**Institution:** University of St Andrews

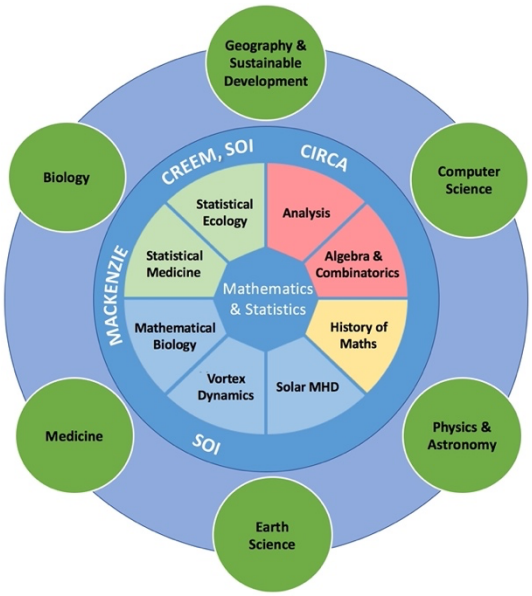
**Unit of Assessment:** UoA 10: Mathematical Sciences

## Section 1. Unit context and structure, research and impact strategy

### Overview and context

The *School of Mathematics and Statistics* at St Andrews has enjoyed major success over the past six years, gaining 12 prestigious prizes and grants totalling £14.25M. The School has grown significantly, to 45 academic staff (from 32 in 2014), 28 research staff and 9 research active emeritus staff, with two new impactful research areas established. Notable achievements include solving long-standing conjectures in combinatorics, group theory and Fourier analysis, pioneering numerical methods and software that make large scale 3-D modelling of climate and MHD feasible, and developing statistical techniques compatible with high-tech data collection methods.

Activity is structured around *research groups* in areas across the mathematical spectrum. Some are long-standing: *Solar and Magnetospheric MHD Theory*, *Vortex Dynamics, Algebra and Combinatorics, Analysis* and *Statistical Ecology*. Since 2014 two rapidly developing groups have been founded with impact in mind: *Mathematical Biology* and *Statistical Medicine and Molecular Biology*. The School is almost unique in the UK with a commitment to *History of Mathematics*, recently underpinned by academic appointments. Staff and research students have a primary research group affiliation, but many are members of more than one group, reflecting intradisciplinary activity.




The School is a founding partner of four *interdisciplinary research centres* joint with other schools across the University: *Centre for Research into Ecological and Environmental Modelling* (*CREEM*), *Centre for Interdisciplinary Research in Computational Algebra* (*CIRCA*), *Scottish Oceans Institute* (*SOI*) and the new *Mackenzie Institute for Early Diagnosis.*

*Computer-intensive* research and modelling features prominently in all areas of applied mathematics and statistics as well as in computational algebra, capitalising on access to high performance computing (HPC) facilities locally and nationally.

### Research and impact strategy

The School's strategy fits into the University's strategic framework described in the Institution-Level Environment Statement (ILES, 1), mirroring the University's four themes: *World-leading, Global, Diverse and Entrepreneurial*. The strategy has developed from that proposed in REF2014: to concentrate on areas based around research groups, to ensure that research and impact remains cutting-edge, to be proactive in exploring new directions, and to develop synergies between interests locally, nationally and internationally. The School has been enhanced by strategic appointments, both senior and early career, and much increased

collaborative, impactful and interdisciplinary activity, within the School, the University and world-wide.

***Ongoing strategy***

Our strategy is to *support existing research groups* to ensure they remain world-leading but evolve as knowledge and needs develop (evidenced by new appointments across all groups) and to *seed impactful new research directions* (new groups in Mathematical Biology and Statistical Medicine).

We seek *funding from a wide range of sources* including research councils, consultancy, government and industrial contracts (significant funding across all research areas and from many sources) and *build on our reputation to leverage further contract and consultancy work* with government and non-government agencies and other external bodies (e.g. considerable environmental statistics consultancy). We continue to *increase connectivity* and *develop synergies* between our groups, with other areas in the University, and with cognate groups nationally and internationally (strategic appointments, interdisciplinary centres, extensive worldwide collaboration). In particular we develop research and impact opportunities in the *priority areas* of research funding bodies and of the University (ILES, 2.5), notably in ecology and environment, biodiversity, climate change and space weather, health and infectious diseases (e.g. new groups with links to public health organisations, Met Office collaborations).

The roles of the *Director of Research* and the *Director of Impact* (appointed in 2015) are embedded within the School structure, to encourage and facilitate research and impact initiatives, link with University officers and units, and keep staff informed of opportunities and funding.

We engender a *culture of impact* throughout our activities, with staff both identifying impact opportunities as they arise in their work and by embarking on dedicated impact projects. Potential impact is frequently developed through *dedicated impact funding* (over 35 projects recently funded by University and EPSRC IAAs, SFC Global Challenges Fund and US Office of Naval Research, with further IAA applications pending). Several research groups work closely with practitioners, especially Statistical Ecology, Mathematical Biology and Statistical Medicine, and the School has recently established an *Impact and Entrepreneurial Advisory Board* consisting of local business representatives with whom we meet regularly to identify and establish mutually beneficial partnerships. The School has a dedicated *Business Development Manager* based in the University Research Funding Support unit who helps staff identify and develop impact initiatives.

We continue to develop impact through *public engagement* and *knowledge transfer* (e.g. free software such as *Distance* and *Hydra*, supported by face to face and online workshops) and *outreach,* for which our research portfolio is well-suited, coordinated by our two *Outreach Officers*.

*Excellence in research and impact* is a key consideration in School planning, academic appointments and assessing promotions. We encourage staff to apply for *research or impact leave*, taken by most staff since 2014, to provide quality time to devote to significant projects.

With much of our work *computationally intensive* and with our world-leading specialist programming expertise, we ensure, in conjunction with the University HPC Board, ongoing access to state-of-the-art high performance computing, including massively parallel computing, through University and national facilities (computationally intensive work in many areas). We

embrace *emergent technology* for collection of data and develop robust statistical techniques for its analysis (e.g. wildlife data from visual and acoustic drones, crowd sourcing methods).

We maintain a *lively environment* that is academically, physically and socially conducive to producing excellent research and that attracts top researchers (evidenced by the quality of applicants for posts, eight seminar series, visitor programmes, local conferences, national and international networks, annual School Research Day and pleasant surroundings).

Despite the unforeseen and sudden challenges of COVID-19, our research groups have continued to flourish with generally little disruption, apart from curtailing statistical ecology fieldwork. Staff adapted well to working from home though special consideration was given to those with young families who understandably found it more difficult than others. With strong support from our computer officers and IT services, computational research has continued and online meetings and seminars have worked well; indeed the flexibility of online working has led to new external collaborations. Several conferences organized by, or with participants from, St Andrews have taken place online (often with much larger attendance than usual), others have been postponed. Staff have gained five grants from Scottish Government and other sources to help mitigate the impact of COVID-19.

***Longer term plans***

Prior to the COVID-19 crisis, the University had agreed to *exciting long term plans* for the School. These included the construction of a *purpose-designed new building* to house the entire School which had reached the architect-planning stage with completion scheduled for 2024. With an exceptionally high number of well-qualified undergraduate and taught postgraduate applicants we were planning an *expansion programme* to increase our overall undergraduate numbers by 80 and our MSc numbers by 24 over the next 5 years. It was the School's intention to appoint 9 additional academic staff between 2021 and 2024, and thus expand and diversify our research and impact activities in accordance with our strategy. We fully intend to embark on this programme but the timing will depend on the overall situation in the HE sector post-COVID-19.

