of the permanent Lectureship appointments over this REF period. This has in part been achieved via the creation of new positions:

- In 2016, the **Corfield Lectureship** (joint between DPMMS and Murray Edwards College) was endowed via a new donation. The objective was to recruit a pure mathematician with not only excellence in research but also active involvement in activities to raise the profile of women in Mathematics.

The job advert included the following: *'The post involves research and other activities aimed at promoting women's participation and achievement in Mathematics. The successful candidate will have a genuine interest in and commitment to developing the role of women in Mathematics, and an interest in establishing evidence-based programmes that will target women at all levels (school and college, University and beyond). In addition, the successful candidate will need to demonstrate the potential to be a strong role model to female mathematicians.'*

This post was advertised simultaneously with two other Lectureships and an intensive search was carried out for strong candidates, including inviting a number of potential candidates to visit the Department and College. The two regular Lectureships received 179 applications (18.4% women) with the Corfield attracting 95 candidates (50% women, a notably high percentage for the subject). Overall, ten candidates were shortlisted for the three positions (40% women) and two women (*Krieger, Keating*) and one man (*Varju*) were appointed.

- Two additional University Lectureship positions with different Colleges have been introduced using the Corfield model (which has subsequently been adopted in other Cambridge departments). Outstanding women appointed with Newnham (*Ubiali*) and Churchill (*Bruna*), as well as a College Teaching Officer post with Murray Edwards to support the Corfield Lectureship (*Khukhro*).
- A further two women have recently been appointed at Lectureship level (*Fintzen* and *Loh*) to arrive in 2020/21.

A Faculty **EDI Committee** (chaired by *Davis* now *Cates*), formed in 2013, drives progress against action plans covering all protected characteristics, supported by the senior administrator in DPMMS (who was previously an EDI consultant within the University) (see also Section 2).

1.4 Increasing research income

- Our grant income has increased significantly from £46M held over the last REF period to £142M held over this period (see Section 3).
- Our strategic initiatives to develop relationships with key partners has resulted in a number of significant new income streams: David and Claudia Harding Foundation (£5M), Cantab Capital (£5M), Nick Corfield (£2.5M), Aviva (£2.5M) and GSK/AstraZeneca (£7M). The development of a major programme in the mathematics of information has been a strategic goal for some time, first started with the appointment of *Schönlieb* in 2010 and *Hansen* in 2013. However, the benefaction from Cantab Capital has allowed us to accelerate significantly, with two lecturer appointments (*Fawzi, Coca*) and a well-funded environment of PhD studentships, postdoctoral positions and visitor programmes. The maintenance of this effort, and indeed expansion, by leveraging further funding is a key ongoing objective.

- The Winton Centre was endowed by a generous donation from the David and Claudia Harding Foundation in 2016, and aims to ensure that quantitative evidence and risk is presented to people in a fair and balanced way. Under the leadership of *Spiegelhalter*, the Centre combines strength in statistics with expertise in psychology (Marteau, Skylark and van der Linden). Winton researchers engage with the NHS, Public Health England and medical professionals across the country as well as legal professionals, law students, forensic experts, press officers, journalists, government departments, evidence-based policymakers and social scientists.

1.5 Increasing measurable impact from research

Facilitating impact has been a key priority in both Departments. Departmental funding has been used to create 3 new posts consisting of our first Knowledge Transfer Facilitator (Stephanie North), appointed in 2014 to identify new opportunities with industry, a Research Facilitator (Milla Kibble), appointed in 2018 to provide high-level support for colleagues preparing grant applications and a Placements Coordinator (Arti Sheth-Thorne) to launch an industry supporters club for summer internships (see Section 4).

Our key policies to facilitate the development of impact include:

Providing a flexible working environment. Colleagues are encouraged to develop strong links with outside agencies, and are given leave from their normal duties to facilitate this. For example, *Gog* was granted a full year of sabbatical leave which provided relief from teaching and examining to further her research and work with the BBC in modelling pandemics, leading to an **Impact Case Study (ICS) on influenza vaccination**. *Aston* was given a three-year secondment to the Home Office as Chief Scientific Advisor, and his work there on SAGE together with *Gog's* work on SPI-M, for which she was given further leave, has led to an **ICS on advice to Government during the current pandemic**. Substantial secondments have also been given to several colleagues to work at the Heilbronn Institute, leading to several **classified ICS**.

Securing large industrial funding. We have targeted large grants from industry (e.g. Cantab Capital, and AZ/GSK), which have played a pivotal role in the creation of new research centres (CCIMI and CCAIM) which are now at the heart of our strategic development of strong, mature ICS over the next REF period. We have also prioritised the continued maintenance of long-standing industrial relationships, including between the CTC led by *Shellard* and Intel and HPE, leading to an **ICS on the co-development of super-computer architecture and visualization**; *Kelly's* work on networks (joint with a colleague in Computer Science) in collaboration with a number of companies including Apple, and leading to an **ICS on a switching algorithm integral to more than 1 billion iPhones**.

Emphasising the importance of public communication. This has been a key element of the culture in Cambridge Mathematics for many years, with much of it facilitated by our major investment in the Millennium Mathematics Project (see Section 4). We have submitted an ICS on **Hawking's extraordinary record in outreach**, and the CTC is building strongly on his legacy for the future. This includes a major new series of documentaries, *The Universe Unravelling*, a flag-ship component in launch of the Discovery Channel's streaming service, in which members of DAMTP explain cutting-edge topics in cosmology to a global audience.



Hawking outside the CMS

We have also submitted an **ICS on Winton Centre research focussing on the use of statistics in public communication**, with their contributions including revolutionising the way that clinical risk is communicated to patients (see Section 4).

1.6 Increasing Interdisciplinary Research

The School of Physical Sciences created nine new **interdisciplinary University Lectureships** in 2017, with the holders having joint appointments shared between two of the eight departments within the School. We successfully bid for four of these; in General Relativity and PDEs between the two Maths Departments (*Warnick*), Astrostatistics with the Institute of Astronomy (*Mandel*), Statistical Mechanics and Soft Matter with Chemistry (*Jack*) and Quantum Complexity with Physics (*Beri*). The potential benefits in terms of widening our activities and accessing new funding sources are very exciting. They join more established interdisciplinary posts appointments with Engineering (*Peake*), Astronomy (*Challinor*), Earth Sciences and the BP Institute (*Neufeld*, *Caulfield*) and Genetics (*Micklem*).

Both Academic and Research staff are extensively involved in a range of Cambridge Research Clusters:

- *Cates* founded and leads the Edwards Centre, a virtual laboratory for Soft Matter Research with membership drawn from academic departments across the University of Cambridge, including Physics, Chemistry, DAMTP, Materials Science and Chemical Engineering.
- The Cambridge Centre for AI in Medicine (*van der Schaar*, *Caulfield*) is a virtual University Centre which brings together ten Cambridge research groups for cross-disciplinary research and development of AI for medicine, biomedical science and health care. It will support 25 co-supervised PhD students as well as postdoctoral data and computer scientists to develop software tools for the health sciences.
- *Caulfield* and *Neufeld* are Faculty members of the BP Institute for Multiphase Flow, an interdisciplinary research institute with a focus on fluid mechanics and surface science, endowed by BP in 1999. Together with the Cambridge Fluids Network, it brings together approximately 100 academics and over 300 PhD students from DAMTP, Chemistry, Chemical Engineering, Engineering and Earth Sciences.
- The Cambridge Exoplanet Research Centre is a collaborative instrument for Cambridge researchers conducting research activities related to exoplanets and life in the Universe with Faculty including *Latter*, *Ogilvie* and *Rafikov*.
- The Cambridge Centre for Data-Driven Discovery (C2D3) brings together researchers from across the University to address challenges presented by our access to unprecedented volumes of data and spans all six Schools of the University (*Schönlieb*, *Caulfield*, *Kelly* and *Mandel* on the steering committee).
- The Statistics Clinic run through the Statistical Laboratory and the Imaging and AI clinic run through CMIH are demonstrative of our interdisciplinary collaborations and commitment to enabling impact.



- The Faculty is one of the three key partners in the Kavli Institute for Cosmology, Cambridge (KICC) with *Shellard*, *Sherwin*, *Sperhake* and *Mandel* all active in leadership roles. The endowment of KICC now stands at £15M, compared to £7.5M in 2014, and the income funds five- and three-year fellowships (some based in DAMTP e.g. *Agathos*) as well as funding a wide range of workshops and other research and outreach activities.
- *Eglen* and *Micklem* are part of the Cambridge Computational Biology Institute (CCBI). The CCBI and the MPhil facilitate very strong outside links including Tavaré FRS (retired as Director of the Cancer Research UK Cambridge Institute in 2019), and Colwell (Chemistry). *Eglen* also belongs to Cambridge Neuroscience alongside *Aston* and *Fokas*, a multi-disciplinary endeavour linking principal investigators from over 60 different departments and institutes across the University.

- The Cambridge Image Analysis group, led by *Schönlieb*, is truly interdisciplinary with active collaborations not just within STEMM subjects but also in the arts and humanities via Mathematics for Applications in Cultural Heritage. This draws on the expertise of art historians, conservators, classicists and medievalists as well as of mathematicians to provide a step change in the use of mathematics for art history, conservation and archaeology.

Future strategic research priorities

Development of key research areas, impact and philanthropy

- **Mathematics of Information** is a key emergent area for development, with clear demand within the University and externally, and we are in an excellent position to build on the considerable progress made since the last REF, including the Cantab Capital Institute for the Mathematics of Information, the Centre for Mathematics in Healthcare and the Winton Centre for Risk and Evidence Communication, as well as strong external links with the Alan Turing Institute.

We aim to lead in the Mathematics of Information and Big Data, including the mathematical foundations of Data Science. This cuts across several more traditional branches including statistics, analysis (pure, applied and computational), probability, geometry and topology, with many important areas of applications. The success of recent appointments is evident, but great potential for growth still exists. CCIMI is an excellent example of joint activity between DAMTP and DPMMS. We wish to build on this by expanding research activity in this broad area, developing and strengthening links with other University Departments, particularly Computer Science, and various application areas in Health Sciences.

The Winton Centre serves as an outreach arm regarding the use of data in the public domain and has a considerable potential for impact. In the coming years, this will expand into other areas under a new Harding Professor of Statistics in Public Life (*Aston*). New appointments in the Statistical Laboratory will include the Chair of Mathematical Statistics and a Lectureship in probability. Links to the Heilbronn Institute will be enhanced by the appointment of *Grimmett* as Director from 2020.

- **Analysis and Partial Differential Equations** is another area in which growth is being actively pursued jointly across the two departments, given its fundamental importance in both pure and applied modern mathematics, and there is a great future in the study of hyperbolic PDEs such as those arising in General Relativity and Theoretical Physics.

For example, our research arc in General Relativity – spanning from *Dafermos*, *Raphael* and *Warnick* working on analysis, through *Reall*, *Santos* and *Wall* working on theoretical physics, *Sperhake* working on computation, all the way to *Shellard* and *Sherwin* working on cosmological data – provides an immensely powerful grouping able to make significant interdisciplinary progress. The recent arrival of *Titi* in DAMTP extends our interests, for the first time, into analysis of the Navier-Stokes equation and offers the opportunity to build a similar research arc, from pure analysis all the way to experimental mathematics. A future aspiration is to expand into geometric analysis which would complement our existing strengths and support growth.

- **Number Theory** already has a strong tradition at Cambridge and two new UL appointments from AY20/21 will provide support for *Thorne*. We will also look to fill the Kuwait Professorship in Number Theory and Algebra when *Scholl* retires in 2023.

Algebraic Geometry is a central area in pure mathematics and will benefit from increased support in the near future, as will **Combinatorics** (a UL appointment is anticipated from AY21/22). Following *Gowers*' appointment to the Collège de France in 2020, a new **leadership appointment** will be sought by filling the Rouse Ball Chair. Further appointments related to discrete analysis and the research interests of *Varju* and *Breuillard* are part of the ongoing strategy. Strategic appointments in **Differential Geometry and Topology** would consolidate

interactions: K-theory (topology / algebra), geometric flows (topology / analysis), complex geometry (topology / algebraic geometry).

- **Mathematics of Health, Life and Sustainability:** Building on pre-existing diverse strengths, we are planning significant growth in the application of fundamental mathematical insights to understanding pressing research challenges in health care and the life sciences, expanding and redirecting our focus on **Mathematical Biology**.
- This overarching, and inherently multi-disciplinary research activity combines rigorous mathematics, physical modelling and data-driven analyses, and naturally has points of intersection with our burgeoning expertise in the **Mathematics of Information**. *van der Schaar* leads data-driven approaches of AI and machine learning applied to medicine (CCAIM), which is ripe for significant collaborative expansion around its founding partnership with AstraZeneca and GSK. The Centre for Mathematical Imaging in Healthcare (CMIH) led by *Schönlieb* is also growing and extending its reach and impact in the application of mathematics to research challenges in “quantitative health”, and recruitment to the vacant Chair in Applied Mathematics (ex *Markowich*) will enhance this activity.

We also intend to strengthen our activity in computational biology, in particular in the modelling of various aspects of infectious diseases. *Gog* leads a multi-institution UKRI-supported consortium in epidemic modelling, and there is a clear potential for even more connections with the proliferating activities in the **Soft Matter** group, led by *Cates* and *Adhikari*.

Disease transmission is also a challenging problem in **Fluid Dynamics**, with major ongoing experimental and modelling expertise being led by *Linden* and *Dalziel*, leveraging the opportunities to exploit connections between mathematics and experimental fluid mechanics. Such connections can also draw in the groups of *Lauga*, *Goldstein*, *Simons* and *Taylor* in cognate areas of the physics and fluid mechanics of life. A healthy society is inextricably linked to ensuring sustainability, adaptability and resilience in a changing climate, and DAMTP intends to build on its traditional strengths in environmental and geophysical fluid dynamics (*Haynes*, *Lister*, *Worster*) to address key modelling challenges for the energy transition, resilience and sustainability (*Caulfield*, *Neufeld*) in a changing climate.

Our **GK Batchelor Laboratory** will play a central role in understanding applications in both the life sciences and sustainability, and is a crucial counterpoint to our expertise in **high performance computing** and **Applied and Computational Analysis**, so recruiting colleagues with a passion for world-class experimental and computational research will be a top DAMTP priority over the next decade.