**Impact case studies**

Our four submitted impact case studies resonate with the above strategy.

CREEM's reputation in ecological statistics led to two case studies in the priority area of ecology and environment. (1) *Statistical methods for wildlife monitoring and conservation in the digital age* develops methodology for new digital methods of monitoring wildlife in remote environments, funded by contracts with conservation organisations in many countries to advise and train their staff. (2) *Distance sampling survey methods contribute to managing wild animal populations and quantifying biodiversity* has led to knowledge transfer through publicly available software, widely used by government and NGOs for wildlife management and conservation.

(3) *Statistical research reduces environmental impact in the world's oceans* covers a range of projects resulting from substantial contracts (e.g. US Navy, Bioconsult) and EPSRC IAA funding, to use spatial modelling to analyse the effects of human activities on the oceans.

(4) *Bringing mathematics and its history to diverse audiences worldwide* demonstrates extensive outreach and public engagement developed from collective staff expertise alongside new appointments, the world-renowned MacTutor History of Mathematics website having been upgraded using EPSRC and University impact funding.

**Research groups – achievements and directions**

Key to our strategy are the *research groups* in which staff, postdocs, postgraduates and visitors all play a full and valued part. Each group runs its own regular seminar programme (which have continued online and attracted international participants during COVID-19) as well as organising reading groups, workshops and conferences. The groups have developed extensive networks that facilitate collaborations with leading researchers world-wide.

*Note ° denotes a staff member who has left during the period and * denotes a retired but research active staff member.*

***Solar and Magnetospheric Theory*** (Archontis, Cairns*, De Moortel, Hood, Mackay, Neukirch, Parnell, Priest*, Roberts*, Wright)

This group, which gained six prizes during the period, develops mathematical models of observed solar and magnetospheric phenomena. The main emphasis is on magnetohydrodynamics (MHD), including solar prominences and flares, space weather, coronal loops and oscillations, flux emergence, coronal heating and particle acceleration. This modelling combines large scale computation with sophisticated analytical techniques, informed by observations from space missions which have group members as invited co-investigators, e.g. ESA (Co-Is for a project on coronal mass ejection on the recently launched Solar Orbiter) and NASA (MUSE, SOLARIS).

Highlights since 2014 include: a new model of small scale coronal heating events by an MHD avalanche (Hood); a key model, based on the observed evolution of photospheric magnetic fields, for the formation of large magnetic structures that can support prominences (Mackay); uncovering the theoretical basis of Alfven wave resonances in 3D magnetic fields (Wright), and a numerical and analytical derivation of mode coupling to demonstrate Gaussian damping (Hood, De Moortel).

Looking ahead, the group will develop new computationally efficient methods to investigate the complex thermodynamical interplay between the coronal and chromospheric plasmas; determine the importance of MHD waves and magnetic reconnection in the energy balance of the corona and magnetosphere; produce computational predictions of eruptions from active regions, based on the development of data-driven models, with implications for space weather.

Since 1996 the group's main funding has come via a large STFC consolidated grant; this was renewed again in 2016 and in 2019 up to 2022. Together with a recent ERC Synergy Grant and a European Consolidator Grant, the group is very well-resourced for the future.

***Vortex Dynamics*** (Burgess, Carr°, Dritschel, Rees Jones, Reinaud, Scott, Tran)

The group focuses on geophysical and astrophysical fluid dynamics, including climate applications. They have developed a unique set of analytical and numerical research methods tailored to studying fundamental aspects of vortex interactions accurately and efficiently and applicable to a wide diversity of problems.

As anticipated in REF2014, considerable advances have been made in understanding the formation of coherent structures, such as fronts and jets, in planetary atmospheres. The methods have been extended to MHD to study turbulence in the solar interior, linking with the Solar Group.

Recent and ongoing research includes: understanding the regularity of the Navier-Stokes equation using a novel pressure-based approach (Tran); the formation of singularities in surface flows (Dritschel, Scott); a comprehensive analysis of Kelvin-Helmholtz instability in stratified flows (Carr°, Dritschel); a model of hurricane development and equilibration (Scott). Significant research concerns planetary atmospheres, e.g. new explanations for the banded circulation patterns on the gas giant planets (Dritschel, Scott). New advances in shallow-water modelling have led to a Leverhulme Fellowship (Dritschel) to understand entirely new flow regimes.

The group continues to extend its computational expertise, especially for 3-D simulations which are becoming feasible with sophisticated coding and HPC. With a new 5-year £474k grant to develop new models of clouds and convection with the potential to improve weather forecasting and climate modelling, these techniques will be developed for 3-D models of shallow flow and for ocean vortices, crucial to understanding transport of heat, nutrients and pollutants in the oceans.

***Mathematical Biology*** (Chaplain, Kursawe, Lorenzi°, Minas, Sfakianakis, Venkataraman°)

The group was formed in 2015 with the appointment of Chaplain to the Gregory Chair and has grown to 5 staff, 3 postdocs and 4 research students.

The group formulates, develops, analyses and simulates mathematical models to study the key mechanisms which underpin the dynamics of a broad range of biological and medical systems. A main focus is mathematical oncology, specifically multiscale modelling of cancer growth and treatment (synergies with Statistical Medicine). A major success has been a new model for metastatic spread of cancer. Other research includes modelling tuberculosis and antibiotics resistance, theoretical ecology (synergies with Statistical Ecology), biological pattern formation, cell migration and evolutionary game theory (potential applications to modelling conflict and security).

The group is a leading partner in two large collaborative projects: 'SofTMech: EPSRC Centre for Multiscale Soft Tissue Mechanics - with applications to heart and cancer' (£2M with Glasgow, Heriot-Watt and Sheffield) and the MRC funded 'Developing new paradigms for overcoming drug resistance in cancer using novel humanised mouse models' (£1.25M with Dundee Medical School).

The group will maintain its position as a world-leading cancer modelling centre and build on its strong foundation to grow and broaden its interests to areas such as evolutionary biology, social sciences and psychology.

***Analysis*** (Bleak, K.Falconer, Fraser, Olsen, Todd)

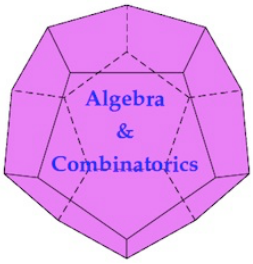
The appointment of Falconer to the Regius Chair and recruitment of Fraser have cemented the group's world-leading reputation in fractal and multifractal geometry and dynamics. The group has grown substantially with grants of £950k that have supported 4 postdocs. As anticipated in REF2014, links with the Algebra Group

have developed, with joint PhD students, e.g. applying dynamical methods to infinite group theory.

Two topics in fractal geometry, the *distance problem* and *affinity dimension*, both initiated by Falconer in the 1980s, have attracted intense international interest over the past 6 years with the group making significant contributions as new methods from ergodic theory and additive combinatorics have emerged. Fraser's work on *Assouad dimension* has opened up a new area with unexpected connections, for example to near-arithmetic progressions.

The group's interests continue to broaden. The solution of an old problem of Kahane on the dimension of Brownian graphs (Fraser) and the use of zeta functions and ideas from number theory to study fractals (Olsen) have raised a diversity of new questions. Research on the underlying mechanisms which produce different kinds of statistical behaviour for various dynamical systems (Todd) and for stochastic processes (Falconer) is ongoing. Todd is a leader in extreme value theory in dynamical systems and will develop impactful work relating to climate change, both global (temperature fluctuations) and local (storms, floods).