- We also plan significant developments in **Theoretical Physics** in order to maintain our historic strength whilst working on the most important and exciting problems in the field. First, we will be recruiting two senior Chairs: the inaugural Stephen W. Hawking Professorship of Cosmology, and the Professorship of Mathematical Physics (1967). In parallel, we have launched an appeal (with a target of £20M) to fund further significant activity to commemorate *Hawking*. This will include 12 new fully-endowed PhD studentships for students working on theoretical and mathematical physics, two endowed Advanced Fellow positions to work between DAMTP and the Kavli Institute, and an endowed new Lectureship in DAMTP in gravitational-wave physics.
- Another priority area is the fundamental mathematical underpinning of field theories, as we wish to play a leading role in the ongoing renaissance in the application of sophisticated mathematics in different branches of physics. As part of that overarching objective, the retirement of *Jozsa* in 2021 gives us the opportunity to make a senior appointment to the Leigh Trapnell Chair of **Quantum Physics** in the broad area of quantum information and computation. We also aim to enhance efforts in data science and scientific computation in theoretical physics, building on the pioneering work of the COSMOS Intel Parallel Computing Centre and our new relationship with HPE. We also wish to further exploit the recent STFC Doctoral Training Centre in Data Intensive

Science (run jointly by DAMTP and Astronomy), which has established connections with a number of high profile companies, including Shell and Microsoft.

- Work will continue to increase the number and range of collaborations, in particular working with pharmaceutical companies and clinicians to extend **impact**, via the four research centres led by *Schönlieb* and *van der Schaar*. There are tremendous opportunities for data-driven mathematics in the discovery and development of new medicines, diagnostics and treatments - as appreciated by the significant industrial investments. We have identified a number of case studies for this REF exercise that required more time for impact to be measured. These include impact in clinical trials, food safety, medical imaging, energy efficient cooling and water supply in desert locations. Gog will continue to lead epidemic-modelling efforts that feed directly into policy decisions.
- It is important to identify **new funding sources** in order to maintain and increase our activity, and philanthropic support is one area in which we have been successful and will continue to direct effort. The two Departments work together and in close partnership with the Development and Alumni Relations Office to secure philanthropic donations and develop a range of offers and possibilities that will be attractive to potential donors. There is scope for expansion with fundraising for Masters (Part III) and PhD level scholarships as a priority, particularly to address the potential impact of Brexit on EU student numbers. We are also seeking support to establish a prestigious Statistics Fellowship (to run alongside the Herchel Smith Fellowship in Pure Mathematics).

2. People

Staffing strategy and staff development

Our overall **academic strategy** is to attract, promote and retain high calibre researchers to support and advance our contributions to research. The responsibility for the strategic development of research lies with the two Strategy Committees, chaired by the Heads of Departments and made up of senior members of staff representing the various research themes across the Departments. They oversee the continued health of existing research strengths as well as identifying new and growth areas. Extensive consultations are made with staff members and recognised experts from the international community. In 2017, a systematic review of research was conducted, identifying strengths, weaknesses and opportunities in each of the main research areas. This resulted in an updated action plan to progress the Faculty's strategic priorities.

The number of opportunities identified for **new permanent appointments** surpass University resources currently available to the departments. We have therefore made every effort to use our existing resources to maximum effect and worked hard to obtain new resources:

- Appointments created following large donations (e.g. Corfield Lectureship, *Krieger*)
- Departmental funds to support a limited number of established positions, for example the appointment in Quantum Information Theory (*Beri*) and five joint academic posts with Colleges (*Bruna, Ubiali, Datta, Dunajski, Khukhro*). The ability to do this relies on a healthy external income stream from teaching, grants and philanthropy. In order to attract candidates of the very highest calibre, we must offer permanent University positions which include the opportunity for promotion.
- A small number of appointments at the Reader level (*Thorne, Miller, Mouhot*) have been highly successful, enabling the Faculty to compete at the highest level for outstanding early-career staff.
- Proleptic appointments have been deployed for a number of University Lecturer posts (for example *Cowley*, due to retire in 2023 replaced with *Fawzi* appointed in 2016; and *Quevedo*, due to retire in 2024 replaced with *Pajer* appointed in 2018). This has allowed considerable flexibility and, we believe, is a very good way of allowing us to reshape the research portfolio of the departments in a strategic way.

New academic staff are supported with start-up funds (for travel, postdocs, equipment etc) and new Lecturers have **reduced teaching** and administration loads from the standard one undergraduate and one masters/graduate level course annually and examining/sitting on committees. They are assigned mentors (a more senior academic in a similar subject area) who, alongside the Head of Department, provide support during the probation process and for promotion. Feedback on teaching is provided via peer review of lecturing (for all staff) and advice is provided to support grant applications (including in many cases matched Departmental funding).

Evidence of successful **career development** support is demonstrated by the promotion record of academic staff, who have the opportunity to apply for promotion in annual rounds. During the REF period there were two successful promotions to Senior Lecturer, 22 to Reader and 16 to Professor. In total, there were 49 applications from the Faculty and the success rate of 82% (83% women, 81% men) is significantly higher than the University five year average of 68%.

Academic staff are awarded one term of fully paid **sabbatical leave** that can be dedicated exclusively to research, for every six terms served. This is an important aspect of the long-term careers of academic staff which allows them periodically to refresh and renew their research activity. Since

2015, 50 individual members of staff have taken sabbatical leave (equalling over 100 terms of leave). In addition, reduced teaching loads are also granted to those with large grants or fellowships.

The relationship between the University and the Colleges is fundamental to the teaching and research environment in Cambridge. The interdisciplinary nature of the Colleges is a major stimulus to teaching and learning as well as providing an enhanced quality of experience for students and staff through College membership. Academic and research staff can benefit from facilities, stipends, teaching opportunities and interdisciplinary contacts afforded via College affiliations.

Support for early career researchers

All new members of staff are given an induction with key information on the Faculty and wider University with additional practical help provided by the HR team. Research staff have appraisals to discuss career progression and a great deal of informal discussion takes place year round. Researchers are given opportunities to teach should they wish to (from lecturing in Part III to taking part in small group teaching). The impact of career development support for postdocs is evidenced by the number who have attained academic positions elsewhere or been supported in their applications for independent fellowships. From 2014-19, 60% of postdocs left Cambridge to directly take up a Faculty position in the UK, EU or overseas, reflecting the quality of appointments as well as career development and mentoring support at Cambridge.

The Faculty provides significant **financial support** for a broad range of seminar series and distinguished visitors. During term time there are >20 weekly seminars for researchers to choose from as well as high profile annual lectures (Mordell, Rouse-Ball, Peter Whittle, Dirac, GK Batchelor) leading to a vibrant environment for the exchange of ideas and development of research collaborations.

Our research is greatly enhanced by many Research Fellows who have won funding on the basis of their demonstrated research potential and research plans. The Faculty encourages both internal and external candidates and researchers are offered application support and mock interviews. The Faculty has been very successful in open funding competitions (>100) (see Section 3). Cambridge College Research Fellowships are highly competitive and attract international fields of applicants, with more than 50 College Fellows hosted in the Faculty since 2014. The Centre for Theoretical Cosmology offers Hawking Research Fellowships and the Isaac Newton Trust offers co-funding for applications for Leverhulme Trust Early Career Fellowships as well as internal schemes directed towards new Lecturers.

The Faculty also recognises the vital role played by Teaching Officers employed by the Colleges and has introduced a **College Teaching Officer (CTO) Scheme** involving a financial agreement with individual Colleges to buy out teaching time, allowing CTOs to spend more time on their research within the Department.

The **Postdoc Academy**, founded in 2013, advocates at the most senior level of the University for postdocs and supports the postdoc community before, during and after their time in Cambridge. The Academy's aims and activities are aligned with the **UK Concordat to Support the Career Development of Researchers** and the University retains the HR Excellence in Research Award from the European Commission. In addition in 2018, the two departments were among the first in the University to sign up to the San Francisco Declaration on Research Assessment (**DORA**) as a commitment to researchers to assess their work on merit rather than journal impact factor prior to the University and Cambridge University Press signing in July 2019.