***Algebra and Combinatorics*** (Bailey, Bleak, Cameron, Huczynska, Len, Mitchell, Quick, Rivin°, Roney-Dougal, Ruskuc, Theran)




The group embraces a wide sweep of algebra and combinatorics, with pioneering research in group theory, semigroup theory, combinatorics of words and permutations, computational algebra, and combinatorics of designs (all areas cited in Cameron's 2017 *Senior Berwick Prize*). The group's ongoing strategy is to proceed from these foundations and explore new topics, areas and methodologies, furthered by appointments of Len and Theran at the geometry/combinatorics interface. Particular trademarks are the group's multiply-connected collaboration network, interdisciplinary research especially through CIRCA, and many PhD students (currently 15).

Highlights since 2014 include: developments on Thompson groups resulting from an intradisciplinary approach between algebra, geometry, dynamics and theoretical computer science, specifically classifying the automorphism groups of the Higman-Thompson groups $G_{n,r}$ (Bleak, Cameron) and proving the undecidability of the torsion problem for the groups nV ($n \geq 2$) (Belk, Bleak); advances on generators for groups and semigroups, including introduction of a new parameter related to the minimal number of generators (Cameron, Roney-Dougal); a complete description of congruence lattices of all standard diagram monoids (Mitchell, Ruskuc). Computational algebra and engagement with the vast GAP computer algebra system remain a significant focus both in terms of development and applications.

***Statistical Ecology*** (Bailey, Borchers, Buckland, Donovan, Durbach, Glennie, Goudie, Illian°, Jupp*, King°, Langrock°, MacKenzie, Marques, Oedekoven, Scott-Hayward, Sutherland, Thomas, Worthington)


The world-leading reputation of this group was confirmed in 2019 with the award of the *Guy Medal in Gold* to its long-term leader Buckland for '*his significant and sustained contributions to the development of statistical methods for ecological applications … transforming the power, accuracy and robustness of traditional methods*'.

The group forms the main component of the interdisciplinary centre CREEM, with 15 research staff, whose work includes new methods development, high-impact applied research,

consultancy, and training workshops for practitioners. Research and contract income since 2014 has exceeded £5.1M, with a major focus on developing methods to monitor more effectively wildlife species impacted by anthropogenic activities and to predict the consequences of these activities.

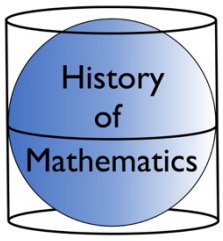
Distance sampling methods for estimating population density remain a particular strength, with a new book and new versions of our industry-standard free software (downloaded 50,000+ times). Another major area, highlighted as new in REF2014, is in Bayesian capture-recapture and spatial capture-recapture. Significant progress includes development of methods for acoustic data, open population modelling, dealing with recapture uncertainty and incorporating animal movement into estimation. Inference on animal movement is an emerging strength with inference from spatial ecological data remaining a focus.

The group will build on its reputation to seek further funding and develop current and emerging strengths. We will look to growth areas such as biodiversity monitoring and the environmental impact of renewable energy, developing methods for high-tech data collection and analysis, for example using acoustic aerial drones, remotely-activated cameras and undersea gliders.

***Statistical Medicine and Molecular Biology*** (Bailey, Donovan, Lynch, Minas, Papathomas, Worthington, Valletta)


This group was founded in 2017 with the appointment of Lynch as professor. There are strong interactions with the Mathematical Biology Group, our Schools of Medicine and Biology and with pharmaceutical and medical organisations including NHS. The group's mission is to develop new methodologies and collaborate in applied studies to advance our understanding of biology and to improve medical outcomes. Significant strengths include methods for high-throughput genomic technologies, statistical genetics, stochastic modelling, estimation and analysis of dynamic gene networks, design of experiments, cancer research (including contributions to the International Cancer Genome Consortium and membership of the international PanProstate Cancer Group), medical imaging, modelling infectious diseases and health psychology.

***History of Mathematics*** (Craik*, I.Falconer, Hood, Kent, O'Connor*, Phillips*, Robertson*, Roney-Dougal)




Even without specialist staff, History of Mathematics at St Andrews has long enjoyed an international reputation, with the library's major historical collection and as home to the vast web-based *MacTutor History of Mathematics Archive*, recognised by the *LMS Hirst Prize* in 2015. Since 2014 small grants totalling £77k have supported a major international conference, 3 workshops on history topics, a long term visiting fellow programme, regular short term visitors, 4 PhD students, and 30 short project undergraduate researchers. Recent additions to MacTutor include newly-researched biographies of African mathematicians, particularly women, about whom very little information was previously available. Two specialists in history of mathematics were recently appointed to develop research and ensure ongoing impact for MacTutor.

**Support for interdisciplinary research**

The School is a key partner in four of the University's *interdisciplinary centres* set up to facilitate collaborative research across the University and with external stakeholders; these all relate to

University or Research Council priority areas. Three are long-standing: *CREEM* (*Centre for Research into Ecological and Environmental Modelling* with Schools of Biology and Geography) www.creem.st-andrews.ac.uk, *CIRCA* (*Centre for Interdisciplinary Research in Computational Algebra* with Computer Science) www-circa.mcs.st-and.ac.uk, and the *SOI* (*Scottish Oceans Institute* with Biology, Earth and Environmental Sciences, Geography and Sustainable Development) https://soi.st-andrews.ac.uk. These centres have their own homes: CREEM occupies the Observatory Building, CIRCA has a dedicated area in the Mathematical Institute, and in 2019 SOI opened a shoreside £16M state-of-the-art research centre. The *Mackenzie Institute for Early Diagnosis of Human* Disease (with Medicine, Biology, Physics, Chemistry, Computer Science, Geography) http://med.st-andrews.ac.uk/mackenzie opened in 2019 and involves our new research groups in Statistical Medicine and Mathematical Biology working with the other Schools and NHS.

These centres are foci for members from different schools to develop multidisciplinary collaborations, bringing mathematicians and statisticians into contact with laboratory and field scientists and opening up new funding opportunities. They promote national and international networking through hosting conferences and visitor programmes. Many School appointments since 2014 were made with membership of these centres in mind.

Interdisciplinary research also develops through informal networking across the University, for example, recent funded joint workshops with International Relations on 'Modelling spatial dynamics of conflict and terrorism' and with Philosophy on 'Mathematical collaboration' have both engendered further research.

**Open research environment**

The School embraces the University's commitment to an open research environment (ILES, 2.4) alongside the mathematics and statistics community ethos that completed research and data should be freely available and widely disseminated. As well as placing papers and software on the University's publicly accessible research information system PURE, submitted and accepted manuscripts are routinely uploaded to Maths arXiv or bioRxiv for immediate free access. We increasingly publish gold open access papers partly facilitated by the University's agreements with major publishers. All researchers have ORCID numbers.

Major software packages developed in the School, such as *GAP*, *Distance* and *Hydra* (see Section 4) are free and open source. In 2019 the *MacTutor History Archive* was transferred to an open creative commons licence and migrated to a sustainable open source software platform.

With its substantial computer- and data-intensive research the School ensures that data and computer code used can be freely accessed, used, modified and shared. Some data and code is stored directly on PURE, otherwise it is put into repositories (linked from PURE) such as publishers' repositories or Github where, for example, the modelling software produced by the Mathematical Biology group is available. The Solar MHD Group, who produce many terabytes of output, have negotiated a data management plan with STFC to store source code and the data underlying figures appearing in papers. Some data for medical related research is stored in the huge European Genome-phenome Archive and equivalent repositories.