We promote the professional development, entrepreneurship and industry collaborations, leadership, pastoral services and mentoring support for postdocs offered by the Academy. Our researchers have particularly benefited from the key worker homes with subsidised rents at Eddington, a new district in North West Cambridge, within walking distance of the Faculty.

We have become increasingly active in engaging more with external partners from industry. The new roles of Knowledge Transfer Facilitator and Research Facilitator have played a key part in the development of impact case studies and regularly engage with early career researchers. The Research Facilitator has supported over 60 grant submissions, created an annual calendar of calls, sends targeted emails about relevant funding calls and has gained insights into funder remits, priority areas and future developments to support future applications.

Cambridge Enterprise helps the University's researchers and academics to commercialise their ideas and supported seed funding for RiverLane, a quantum computing software development company founded by Steve Brierley, a former Senior Research Fellow in Applied Mathematics. Cambridge Enterprise has also supported the filing of a number of patents including an algorithm for medical imaging software and noise control devices for wind turbines.

Research students

The number of new postgraduate research students in the Faculty has increased with 75 new students in 2020/21 compared to 50 in 2015/16 (with an increase in total numbers from 220 in 2014 to >300 in 2020). The Faculty at present accepts ~25 new PhD students per year in DPMMS and 50 students in DAMTP, funded by a mixture of Research Council doctoral training funds (EPSRC, STFC, NERC), industry sponsorship, various University/external scholarships and Departmental reserves. Postgraduate issues are overseen by Departmental Postgraduate Education Committees. We are aware of the need to identify and attract strong female candidates for PhD places and due to the flexibility in making offers, underwriting from Departmental funds has been key to securing outstanding female applicants. The Cambridge Centre for Analysis (CCA) CDT (final cohort started in 2018) has admitted 56 students over the course of five years. Building on the experience of the CCA, a new CDT in the Mathematics of Information had its first intake in 2019 with financial support provided by CCIMI (31 students across the first 2 cohorts).

The Faculty offers a tailored **researcher development programme** which, alongside core University training covering writing and presentation skills and time management, includes training in supervisions, grants and fellowships, industry seminars, computer training and public engagement. There is a wide range of skills development and employment preparation support at University level via the Careers Service and Researcher Development Hub. Around £0.5M has been provided to support research-related activities that students may undertake during the course of their studies, for example conference attendance and workshops, research visits, summer schools and fieldwork.

Progress is monitored via termly supervisor reporting with formal assessments in years one and two. As well as their principal supervisor, all PhD students have a graduate advisor, usually from the same research area, to provide academic support and the students also actively engage with the administration team in the dedicated Postgraduate Office. PhD completion rates currently stand at 76% completing within four years (85% in DAMTP, 71% in DPMMS) with an overall 93% completion rate. Wellbeing advisors are available to provide pastoral care alongside College support.

Students can apply for an intermission from their programme of study with a concurrent extension of their submission date. Intermissions can be medical or non-medical and include for example illness, maternity, parental or adoption leave, family circumstances or courses/fellowships/placements which are not intrinsic to their research. In 2020, students were supported by extensions to reduce the negative impact of the COVID lockdown.

Research Integrity

The Faculty promotes Research Integrity and the Good Practice Checklist, highlighting the **Concordat to Support Research Integrity** as part of the induction for new staff with research responsibilities. The Code of Practice for Research Students sets out what students should expect during their study in terms of supervision, support and assessment, as well as what the University expects of research students. Researchers are made aware of individual funder codes of conduct. The Betty and Gordon Moore Library, targeting researchers on the CMS site, run events in managing research data, being an ethical researcher and working openly and reproducibly as part of their research skills programme. These run alongside the University series of Research Integrity Training with both online and face to face courses which our researchers are encouraged to complete.

Where required, appropriate approvals are sought from the DAMTP, School of Physical Sciences or collaborating Department Research Ethics Committees. The Cambridge University Ethics in Mathematics Society was set up in 2016 to discuss and promote awareness of ethical issues faced by mathematicians and mathematics graduates in their working life *via* a series of lectures, online material and events.

Equality, diversity and inclusion (EDI)

The Faculty is committed to a pro-active and inclusive approach to equality, which supports and encourages all under-represented groups, promotes an inclusive culture, and values diversity. The aim is that staff and students from all backgrounds feel confident in their ability, feel empowered to be themselves and can achieve their best in the Faculty. The Faculty recognises that diversity promotes innovation and creativity, and provides exposure to a wider range of ideas, skills and experiences which benefits all, as well as helping attract and retain the best talent from around the world.

The Faculty is a member of the LMS Good Practice Scheme and has held an Athena SWAN Bronze award since 2013. The Faculty **EDI Committee** meets termly and includes both Heads of Department leading to a regular review of our action plan and identification of new actions directed across all protected characteristics. There has also been a substantial **financial commitment** from the departments over the last five years (~£10M endowment) to fund positions with a specific remit to support women in maths and widening participation (Faculty Admissions Officer, University Lectureships, College Teaching Officer) as well as providing resources for EDI events.

There has been significant progress over the last five years in the proportion of women in academic and researcher staff populations. In particular, the number of women academics has increased since 2013 from six (three Lecturers, two Senior Lecturers/Readers, one Professor) to 13 (seven Lecturers, two Readers and four Professors). This is in part due to three joint lectureship appointments with Colleges all with specific remit to support Women in Mathematics (*Krieger, Bruna, Ubiali*). During the REF period three women academics retired (Pitts, Mason and Davis). However, the number of women in senior positions has increased due to successful promotion (*Datta, Gog, Schönlieb, Sousi*) and new recruitments (*van der Schaar, Krieger, Keating, Bruna, Ubiali, Wolf, Fintzen, Loh*). In addition, personal circumstances have been taken into account in supporting successful applications for academic promotion for both women and men in the Faculty.

DPMMS has developed a **distinguished visiting professorship** scheme to bring senior women mathematicians to Cambridge, supporting Faculty collaboration as well as strengthening the Cambridge maths community by inviting engaging, dynamic speakers to visit for an extended period. Visitors to date include Sara van de Geer (ETH Zurich) and Nathalie Wahl (University of Copenhagen). *Schönlieb* is an International leader for Women in Mathematics as Ambassador, IMU Committee for Women in Mathematics (CWM) (2016) and Convenor, European Women in Mathematics Association (2016). The proportions and numbers of women at Research Associate/Research Fellow level have also increased from 10% in 2012 (eight) to 25% (29).

- all staff involved in recruitment are required to complete the University's online E&D training as well as face-to-face recruitment training which includes awareness of Unconscious Bias
- addition of wording to advertisements to encourage women and BAME applicants
- adverts are posted on women in maths national and international mailing lists
- applications from appropriately qualified under-represented groups are actively sought via collaborator networks and by contacting potential candidates to encourage their application
- promotion of varied role models continues with changes to the website including new 'Women in Maths', EDI and Black Mathematicians webpages as well as increased diversity in the images used.

Cambridge Women in Mathematics portraits on display since 2017

The Faculty is committed to achieving the University's aim to improve **racial equality** by driving cultural and organisation change to ensure that we excel in attracting and supporting Black, Asian and Minority Ethnic staff and students, while creating an environment that is conducive to openly discussing race-related issues and challenging racism (Race Equality Charter Award 2019 Action Plan). We currently have staff and postgraduate students from over 80 countries. An event to **celebrate Black Mathematicians** as part of Black History Month was organised by the Faculty in October 2019 along with a series of posters created celebrating Cambridge mathematicians. Race Awareness: Whiteness and being a White Antiracist Ally and Active Bystander training is ongoing. In addition, *Quevedo* was awarded the 2021 APS John Wheatley Award 'For sustained commitment and achievement in the advancement of physics and science in developing countries'.