**Research integrity and ethical research**

The School is compliant with the several University and external statements on *Good Research Conduct* on the University website including the *Concordat to Support Research Integrity* (ILES, 2.6). New staff and research students take a series of online training modules on these policies,

which are highlighted and linked in our School Handbook. All research involving humans or animals or requiring questionnaires must get prior approval from the School and/or University *Ethics Committee*, particularly relevant for our ecological, medical and biological applications.

**Section 2. People**

**Staff development**

The School implements the principles of the *Corcordat to Support the Career Development of Researchers*. An individual induction plan is set up for all new academic and research staff. They are assigned a senior School member as a *personal mentor* and take standard training courses (e.g. Diversity, Computer Security) and a choice of many others (e.g. Attracting Research Funding, Networking, Research Leadership) from the University OSDS (Organisational and Staff Development Services) programme. A web-based *School Handbook* provides a quick reference with links to detailed information on all aspects of the School and University including development material for new and established staff. The School operates a comprehensive *appraisal and development scheme* for all staff on a yearly cycle, which includes discussions of research and impact directions and the promotion horizon. The reviewer is normally the Head of School, or PI for research staff, but staff may request an alternative reviewer for reasons of diversity characteristics. Crucially important are the *research groups* that provide subject specific support, with established members helping new researchers network, set up collaborations, identify grant and impact opportunities, and prepare applications.

Several staff have participated in the joint mentoring scheme with Dundee and Abertay Universities that matches experienced academics with early career colleagues, others have participated in the University 'Elizabeth Garrett' scheme to support mid-level female staff to develop their careers.

In 2016 the School introduced a *workload allocation model* to balance staff loads, taking into account research, impact work, PhD and postdoctoral supervision, grant income, internal and external service and teaching. The model ensures that staff can devote a substantial and appropriate amount of time to research but also helps optimise usage of the many varied talents across the School. New lecturers have reduced teaching loads for two years.

Research active staff (including part time staff) may apply for paid *research* or *impact leave* of one semester in eight, normally granted given an appropriate work plan; most staff have taken such leave since 2014. Staff are strongly encouraged to participate in international conferences and research visits, with School funds available to supplement grants and conference funding. There is a flexible approach to teaching arrangements to facilitate such visits.

Staff are encouraged and supported in applying for *external funding*. Senior staff routinely help early-career researchers with grant applications, including arranging mock presentations and interviews. This complements support from the University units (ILES, 4.1). Similarly, staff are supported in setting up impactful partnerships with organisations and industry through our extensive consultancy networks, our contacts with practitioners, particularly in statistics and medicine, and our *Impact and Entrepreneurial Advisory Board*.

Achievement in research and impact is recognized through reach and significance of work, quality of papers, funding obtained, leadership, external recognition such as invited lectures, learned society positions and other esteem indicators. Research and impact achievements are highlighted in the monthly *School Newsletter*. The School enthusiastically encourages and supports promotion applications of staff whose activity is judged to be of the appropriate standard following annual review and in consultation with senior staff with promotions

determined by the Faculty Promotions Committee. Since 2014, 5 staff have been promoted to Chairs, 3 to Readerships, 2 to Senior Research Fellowships and 4 to Senior Lectureships.

**Staffing strategy**

In implementing the strategy in Section 1 the School combines *strategic appointments* at a senior level with appointing promising *early career researcher*s, often linking such appointments to initial fellowships funded externally or by the University. Paramount is the selection of researchers with high potential, keeping in mind both enhancing and evolving existing activities and developing new directions. Appointments are advertised internationally and attract up to 150 applicants, over 70% from abroad, with 9 appointments from UK, 4 from Europe and 4 from US since 2014. Appointment committees include male and female members who have all undergone 'Recruitment and Selection' and 'Unconscious Bias' training and who are involved from long-listing to interview and decision.

*Appointments since 2014* are consistent with our strategy. As well as two new professors, 13 new earlier career staff will ensure the long-term vitality of the School.

Specifically, professorial appointments have established two new impactful research areas. In Mathematical Biology: Chaplain, with supporting appointments of Lorenzi° and Venkataraman°, since replaced by Sfakianakis and Kursawe, with Stewart in evolutionary dynamics starting in January 2021. In Statistical Medicine: Lynch, appointed jointly with the School of Medicine, supported by Minas.

Rees Jones in geophysical and environmental flows with synergies in the School of Earth and Environmental Sciences, and Burgess in vortex scaling have broadened Vortex Dynamics.

In Pure Mathematics, Fraser's appointment has ensured the School's continuing reputation in fractal geometry and dynamics, and Theran in geometrical and algebraic combinatorics and Len in tropical and algebraic geometry have broadened Algebra and Combinatorics.

Replacing departing staff provided an opportunity to broaden statistical ecology and statistical inference, bringing in Sutherland as Reader and early career Glennie and Worthington.

St Andrews' reputation in History of Mathematics has been consolidated with specialist academic staff for the first time with I.Falconer and Kent.

Since 2014 the number of Category A staff has increased from 32 to 45 (30.6 to 42.0 FTE) (including 17 Professors, 6 Readers, 6 Senior Lecturers, 2 Senior Research Fellows) of whom 12 are women (4 Professors, 1 Reader, 2 Senior Research Fellows, 3 Senior Lecturers). Each research group now has a balance of senior members and future leaders.

| Age range | 25-34 | 35-44 | 45-54 | 55-64 | 65+ | Male | Female |
|---|---|---|---|---|---|---|---|
| | 6 (13%) | 11 (24 %) | 15 (33%) | 7 (16%) | 6 (13%) | 33 (73%) | 12 (27%) |

Some 9 *retired staff* remain research active and have office space and research facilities; the School benefits enormously from their expertise and experience.

Several staff who have developed their careers in St Andrews have moved to senior positions elsewhere including Illian°, King° and Langrock° who are professors at Glasgow, Edinburgh and Bielefeld respectively.

**Research staff**

The School currently has 28 *postdoctoral research fell*ows (16M,12F), including 15 in CREEM, mainly working on ecological and environmental consultancies, and 6 in the Solar Group, funded by STFC and ERC. On several occasions the School has used its own funds to provide bridging for RAs between externally funded positions. Research staff are fully integrated into research groups and centres which provide support and mentoring, they participate in the OSDS career development programme, and a School Contract Research Group meets regularly. Research staff are represented on key School committees, including Staff Council and E&D Committee, and three are members of the University Research Staff Forum. Postdoctoral staff are offered the opportunity to teach if they feel the experience will help their career.

Six staff have held *early career personal fellowships* during the period:

Aguilar de Soto (Marie Curie), Burgess (Leverhulme), Glennie (Biometrika), Olukoya (LMS), Photopoulou (RS Newton International), Yavicoli (Swiss NSF).

Many research staff go on to permanent academic positions, including recently to the Universities of Auckland(2), Cape Town, Edinburgh, Manchester, Northumbria and St Andrews.

**Visitors**

Since 2014 the School has hosted and provided office space and research facilities for over 60 international visitors for a week to a year, many funded by EPSRC, Royal Society, LMS, etc.. They include: Alfonso Caiazzo (Berlin), Gisela Cheoo (Lisbon), James East (Sydney), Katherine Hare (Waterloo), Allen Herman (Regina, Canada), Peter Mayr (Boulder, Colorado), Francesco Matucci (Unicamp, Brazil), Alia Sajjad (Windsor, Canada), Kathy Ruggiero (Auckland), Pablo Shmerkin (Buenos Aires), Zuzanna Szymańska (Warsaw), Sandro Vaienti (Marseille), Sanming Zhou (Melbourne).