Banner on permanent display highlighting a code of conduct for promoting a welcoming and inclusive environment.



UNIVERSITY OF
CAMBRIDGE

CENTRE FOR MATHEMATICAL SCIENCES



Say **hello** to everyone
You might make someone's day



Introduce yourself to people you don't know
It could be the start of a friendship or a collaboration



Stop and **smile**
You will brighten the room considerably



Be **understanding**
Everyone makes mistakes



Help those with less experience
We were all novices at some point



Respect others
We all have something valuable to contribute



Value professional and support staff
They are here for you



Be **kind**
You will never like everybody but you can be cordial to all



Enjoy being in the CMS

Acknowledgements:

Thanks to the AICHE for the banner **code of conduct** aiming to foster a positive environment of trust, respect and open communication.

The Faculty is also actively engaged with University EDI initiatives including the Breaking the Silence Campaign, which addresses harassment and sexual misconduct. The Faculty expects **all staff** to complete the EDI training as well as face-to-face training on Respect at Work (160 attendees over three sessions to date).

An inclusivity@maths email address and anonymous reporting postboxes have been introduced alongside focus groups so that concerns and suggestions can easily be communicated to the EDI Committee. Our induction information also includes a message from the Heads of Department regarding expectations of behaviour and key links to E&D information and support.

Professor Anne Davis was the University Gender Equality Champion (2015-2018), sits on the LMS Women in Mathematics Committee and was awarded the Richard Glazebrook Medal and Prize (2019) for her outstanding support and leadership in physics, particularly for women and those from non-traditional backgrounds.

Maths is the first Faculty in the University to have a dedicated **LGBT+ Action Plan**. While many of its actions are applicable to other protected characteristics, such as race, gender and disability, some are specifically aimed at supporting the LGBT+ community. These include trans awareness training, events promoting LGBT+ awareness (including during LGBT+ History Month), updated signage for gender neutral toilets (the majority of facilities in the Faculty) and providing the environment and resources for our local LGBT+ student network to flourish. The Faculty has also set up its own mailing list specifically on LGBT+ issues.

Resources have been provided to support this network as well as funding for the Emmy Nöther Society, which promotes women studying mathematical sciences.

The Centre for Mathematical Sciences is accessible for wheelchair users. There are multiple disabled toilets in every Pavilion and induction loops are available in all 10 lecture theatres for those with hearing impairments. Assistance dogs for the visually impaired are welcome. Arrangements for members with Specific Learning Difficulties are on an individual basis, in conjunction with the University **Disability Resource Centre**.

“A successful application Returning Carers Scheme provided 4 months RA support, which was extremely helpful in continuing with scheduled lab and fieldwork ... the work [was] published in a leading journal”
RCS recipient

We have encouraged our staff to apply for the University’s **Returning Carers’ Scheme** which supports researchers and academics returning to work following leave for caring responsibilities. All applications from the Faculty (three women and one man) have been successful and supported by **matched funding** from the departments, when full funding was not awarded by the University. The support has enabled attendance at conferences, by covering childcare costs or travelling with a carer, as well as postdoc (RA) support.

The University offers a range of support which is highlighted at induction and which our staff regularly benefit from. These measures include:

- **Relocation support** via the accommodation service, a shared equity scheme to provide financial assistance with the purchase of living accommodation to qualifying new members of staff as well as a visa loan scheme.
- Employees are rewarded for outstanding contribution through a number of regular **pay progression schemes**. For example, since 2016, 32 postdocs have benefitted from the researcher-specific scheme (31% women).
- We offer an employee benefits scheme (CAMbens) for University employees.
- **Family friendly policies** are promoted by our Faculty HR team which include:
 - maternity, adoption and shared parental leave entitlement of 18 weeks full pay
 - emergency family care support via My Family Care;
 - Five days’ **paid emergency leave** for unforeseen emergencies involving dependants
 - highly regarded workplace nurseries
 - childcare vouchers, a childcare salary sacrifice scheme and a high quality holiday play scheme
 - a career break scheme and additional flexible working policies for all other staff
 - the SPACE parents and carers network

The Faculty has ten **Wellbeing Advocates** who act as points of contact as well as actively promoting the physical and mental health support offered by the University and Colleges (including counselling, occupational health and the University’s Sport Centre). The Faculty offer local wellbeing events including mental health awareness and activities as part of the annual University Festival of Wellbeing. The level and variety of support offered has increased significantly over the COVID lockdown period.

“I feel fortunate to work in a Faculty that is so supportive of my family needs. For example, I usually leave the Department at 3pm to collect children from school. Colleagues are very supportive of this, and have never objected to when I ask for meetings to be scheduled to finish before 3pm. Likewise, my lecturing duties (mostly at the graduate level) are flexibly scheduled not to clash with the daily school-run.”

Academic (M) promoted twice during REF period

3. Income, infrastructure and facilities

Funding strategies

3.1. Grant income

The total amount of current research grants held by the UoA is >£87M. In total, the Faculty has held >£142M in grants over the REF period which represents a significant increase in the figures from the last REF (~£46M).

We have been awarded some **notable grants** over recent years – these include:

- Twenty-one ERC Advanced, Consolidator and Starting Grants (>EUR23.1M) held (*Lauga, Tong, Cates, Linden, Goldstein, Baumann, Nickl, Mouhot (x2), Thorne, Varju, Miller, Randal-Williams, Breuillard, Raphael, Reall, Sherwin, Bauerschmidt, Fintzen, Ubiali and Mandel*)
- Maths in Education: CMEP (Hyland) and MMP/NRICH (Barrow)(Total £7.8m)
- Five consolidated grants from STFC (*Allanach and Shellard*), two in astrophysics and three in theoretical particle physics (joint with the theory group in Physics). Overall, these grants (£7.5M) alongside STFC grants for Hawking (£1.2M) and *Manton* (£1.1M) provide important stability for activities across these areas
- EPSRC CDTs in Analysis (*Norris and Peake*) (£7.2M)
- *Linden's* EPSRC Programme and Grand Challenge Grants (£6.5M)
- Royal Society Professorships for *Birkar, Cates, Gowers* and *Simons* (£5.1M)
- *Aston* and *Schönlieb's* EPSRC Centre for Mathematical Sciences of Healthcare and the new EPSRC Hub for Mathematical Sciences in Healthcare (£3M)
- *Goldstein's* Wellcome awards (£3M)
- Large collaborative grants with Lancaster (*Aston/Samworth/Shah*), Warwick (*Dafermos*) and Imperial (*Gross*) respectively (Total £3M).
- *Grimmett's* EPSRC Programme Grant in Probability (£1.5M)

Over 100 **competitively-funded fellowships** held over the REF period include:

- EPSRC Fellowships for senior academics: *Goldstein, Fokas, Berestycki, Samworth* and *Smith* (£6.2M)
- Royal Society University Research Fellowships (13, £6.2M; including *Bruna, Varju, Hansen, Strelchuk, Fintzen and Dervan*)
- EPSRC Career Acceleration, Early Career and Postdoctoral Fellowships (19, £4.8M)
- STFC Ernest Rutherford Fellowships for *Davison, Hiller, Lee and Noller* (£2.3M)
- Leverhulme Early Career Fellowships (14, £1.2M)
- Five Royal Society Wolfson Merit Awards
- Five Marie Skłodowska-Curie, ten Herchel Smith, two Dorothy Hodgkin and seven Alan Turing Institute Fellowships

Pursuing and winning large grants and fellowships will continue to be a big part of our effort, as will developing large multi-investigator projects. Applying for funding, especially for large grants, takes a great deal of PI time and effort, and the finance officers in both Departments, provide detailed financial information and support for applicants.