**Professional service staff**

In 2019 a School Manager was appointed to restructure and modernize the School's support structure and oversee support staff, as a result academic staff are spending noticeably less time on administration. The Solar Group and CREEM have dedicated secretaries funded from grant income and three other secretaries support the remaining areas. The School has four computer officers, including three funded by grant income to support CREEM, Solar MHD and HPC.

**Research students**

***Recruitment***

Given its size, the School has been outstandingly successful in recruiting and training research students with 63 PhDs graduating since 2014 and the number of starting PhDs steadily increasing to 19 (10M,9F) in 2020. The number of interdisciplinary students jointly supervised with other schools continues to rise, currently three with Computer Science, two with Biology and one with Sustainable Development.

There is a strong international presence, with recent students from Australia, China, Nigeria, Pakistan and South Africa. Several participate in a 'Co-tutelle' programme for joint PhD degrees with other universities, recently Aveiro, Évora, Grenoble, Lisboa and Porto. The School also hosts visiting PhD students for 2-12 months, recently from China, Czech Republic, France and Pakistan, with mutual benefit to them and our research groups.

There are around 70 PhD applications each year, many from our own undergraduates or via our research groups' international networks. Our Summer Research Programme gives a taste of research for over 20 good undergraduates about to enter their final year from St Andrews and elsewhere (recently Oxford, CalPoly, Shanghai, Ghana), funded by LMS, RAS, Carnegie, Cormack and Laidlaw foundations and the School, enthusing many to apply for PhD places. Applicants are encouraged to contact potential supervisors directly and promising applicants are invited to St Andrews to discuss their proposed studies (the School covers travel and overnight costs) or for an online discussion if from outside the UK.

***Funding***

As well as research councils, trusts and overseas government scholarships, a substantial amount of PhD funding comes from research overheads, consultancy income and School funds. Different sources are often combined imaginatively to maximize the overall benefit. The University runs several targeted schemes, including dedicated Interdisciplinary Scholarships and a full funding arrangement with the China Scholarship Council for Chinese students, and we have had several students under these schemes.

***Supervision and monitoring***

Supervisors must undergo University training on PhD supervision every five years. Each research student is assigned two supervisors (main and secondary, or joint), with interdisciplinary students having a co-supervisor from other schools. Students normally have weekly scheduled meetings with supervisors with informal contact often daily. There is a formal progress review at the end of each year, requiring a substantial write up and oral presentation by the student, assessments by supervisors and a staff member from a different area, and a confidential meeting with Postgraduate Committee members to identify problems students might feel unable to discuss with their supervisors. Meetings with supervisors are recorded at School level and the University records attendance at training events.

***Training***

*General and transferable skills:* All PhD students take part in the GRADskills programme of the Researcher Development Framework supported by the St Leonards' Postgraduate College (ILES, 3.3). In particular, they chose two GRADskills workshops each semester, those on *Scientific writing, Research data management* and *Conference presentation* are found particularly useful. The School arranges training for students unfamiliar with *LaTeX*.

*Broad mathematics training:* The School is a main partner in the *Scottish Mathematical Sciences Training Centre* (*SMSTC*) which provides 16 broad subject modules taught through a video-conference network. Students take up to 6 modules in their first PhD year selected in consultation with their supervisors. St Andrews staff lecture in 5 modules and are involved as module leaders and on the SMSTC Academic Steering Committee.

*Specialist training:* Research groups arrange specialist training, e.g. courses in GAP algebra, parallel computing, STFC Summer Schools, a three month Solar MHD induction programme, SUPA (Scottish Universities Physics Alliance) courses and APTS (statistics training) weeks. Students also take appropriate modules from our Masters level portfolio.

Nearly all research students tutor undergraduate groups. General and module-specific training is provided together with mentoring by staff.

***Environment for research students***

Above all, it is the research groups that create a supportive and lively research environment in which PhD students, alongside staff, play a full part and develop both a broad perspective and specific expertise. All research students have a desk in an office shared with others with cognate interests and a suitable computer and software. Students interact informally with each other and with staff on a daily basis in our common spaces; with COVID-19 online networks have developed.

Each student presents at least one research group seminar each year on their own or other recent work. Students also organise seminar programmes on their own initiative, including a weekly *Postgraduate Student Seminar* from which staff are specifically excluded. Each year students organise a *Postgraduate Intradisciplinary Mathematics Symposium*, a two-day retreat at *The Burn*, a Highland country house, where they give talks on their work and discuss research skills and career issues.

All research students are funded (by the School if external funds are unavailable) to attend and speak at international conferences, to go on research visits and to participate in broader meetings for research students organised by LMS, EdinMS, SMSTC, etc. which facilitate networking and often collaborative work. Notably, our students organised the *UK Young Researchers in Mathematics* conference in St Andrews in 2016 as well as the national *Postgraduate Group Theory Conference* in 2018.

Students are strongly encouraged to publish work when it reaches an appropriate stage. They often collaborate with other School members, not only their supervisors, and since 2014 over 120 papers (single- or co-authored) have been published by research students.

The University *Advice and Support Centre* covers all student matters and liaises with the School to support students with disabilities during recruitment and as research students. For example, a blind PhD student who recently graduated was provided with specialised reading and writing equipment and STFC funding for an accompanying guide for conferences.

Several PhD students have won prizes: American Statistical Society Student Paper Prize (*Stevenson*, 2015), Best student talks at the International Statistical Ecology Conference (*Glennie, Howe*, Seattle 2016), TakeAIM ('Articulating the Influence of Mathematics') Prize of the Smith Institute (*Franssen* 2016 & 2018) for her work on modelling the spread of cancer, also a finalist in L'Oréal-UNESCO For Women in Science Award (2018) and a finalist in STEM for BRITAIN (2019). Other exceptional students include Han Yu, who published/submitted 20 substantial analysis papers during his PhD period and went on to a Cambridge college fellowship, James Hyde, who had papers accepted in both the *Annals* and *Inventiones* shortly after completing his PhD, and Craig Johnston, whose innovative numerical code development for the solar community has reduced computation time for MHD calculations by an order of magnitude.

Supervisors maintain a dialogue with students about their future careers, academic or non-academic, and this is routinely discussed during annual reviews; students may be referred to career-related *GRADskills* modules and the *Careers Centre*. About 50% go on to postdoctoral positions and about 30 of our PhD graduates from the past 15 years now hold permanent university positions; others take their skills outside academia, including recently: US National Solar Observatory, Met Office, GCHQ, Ontario Ministry of Natural Resources, International Council for Exploration of the Sea, i-Tech7 (subsea engineering), Deutsche Bank, Civil Service, University administration.

**Equality, Diversity and Inclusion**

EDI policy (ILES, 3.1) is implemented throughout the School, overseen by our *Equality and Diversity Committee*. All staff take Equality and Diversity and Unconscious Bias training.

The School received an *Athena Swan Bronze Award* in 2014 which was renewed in 2018 until 2022. The feedback from Athena Swan particularly commended the School for female staff promotions, for introducing family friendly 'core hours' of 10am-3pm for seminars and meetings, for the monthly informal 'lunch and chat' discussion meetings for all staff, for 3 months of maternity leave for postdocs covered by School funds where not covered by grants, and for provision of onsite crèche facilities for conferences hosted by the School.

*Flexible working*, including working at home, is supported with the proviso that staff are contactable; this became the norm during the COVID-19 outbreak. When allocating and timetabling teaching we try to ensure that those with family or caring responsibilities have lectures and tutorials times consistent with those responsibilities, for example some colleagues stop working mid-afternoon to collect schoolchildren and work in the evening. Staff returning from longer-term leave such as parental or sick leave are given reduced teaching loads. To facilitate caring responsibilities some postdocs and PhD students have permission to work remotely with periodic visits to St Andrews.

A detailed E&D *Action Plan* was part of the 2018 Athena Swan presentation and was considered suitably SMART (Specific, Measurable, Achievable, Relevant and Time-bound). Included is a commitment to increase the number of female research students to 5% above the national average. Moreover, whilst the proportion of female professors of 24% (13M,4F) is above average, we strive to increase this to over 30%. We aim to 'future proof' the School's position by focusing on recruitment opportunities at lecturer-level and the long-term flow from undergraduates to research students to researchers. The School is implementing this action plan to be in a position to apply for an Athena Swan Silver Award in 2022 with regular School surveys and data analyses to monitor progress.

School management gives a high priority to *health and well-being*. For instance, adjustable height desks have been provided for several staff with back problems and a staff member with an arm injury was allocated personal secretarial support to alleviate writing difficulties.

Not least, the School prides itself on providing a welcoming, collegial atmosphere, something often commented on by visitors. Staff and research students interact socially as well as academically, for example (during normal times) staff regularly bring cakes to coffee breaks and there is a twice-weekly lunchtime football game for School members.

**REF submission**

The School has followed the *University Code of Practice* in selecting outputs, with potential submissions graded by internal reviewers with grading moderated by external assessors to identify the best papers. The School's REF panel underwent REF-specific training on Diversity, Unconscious Bias and GDPR. The panel held interviews with all researchers to consider special circumstances and potential EDI issues. The University REF E&D Review Group, a body independent of the output selection process, made decisions on independent researchers and determined output reductions in the light of staff circumstances. Of our submitted outputs, 27% have a female Category A or B staff member as an author and one of our four impact case studies was led by a woman.

## Section 3. Income, infrastructure and facilities

### Income and research funding

The School's breadth of research allows access to a wide range of funding including from Research Councils, Scottish, UK and foreign Government bodies and NGOs, private companies, charities and international commissions. Since 2014 the School has received £14.25M grant and contract income across all research groups with an average annual income of £49.3k per FTE, plus £1.59M income in kind. The School's own funds supplement each research group with a budget for travel, conferences, visitors and equipment.

### Strategy for generating income

The School proactively explores income possibilities and identifies opportunities for diversifying and increasing funding. We raise awareness and disseminate information amongst staff about funding possibilities, identifying sources particularly appropriate for our specialisms. The Directors of Research and Impact circulate information, including monthly lists of subject specific calls and funding, and a University Business Development Manager visits the School monthly to discuss funding opportunities and provide guidance on applications. We make full use of the University Research Funding Support teams (ILES, 4.1) who provide support from writing applications through to managing awards, as well as negotiating with stakeholders and overseeing contracts.

Staff are incentivised to obtain funding by being allocated a proportion of the overheads and with funding having significant weight in the workload model and in promotions. Earlier career staff are encouraged and mentored by senior staff in making grant applications.

In particular we seek funding from calls in priority areas suited to our expertise, e.g. NERC Climate Resilience (cloud and climate modelling), EPSRC Mathematics in Healthcare (tumour growth modelling), BBSRC Data Driven Biology (Statistical Medicine). Our centres CREEM, CIRCA, SOI and Mackenzie attract considerable funding for interdisciplinary and impactful projects, increasingly so in medicine with our new research groups. We continue to identify potential collaborating institutions worldwide suitable for networking grants.

We capitalise on our network of local, government, NGO and industrial contacts to increase *consultancy and contract income*, particularly through CREEM, in areas such as space weather, environmental applications of fluid dynamics, and medicine (e.g. CREEM has attracted consultancy worth £5.1M since 2014 with additional income from training workshops).

We work with the University Development Team and Global Office to share our activities and successes with alumni and business leaders to raise money for targeted projects.

We will apply for *Centres for Doctoral Training* in the next round, alongside partners in the Schools of Computer Science, Physics and Astronomy, Biology and Medicine.

We will monitor national and international developments to be ready to take advantage of the recently announced £300M EPSRC funding for UK Mathematics and changes in funding opportunities.

### Funding obtained

*Major long term funding* includes:

- The *Solar Group* has been supported by an *STFC Rolling Grant* since 1986, renewed for £1.34M for 2016-19 and for £1.03M for 2019-22.
- *Archontis* leads an *ERC Synergy Grant* from 2019-25 with Paris-Saclay, Oslo and the Max Plank Institute of €11.2M with €2.2M coming to St Andrews for *The Whole Sun Project.*
- *De Moortel* has an *ERC Consolidator Grant* £2M for Multi-scale coronal heating, 2015-20.
- *Thomas* has been awarded about £4M since 2014 in contracts largely from *US Department of Navy* and *Office of Naval Research* and *Sea Mammal Research* for projects involving impact on sealife.
- *Venkataraman*° was a partner in a £3.3M *EU Research Training Network* grant with RWTH Aachen on Integrated component cycling in epithelial cell motility.
- *Mathematical Biology* are partners in two collaborative grants: EPSRC £2M (with Glasgow, Heriot-Watt and Sheffield), and MRC £1.25M (with Dundee).
- *CIRCA* has €900k of a 16 site €7.6M *EC Horizon 2020* project for the *Open Digital Research Environment Toolkit for the Advancement of Mathematics*.
- *Income in kind* of £1.59M for DiRAC computing and the ALMA radio telescope.

We will obtain continuations or replacements of major funding in these areas to ensure their sustainability.

*Further exemplars of grants* across our research areas:

- *Archontis,* Royal Society £299k, Discovering the nature of outstanding aspects of solar activity.
- *Cairns*,* EPSRC £760k (with Strathclyde) and £4.5M (with Glasgow, Strathclyde and Lancaster) for work on plasmas.
- *Scott,* NERC £280k, Structure and transport properties of jets in the atmosphere and oceans.
- *Dritschel,* EPSRC £474k, Diabatic evolution of clouds.
- *K.Falconer and Fraser,* 4 grants totalling £950k from EPSRC and Leverhulme, projects on fractal geometry.
- *Bleak and Cameron,* EPSRC £524k, Linking combinatorics (automata), group theory (Thompson groups and relatives) and dynamics (shift automorphisms).
- *Buckland, Borchers and Illian*°, EPSRC £320k, Modelling spatial distribution and change from wildlife survey data.
- *Lynch,* MRC £700k (Medicine and Biology Schools), Holistic approach to unravel antibacterial resistance in East Africa.
- 5 recent grants totalling £152k from NHS-Scotland Rapid Response Programme and Scottish Government Restarting Research Fund for projects relating to COVID-19.
- *I.Falconer, Hood and Robertson*, £77k in grants from many sources to support History of Mathematics projects and workshops.
- Over 45 *small grants* totalling over £100k from LMS, EdinMS, RAS, RS, etc. are particularly beneficial for visits, visitors and conferences.

**Infrastructure and Facilities**

**School organisation**

The School is managed by a Head of School in consultation with the School Management Group, which includes a Deputy Head, Directors of Research, Postgraduate Studies, Teaching and EDI, Heads of Pure, Applied and Statistics Divisions and School Manager. Several committees are particularly relevant to research and impact: Research, Postgraduate and

Equipment Committees address matters spanning the research groups, allocate School resources, and link to University and external bodies. The Ethics Committee monitors projects where there may be ethical concerns.