3.2 Philanthropy

The departments are quite distinctive in the breadth of the research undertaken and have a range of very attractive philanthropic opportunities. Our students (undergraduates, Part III and PhD) and postdocs are outstanding and highly sought after by employers. Cantab Capital Partners (now part of GAM) is an excellent example, being populated by several former graduates, and their philanthropic intentions also stem from a genuine interest for the well-being of the discipline. The outreach programmes (e.g. the Millennium Mathematics Project) also generate lots of interest, as do the departments' connections with Big Data, the Alan Turing Institute and strong presence in Statistics and Mathematics of Information. Relationships with donors are cultivated and nurtured over long periods (e.g. Corfield, Harding and Kuwait Foundation) and new ones are approached with the same enthusiasm, regardless of where specifically the interest of the donor lies. This approach has produced substantial donations.

These projects required a degree of creativity and substantial collaboration between Departments in identifying and matching needs with opportunities. Funding has been provided to support the development of an **Alumni Newsletter** which was launched in 2017, with additional videos and case studies added as features on our website. DAMTP has initiated an ambitious programme to raise £20m in gravitation wave physics to extend the **legacy of Stephen Hawking**.

Small donations for certain projects also have a significant impact. A good example is the Cambridge Mathematics Placement (CMP) Scheme that provides opportunities for undergraduate and Masters students to get practical research experience outside the CMS. The Scheme is primarily funded by philanthropic donations but a new **Industry Supporters Club**, launched in 2018, has already secured donations (~£300k) from a range of industry partners, most notably Symmetry Investments, GSK and BP for the next three to five years (see also Section 4).

3.3 Infrastructure and facilities

CMS provides a high-quality built environment for mathematical research, designed for collaborative working. Offices are situated in seven pavilions (four occupied by DAMTP, three by DPMMS) arranged around a central core containing a large common room, with lecture theatres and cafeteria facilities open to undergraduates as well as research students and staff. Individual pavilions also have common room space, plus one or two further lecture theatres. All common space is regularly used for informal mathematical discussion.

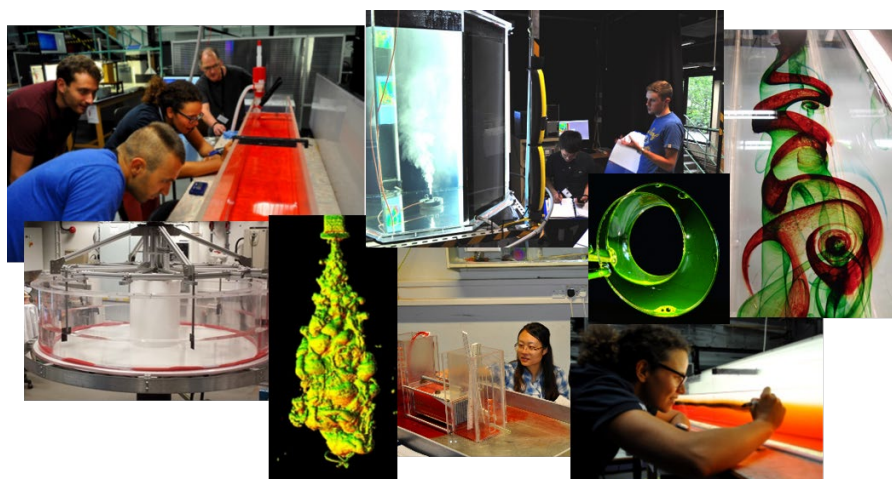


The Centre for Mathematical Sciences designed for mathematicians as well as energy conservation connection to the outdoors via natural ventilation

The site is regularly used to host conferences with participants coming from all over the world. Between 2015 and 2019 >175 events/conferences were hosted at the CMS with ~13,000 participants. This included the 2015 joint BMC/BAMC with 600 participants. Once every two years the Faculty runs an open day during the **Cambridge Science Festival**, in which several thousand people attend mathematical talks and demonstrations at CMS.

Since 2014, the majority of professional and support staff work in Faculty shared services teams which includes HR as well as undergraduate and postgraduate offices. We have a dedicated on-site IT team who respond to computing needs from research computing and bespoke maths systems to supporting day to day operations. The site is supported by an outstanding facilities team who work closely with the Departmental Administrators and colleagues in the Isaac Newton Institute and Betty and Gordon Moore Library.

Since its foundation in 1964, the **GK Batchelor Laboratory** has carved out a strong international reputation for experimental research in fluid mechanics and is the most significant such facility in a UK mathematics department. At 820m², the Laboratory has the scale and flexibility to maintain a critical mass of researchers and technicians for broad swathe of research. While its origins are in geophysical, geological and environmental fluid mechanics, the research portfolio has expanded to include building ventilation, biological physics, microfluidics, flow chemistry and granular flows, undertaking not only world-leading research, but developing innovative technology and unique diagnostics of value to the international community.



Images celebrating the diversity of research carried out in the GK Batchelor Laboratory.

Since REF 2014, significant new endeavours have included inner city air quality (EPSRC), stratified turbulence (ERC), natural material innovation (Leverhulme), decontamination processes (DSTL), tissue biomechanics and physical aspects of marine biology (Wellcome), attracting over £19M of funding during the REF period by *Linden*, *Dalziel* and *Goldstein* alone. In addition to this directly funded research and the resources it brings with it, the Laboratory has benefitted from a substantial investment from the University in the last five years to expand the core pool of research equipment and capabilities of the workshop. The six technicians and a technical officer are very much part of the team, supporting both funded and unfunded research. The flexibility of experimental research in the Laboratory is illustrated by the COVID-19 related experiments on the ventilation of hospitals, public transport and understanding the emissions from musical performance rapidly starting in June 2020.

Our research also benefits from cross-HEI **collaborative infrastructures** with many researchers spending time at CERN (*McCulloch*, *Allanach*, *Ubilai*), LIGO (*Sperhake*, *Agathos*) and studying cosmic microwave background (CMB) using the Atacama Cosmology Telescope (*Sherwin*).

The Mathematics Faculty provides an excellent environment for **research computing** based around the heterogeneous 90Tflops 'Fawcett' system with a low latency high bandwidth network connecting CPUs and GPUs, including a 'fat node' with 7TB shared-memory; there is also a desktop-based network with over 250 cores for serial jobs. The Fawcett platform represents a major investment (>£1m) by the Faculty during the assessment period and allows researchers to rapidly prototype and run highly parallelised and vectorised codes for later deployment on larger Tier-2 (3 PFlop Cambridge University CSD3/Wilkes supercomputer system which is free to access) and Tier-1 HPC facilities for large scale production runs (via University and national resources e.g. ARCHER and DiRAC). A full-time research software engineer assists with code development and a longstanding collaboration with Intel and HPE has resulted in the Faculty hosting an Intel Parallel Computing Centre since 2014 and an Intel Graphics and Visualization Institute since 2020.

4. Collaboration and contribution to the research base, economy and society

4.1 Academic Collaboration

Our academics have active research collaborations with mathematicians all over the world. Since 2014 we have recorded over 350 specific visits by collaborators to the CMS.



A major collaborative role is also played by the **Isaac Newton Institute** and the Newton Gateway to Mathematics (formerly Turing Gateway to Mathematics) as an interface

between academia and industry, enhancing the Cambridge Mathematics environment. The Institute runs scientific programmes varying in length from 4 weeks to six months. At any particular time there are typically two to three programmes running, with workshops, satellite meetings and other special events are organised as part of the programmes.