**Communication**

Mechanisms for keeping staff informed on School and University matters and ensuring staff can input to management include twice yearly formal Staff Councils, a monthly informal 'lunch and chat' meeting, circulating committee minutes, a monthly School Newsletter, the School Handbook, and a twitter feed @StA_Maths_Stats. The Head of School traditionally operates an 'open door' policy to be easily accessible.

**Buildings**

Staff and postgraduate students are housed in two buildings: the *Mathematical Institute* and the nearby *Observatory Building* which houses CREEM and most of Statistics. Both have space to facilitate interaction and foster collaboration. Offices are provided for all staff, postdocs, research students, visitors and active retired staff. Both buildings have refurbished lecture and seminar rooms with multimedia facilities, computer laboratories, video conference suites and the all-important common rooms. An ongoing programme has refurbished about one third of offices since 2016. Both buildings are full to capacity and the University has approved a £20M, 600sq.m. *custom-designed building* in the North Haugh science area to house all the School to bring together cognate research currently in two buildings and to allow further expansion. Completion was due in 2024, but will be delayed following COVID-19.

**Computing facilities**

The University *High Performance Computing Board* steers the University's HPC strategy to ensure continuous funding and regular upgrading for HPC resources. Solar, Vortex and Mathematical Biology groups are major users of the 3520 core *Kennedy* cluster. Statistical Medicine uses the Bioinformatics 320 core cluster STABU and CREEM has 4 dedicated workstations totalling 140 cores.

The Solar Group leads the UKMHD Consortium which coordinates UK community access for MHD researchers to the STFC DiRAC supercomputer. The Vortex Group regularly use the UKRC facility ARCHER.

All staff and PhD students have up to date desktop/laptop computers as standard and specialist software as required. Safe arrangements were made to maintain computers used at home during COVID-19, with tablets and other equipment dispatched where required, supported by our computer officers and central IT services.

**Library resources**

The University has a large refurbished Main Library, complemented by the Maths/Physics Library adjacent to the Mathematical Institute. There are 2000+ e-journals in mathematics, statistics and physics, providing direct access from office or home to almost all relevant research journals and to e-books and databases; a reciprocal arrangement with 20 other university libraries further extends access. CIRCA and CREEM have their own specialist resource areas. The School's library budget is sufficient to purchase research books where needed. Under the University Library 10 year Strategic Plan the School will benefit in particular from the focus on provision of material in a digital, searchable, form, together with support for data intensive and

open access research. The library has a superb collection of historic mathematics books and manuscripts, including the James Gregory, J.D. Forbes and D'Arcy Thompson archives, a major resource for history of mathematics and for regular public displays.

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

**Collaboration**

Collaboration is universal in the School's research: of the 1400+ papers published by members of the School since 2014 over 95% are multi-authored, 70% have collaborators from outside the School and 50% have collaborators from abroad. (Cameron alone has had 60 different collaborators since 2014 including 47 new co-authors.) Our research groups' and centres' networks facilitate collaborations locally and globally. Many School members are involved in funded international or national networks. However, many collaborations are initially opportunistic resulting from interactions during conferences or visits, often leading to grant funding.

Mechanisms to support collaborative research include: research leave arrangements (ILES, 2.3), teaching cover to enable short visits, School funds available for visits, support for internet networking including video conference suites, research facilities for visitors and an annual research day to showcase work and identify potential collaborations.

Much research is at the same time collaborative, interdisciplinary and impactful and *many exemplars below would fit under multiple headings*.

**Exemplars of collaboration**

- Considerable funded *network* participation: *UKMHD Consortium* (lead), *NASA (e.g. MUSE, SOLARIS)* and *ESA mission (e.g. Solar Orbiter) networks,* Solar *ERC Synergy Grant* (with Paris-Saclay, Oslo and Max Plank Institute), LMS Scheme 3 Networks *One Day Ergodic Theory Meetings, North British Semigroups and Applications, North British Geometric Group Theory*, Scottish Network *Groups, Generalisations and Applications*.
- St Andrews is lead partner in the *National Centre for Statistical Ecology* with 7 UK universities and 5 partner institutes, providing workshops, video-linked seminars and the main biennial statistical ecology conference.
- 'Research in pairs/groups' grants: LMS (*Fraser, Kempton, I.Falconer*), ICMS (*Todd*), Schrödinger Institute (*Todd*), Oberwolfach (*Bleak, Fraser*).
- *Ruskuc* EPSRC collaboration grants: £35k with Western Sydney University on Diagram monoids, £97k with Heriot-Watt and York on semigroups.
- *Todd* A transdisciplinary project with 8 collaborators culminating in a definitive 312 page book *Extremes and recurrence in dynamical systems*.
- *Borchers* LMS scheme *Mentoring African Research in Mathematics*: Methods for modelling bird distribution in South Africa, with University of Cape Town researchers.
- *De Moortel* Frequent collaborative visits as Affiliate Scientist at the High Altitude Observatory (Boulder, Colorado), and adjunct professor at the Rosseland Centre for Solar Physics (Oslo).
- *Vortex group* Collaborations with the Met Office include two CASE studentships on cloud and climate modelling.
- *Lynch* Collaboration with STORM Therapeutics (Cambridge) for statistical analysis of product data.

**Further exemplars of impact and engagement with users**

Projects other than the submitted case studies include:

- *CIRCA* has developed software for industrial partners, including Spatial Flow Ltd., SimpleHelp Ltd., and NHS Lothian. CIRCA maintains the Constraint Modelling Pipeline providing a world-class platform for automatically modelling and solving complex combinatorial optimisation problems, from domains such as planning, scheduling, configuration and design.
- *Carr°* (whilst on impact leave) and *Dritschel* undertook an EPSRC IAA funded project to model the dynamics of oxygen depletion in the Clyde estuary and improve water quality, which is being adopted by the Scottish Environmental Protection Agency.
- *Bailey* has devised new designs for first-in-human dose-escalation trials for new drugs which reduce the estimator variances in earlier methods by a factor of three. Several drug companies are investigating applying to the European Medicines Agency for approval to use the method.
- *Antolin* and *De Moortel* are Co-Is on a NASA Lockheed Martin satellite project, providing model-based predictions to determine instrument specifications.
- Mackay had a £21k STFC IAA collaboration with the Met Office to improve space weather predictions, a case study featured in the UKRI booklet 'From Knowledge to Impact: STFC Impact Acceleration Account'
- The *Mathematical Biology Group* have engaged with NHS Scotland and healthcare organisations to pilot three projects on mathematical modelling leading to improved patient care on tuberculosis, breast cancer invasion, and radiotherapy and chemotherapy treatment.
- *Borchers* and *Menze* Collaborations with HiDef Aerial Survey Ltd. on developing methods for aerial survey.

**Exemplars of interdisciplinary research**

- *CIRCA* undertakes wide-ranging computer assisted mathematical research, developing new techniques for computation in abstract algebra. This feeds into the open access algebra software system GAP (*Groups, Algorithms, Programs*) providing a vast range of algorithmic mathematical tools used across research, industry and education, with St Andrews one of five international coordinating centres. Recent input from St Andrews includes a comprehensive software package on semigroups and a data library of primitive permutation groups.
- *CREEM* has many interdisciplinary collaborations with Biology, particularly on ecology and the environment, e.g. *Thomas* and *Harris* (Biology) a recent £799k grant to study the effects of multiple stressors on marine mammals. See also Section 1 'Statistical Ecology' and impact case studies.
- *Fraser* was the first pure mathematician selected for the Scottish Crucible in its 10-year history (an RSE development scheme for early career researchers), leading to funded interdisciplinary projects on multifractal analysis to determine the health of Scotland's maerl (algae) beds, and on the dynamics of debate.
- *Chaplain, Kursawe and Sfakianakis* have ongoing interdisciplinary collaborations with cardiovascular surgeons, oncologists and cell biologists.