Over the REF period the Institute has organised 48 programmes, with >2300 programme participants and >6300 workshop participants. Participants include 30 Fields Medallists, 13 Nobel Laureates, 12 Abel Prize winners, 25 Wolf Prize winners and over 50 Clay Senior Scholars. We look forward to the arrival of Ulrike Tillmann FRS as the new INI Director from October 2021.

Although the INI is a national resource, a number of synergies naturally occur with the activities of the Departments, and joint events have included showcase events, an industrial engagement day with Unilever, and a series of engagement events for Cantab Capital Institute. There have been more than 150 Cambridge Maths participants at INI events, including programmes and workshops, and eight Cambridge Maths staff involved as organisers. Of INI event participants surveyed, 54% also attended seminars at CMS, 70% participated in informal discussions with CMS colleagues, and 17% went on to set up collaborations with CMS colleagues. The additional funding announced for the INI in January 2021 will provide increased opportunities for joint activities.

4.2 Industrial Collaboration

Our **Knowledge Transfer Facilitator (KTF)** has helped us to develop our impact strategy and improve our research impact through interaction with industrial end users. The KTF works directly with academics across both Departments and has established a significant range of industrial contacts, many of which have provided research funding. Her work includes the following areas:

- Making initial contacts with new companies, identifying opportunities for engagement and nurturing these relationships over time
- Contributing to a range of engagement activities between industry and members of Cambridge Mathematics at all levels. This includes: showcase events, an industry seminar series, aimed at undergraduate and postgraduate students upwards; supporting student and postdoc industrial placements and research projects.

Since 2014, the KTF has developed ~500 contacts with ~170 organisations. These are from a diverse range of sectors spanning global players to SMEs. Engagement events are held regularly with external businesses and organisations. The objectives are an exchange of research challenges and ideas between industry and academics to identify potential joint projects or other areas of collaboration. Connections made at these sessions also have the benefit of initiating relationships that may develop into collaborations in the longer term.

Companies that have participated include AstraZeneca, Aviva, BP, Cantab Capital, Cognizant, DSTL, GlaxoSmithKline, Faraday Predictive, Hitachi, Iconal, Landesbank Baden Württemberg (LBBW), National Physical Laboratory (NPL), PepsiCo, RiverLane, Schlumberger, Sellafield, Siemens, Thales, Unilever and Xaar.

Awards for impact via the EPSRC Impact Acceleration Account (IAA) schemes include:

- a follow-on fund for development of a mobile EEG device
- an IAA Partnership Development award with Unilever investigating mathematical image analysis to improve safety in food production
- a Knowledge Transfer Fellowship with Biddle for the development of air curtains
- a postdoc placement scheme with AstraZeneca to improve accuracy in determining bioavailability.

European Study Groups with Industry (ESGI) is a well-established knowledge exchange event for the mathematics community, where organisations from industry and other sectors submit real problems for academics to address over the course of a week. Hosted at Cambridge in 2019, a record ten industrial problems were submitted from eight organisations and over 160 delegates attended from national and international institutions. At least two of the companies are now proposing funding further PhD projects with Cambridge in addition to a range of CASE industrial studentships currently in place with partners such as Arup, Intel and NPL.

Students and industry

To develop relationships with industry and enhance understanding of research outside academia, researchers from business and industry are invited to speak in the Industrial Seminar Programme (35 seminars between 2015 and 2020). These are targeted at postgraduate students and Part III students, but open to all. CDT students have taken part in week-long workshops with the **Smith Institute** with expertise in modelling, algorithms design and analysing complex real-world scenarios. First year CDT PhD students can undertake an external research project with a record 50 industrial proposals received from companies in 2019/20.

The first iteration of what is now the **Cambridge Mathematics Placements (CMP)** programme was launched in 2013. CMP enables students to find funded summer research placements in industry, other University departments or other organisations via the Faculty's wide interdisciplinary network of University, industrial, business, governmental and academic partners. In the REF period, the programme facilitated 185 academic and industry placements and, alongside our internal summer placements, has provided bursaries (~£410k) for 265 students both within (177) and outside CMS (88) to gain research experience. Placements have increased (from 11 projects in 2013 to 35 in 2019) due both to the impact of the student's research and relationship development with industry. The CMP aims are for the students to develop transferable skills, for the hosts to engage talented mathematicians and to create a knowledge exchange community. The CMP Supporters Club is supported by a part-time administrator funded by the University EPSRC IAA and now DPMMS (13 members to date from individuals to large multinational corporations).

4.3 Academic Leadership

We promote a stimulating research environment where academics, research staff and students benefit from, and contribute to, a busy and broad programme of lectures and seminars. We appoint individuals of the highest quality to academic and research posts, providing mentoring, encouragement and support so that throughout their career their own research evolves to follow, and indeed define, profitable new areas of inquiry.

This approach has supported our staff in producing exceptional research contributions and receiving **>70 awards and prizes** which include:

- Adams Prize (*Mouhot* 2016, *Samworth* 2017)
- Alexander Graham Bell Medal (*Kelly* 2015)
- AMS Moore Prize (*Birkar* 2016)
- ASTRA Ramanujan Prize (*Thorne* 2018)
- Bingham Medal, US Society of Rheology (*Cates* 2016)
- Breakthrough New Horizons in Physics Prize (*Wall* 2019)
- Calderon Prize (*Schönlieb* 2019)
- Clay Research Award (*Gross* 2016, *Miller* 2017)
- COPSS Presidents' Award 2018 (*Samworth*)
- David Crighton Medal (*Kelly* 2015, *Abrahams* 2017)
- De Morgan Medal (*Gowers* 2016)
- Dirac Medal, Institute of Physics (*Barrow* 2015)
- Fields Medal (*Birkar* 2018)
- Forder Lectureship (*Gog* 2016, *Wolf* 2020)
- Franklin Medal and Prize of the Institute of Physics (*Goldstein* 2016)
- G.K. Batchelor Prize, IUTAM (*Goldstein* 2016)
- IMA Prize in Mathematics and Applications (*Hansen* 2018)
- IMS Medallion Lecture (*Samworth*)
- IUPAP Young Scientist Prize (*Santos* 2014, *Bauerschmidt* 2015, *Wall* 2017)
- L'Oréal-UNESCO UK and Ireland For Women in Science Fellowship, Women of the Future Award (*Bruna* 2016)
- Mahler Lectureship (*Krieger* 2019)
- Michael Faraday Prize and Lecture (*Spiegelhalter* 2020)
- Philip Leverhulme Prize (*Samworth* 2014, *Randal-Williams*, *Schönlieb & Hansen* in 2017, *Birkar*, 2018)
- Philippe Meyer Prize (*Wall* 2018)
- Prospects world top thinker (*Birkar* 2019)
- Royal Astronomical Society Gold Medal (*Barrow* 2016)
- Royal Astronomical Society Annie Maunder Medal (*Mason* 2018)
- Royal Society Rosalind Franklin Award and Lecture (*Gog* 2020)
- Sylvester Medal (*Gowers* 2016)
- Whitehead Prize (2014-2020): *Birkar*, *Miller*, *Mouhot*, *Randal-Williams*, *Varju*, *Gog*, *Schönlieb*, *Bruna*, *Krieger* and *Wilton*
- William Hopkins Prize (*Birkar* 2018)

Fellows elected to **Learned Societies** since 2014 include:

- Eight to the Royal Society (*Markovic* and *Grimmett* 2014, *Gross* 2017, *Jozsa* 2019, *Haynes* and *Birkar* 2019, *Thorne* and *Osborn* 2020)
- American Statistical Association (*Aston* and *Samworth*)
- American Mathematical Society (*Dafermos*)
- American Physical Society (*Caulfield*, *Lauga*, *Sperhake*, *Dalziel*)
- Foreign Member, US National Academy of Sciences (*Cates*)

Thirty-seven members of staff have served on **National and International Committees** including London Mathematical Society (LMS), Institute of Mathematics and its Applications (IMA), Institute of Mathematical Statistics (IMS), REF (2014 and 2021), UKRI (EPSRC and STFC), Royal Society, Royal Statistical Society, American Physical Society, Alan Turing Institute, Smith Institute, Bernoulli Society and the London School of Geometry and Number theory.

Twenty-one Faculty have been members of >40 **Scientific Advisory Boards** worldwide including ICMS, Higgs Centre for Theoretical Physics, Max-Planck-Institute, Penrose Institute, Delta Institute for Theoretical Physics, Istanbul Center for Mathematical Sciences and the African Institute of Mathematical Sciences. The majority of Faculty have organised **National and International conferences/programmes** including ICM, BMC/BAMC, EUROMECH, Sampling Theory and Applications, AQIS, PASCOS, APTS, JMM, ECM.

Keynote lectures:

Ten invited speakers at the **International Congress of Mathematicians** (2014: *Grimmett, Gross, Dafermos, Breuillard* and *Raphael* and 2018 *Birkar* (Fields Medal Lecture), *Miller, Mouhot, Smith* and *Thorne*). Plenary speakers at the European Congress of Mathematics (*Mouhot, 2014* and *Titi, 2020*). A selection of other keynote and plenary lectures include: GK Batchelor Lecturer, Australian Fluid Mechanics Conference 2016 (*Linden*); Loo-Keng Hua distinguished lecture, Tsinghua University 2019 (*Birkar*); Séminaire Bourbaki Paris 2019 (*Randal-Williams*); First Annual Endowed Lectureship in Fluid Mechanics, 2015 (*Worster*); IOP HEPP keynote 2015 (*Allanach*); Society of Rheology Annual Meeting (Plenary Prize Lecture) 2017 (*Cates*); Keynote speaker at FoCM: Stewartson Memorial Lecture at BAMC 2019 (*Kerswell*); Plenary talk, Euromech Fluid Mechanics Conference, 2018 (*Lauga*); Frenkiel Award Keynote Lecture, 68th Meeting of the APS/DFD, 2015 (*Lauga*).

Editorial Boards:

Our staff have held over 125 appointments as Editors, Associate Editors and Editorial Board members across 65 journals spanning the whole spectrum of the mathematical sciences. The Journal of Fluid Mechanics (*Worster*), Annals of Statistics (*Samworth*), Advances in Combinatorics (*Gowers*), and J. Algebraic Geometry (*Birkar/Gross*) are led from Cambridge.

4.4 World-leading mathematics education and outreach

- **The Millennium Mathematics Project (MMP)** is a maths education and outreach initiative for ages three to 19 and the general public. The MMP is a collaboration between the Faculties of Mathematics and Education, and is active nationally and internationally. In the 2018/19 school year MMP web-based mathematical resources attracted over ten million visits from users worldwide and more than 35 million page views; around 10,000 school students and more than 4,000 teachers were involved in face-to-face activities and events.
- **Underground Mathematics** developed web-based teaching resources to enhance post-16 mathematics education via a £5.5m grant from the Department for Education (led by Martin Hyland).
- The **Winton Centre for Risk and Evidence Communication** is becoming a leading global hub for the transparent communication and improved public understanding of risk, statistics and evidence. *Spiegelhalter*, the Academic Director, is one of the Institute for Scientific Information's highly cited researchers (>122K citations) and has an extremely strong media presence, regularly appearing on TV and radio in response to scientific headlines involving statistics and risk.
- *Krieger* has almost 9 million views to date for her free educational mathematics videos for a general audience via the **Numberphile** YouTube channel. She also runs outreach activities to raise the profile of women in Mathematics.

- *Tong* has over 2 million views for his lectures on Quantum Fields including the 2017 Royal Institution lecture.
- In 2016, *Mason*, awarded an OBE for her work in Higher Education and to Women in SET, became an **STFC Public Engagement Fellow** and was awarded the Annie Maunders Medal by the Royal Astronomical Society in 2019 for bringing the excitement of solar physics to the wider public.

4.5 Response to COVID pandemic

The Faculty continues to make contributions in response to the global pandemic:

- *Gog* has been providing advice to the Government through the Scientific Pandemic Influenza Group on Modelling (**SPI-M**), that feeds into **SAGE**, the Scientific Advisory Group for Emergencies. She was awarded an OBE in 2020 for services to academia and the COVID-19 response.
- *Aston*, as Home Office Chief Scientific Advisor (2017-Dec. 2020), has been advising on all aspects of Home Office policy with respect to the COVID pandemic as well as bringing statistical expertise to SAGE.
- *Spiegelhalter* has appeared via multiple media outlets discussing the statistics of the coronavirus pandemic. He leads the **Winton Centre** which has produced a whole series of resources providing clear explanation and analysis of COVID numbers. In addition, the Winton team have run a series of international surveys exploring risk perception of COVID around the world and at how levels of trust in government and the media have changed over time.
- *Cates* devised the **Rapid Assistance in Modelling the Pandemic** (RAMP) initiative and chaired its Steering Committee on behalf of the Royal Society. It was set up as a national voluntary effort April-July inclusive, and involved hundreds of active volunteers reinforcing existing modelling teams and creating new ones.
- *Linden* co-leads a major RAMP Task Team (70 people) working on **Environmental and Aerosol Transmission** of COVID-19. A paper in J. Fluid Mech. with *Dalziel* looks at the effects of ventilation on the indoor spread of the virus and the pathways of airborne particles. Two new grants have been awarded in this area.
- The *van der Schaar* Lab has played an active role in the academic and clinical response including developing and implementing tools such as **Cambridge Adjutorium** to enable clinicians to predict utilisation of scarce resources, such as ventilators and ICU beds and creating **Policy Impact Predictor (PIP)**, a machine learning tool developed to guide government decision-making around measures to prevent the spread of COVID-19.
- *Schoenlieb's* group are developing an open-source artificial intelligence tool that combines chest imaging data, clinical and laboratory data to support the diagnosis, triaging and treatment planning for COVID-19. This includes participation in **DRAGON**: A new international project funded by IMI and supported through the Horizon 2020 Framework.
- *Adhikari* enlisted a team of around 20 (including *Jack* and a team from JP Morgan) to develop **PyRoss**, a codebase and platform for Bayesian parameter inference and model comparison among compartmental epidemic models, a type widely used by SPI-M teams to model COVID.
- *Gowers* participated in **DELVE**: Data Evaluation and Learning for Viral Epidemics convened by the Royal Society.

- *Kontoyiannis, Kent, Samworth, Shah, Zhao, Bacallado and Grimmett* have all published on a range of aspects of COVID including Public Health Policy and Effective Mass-Testing Rates, Counting the costs of COVID-19, Models for transmission and for the mobile phone test/trace app, highlighting bias in early analyses, and role of asymptomatic carriage in COVID-19 transmission.
- Providing emergency packages of resources to support learning from home, the **NRICH website** attracted up to 1.25 million page views a week during lockdown, with up to 724K page views from the UK each week. In addition, NRICH also collaborated with the BBC to provide resources supporting BBC Bitesize's online daily homeschooling lessons. Work is now continuing to help schools address the ongoing effects of educational disruption caused by the pandemic including large-scale interactive student webinars.