*MapMySmoke*, a phone app to help users monitor and quit smoking, was developed with Computer Science, Medicine and two external collaborators.

**Sharing research expertise**

Much of our teaching is research-driven to inspire and prepare students for postgraduate work or industry, with advanced undergraduate/MSc modules covering all research areas. Since 2018 we have set up MScs in *Statistical Ecology*, *Digital Health* (with Medicine) and (from 2021) *Mathematical Biology*, as well as maintaining longer-standing MScs including *Applied Statistics and Datamining* and *Data-Intensive Analysis* (with Computer Science). We contribute to

interdisciplinary MScs run by the University Graduate Centre on *Conservation Science* and *International Development Practice*. The School's *Summer Research Programme* helps good undergraduates experience research with published papers often resulting.

Recent books aimed at practitioners and/or researchers include Borchers, Buckland et al. *Modelling Population Dynamics*; Buckland et al. *Distance Sampling: Methods and Applications*; Cameron *Notes on Counting: An Introduction to Enumerative Combinatorics*; K.Falconer *Fractal Geometry* (3rd ed.); Fraser *Assouad Dimension in Fractal Geometry*; Roberts* *MHD Waves in the Solar Atmosphere*.

St Andrews has authored and continues to develop openly available software packages: *Hydra* for studying fluid dynamics of the atmosphere and oceans; *Distance* for estimating wildlife abundance; *GAP (Groups, Algorithms, Programs)* algebra software. St Andrews hosts regular user workshops for *Distance* and *GAP* and free online workshops (developed under a University IAA), for example the *Distance* workshops have attracted over 800 people from 67 countries.

Through its commitment to the history of mathematics, including the MacTutor website (8 million hits each month) and its historic library collections, St Andrews makes a unique contribution to the research base and the common good of the discipline.

**Outreach and public engagement**

Our research areas (e.g. wildlife statistics, cancer research, fractals, history of mathematics) are ideally suited to outreach and public engagement. Our *Outreach Team* coordinates presentations to young and adult audiences on a wide range of research related topics. CREEM has its own team, with its leader part-funded specifically for outreach and engagement, which won a University award for excellence. Many staff give lectures or displays at public events including British Science Festival, Edinburgh Science Festival, Gresham College, Maths Week Scotland, annual local Science Festivals, and in many schools. Four female staff regularly participate in multi-school regional meetings to enthuse pupils, particularly girls, into mathematics. Staff have been panellists on radio programmes, especially history of mathematics topics, including six Radio 4 *In Our Time* programmes and *The Curious Cases of Rutherford and Fry*, and have been consultants for many radio and TV programmes. For visitors we have designed a walking tour of St Andrews taking in 30 locations with mathematical or scientific connections.

**Indicators of wider influence**

**Prizes and distinctions**

The School has gained prizes across its research areas:

RAS Chapman Medal: *Hood*, 2015
RAS Geophysics Group Achievement Award: *UKMHD Consortium Team led by Hood,* 2015
RSE Lord Kelvin Medal: *Hood*, 2020
European Geophysical Union - Hannes Alfvén Medal: *Priest**, 2017
Solar Physics Division of European Physical Society - Senior Prize: *Priest**, 2020
Leon Davies Medal of Astronomical Society of Glasgow: *Parnell*, 2018
European Society for Mathematical and Theoretical Biology - Reinhart Heinrich Prize: *Kursawe*, 2018
Lee Segel Prize for best paper in Bulletin of Mathematical Biology: *Chaplain & coauthors*, 2014
RSS Guy Medal in Gold: *Buckland*, 2019

LMS Hirst Prize: *O'Connor* & Robertson**, 2015
LMS Senior Whitehead Prize: *Cameron*, 2017
LMS Shephard Prize: *K.Falconer*, 2020
Elected FRSE: *De Moortel*, 2015, *Bailey*, 2015, *Cameron*, 2018, *Borchers* 2020; 9 current (+6 retired) staff are FRSE and *Priest** is FRS
Elected to RSE Young Academy: *Fraser*, 2018, *Bowness*, 2018
Elected Fellow of the Society of Mathematical Biology: *Chaplain*, 2017

**Personal fellowships**

6 established staff have held personal fellowships:

Royal Society University Fellowship: *Archontis*
Royal Society Wolfson Fellowship: *De Moortel*
STFC Ernest Rutherford Fellowship: *Antolin*
Leverhulme: *Scott, Fraser, Borchers,*

**External service**

Staff support the discipline in many roles including:

**(a) Funding panels**

UKRI Future Leaders Fellowships: *De Moortel*
EPSRC Grants Panels: *Bailey, Bleak, Fraser, Ruskuc*
EPSRC Peer Review College: *Bailey*, *Chaplain, K.Falconer, Reinaud, Ruskuc*
STFC Ernest Rutherford Fellowships: *Archontis, De Moortel*
STFC Astronomy Grants Panel (Solar Studies): *Mackay*
STFC Solar System Advisory Panel: *De Moortel* (Chair), *Hood*
NASA Grants Panel for Heliophysics: *De Moortel*, *Hood*
Cancer Research UK Multidisciplinary Expert Review Panel: *Chaplain*
Academy of Finland - Mathematics Panel: *K.Falconer*
Polish National Science Centre Expert Panel: *De Moortel* (Chair)

**(b) Other external roles**

EPSRC/KTN Review panel for Bond Review of Knowledge Exchange in Mathematical Sciences: *Bleak*
EPSRC Mathematical Sciences Review Panel: *De Moortel*
REF 2021 Mathematical Sciences Panel: *Chaplain*, *Fraser*
INI Scientific Steering Committee: *Chaplain*
ICMS: *De Moortel* (Board), *Chaplain* (Programme Committee)
LMS: *Chaplain* (Council), *Cameron* (Prizes Cttee.), *K.Falconer* (Chair, Nominating Cttee.), *I.Falconer* (Library Cttee.), *Fraser* (International Affairs Cttee.), *Roney-Dougal* (Development Cttee.), *Todd* (Lectures & Meetings Cttee.),
Edinburgh MS: *De Moortel* (President), *Huczynska* (Chair, Education Cttee.), *Carr°, Quick, Sfakianakis* (Council)
BMC Steering Committee: *Huczynska*, *Todd*
British Science Festival - Mathematical Sciences Section: *Roney-Dougal* (President)
European Solar Physics Division: *De Moortel* (Secretary)
ESA VOYAGE2050 Topical Team: *De Moortel*
ESA Solar Orbiter planning group: *Mackay*

NASA Working Group on Magnetic Flux Ropes: *Mackay*
STFC Post Launch Support Cttee.: *De Moortel*
STFC Skills and Engagement Advisory Board: *De Moortel*
RAMP Leader of Task Team on within-host dynamics of COVID-19: *Chaplain*
British Combinatorial Committee: *Cameron* (Chair), *Huczynska*
RSS Working Group on guidelines for EMA first-in-human clinical trials: *Bailey*
British and Irish Region of International Biometric Society: *Lynch* (Council)
Fisher Memorial Trust: *Bailey* (Trustee)
Scientific Advisory Board: Global Snow Leopard Ecosystem Protection Program PAWS Survey Initiative**:** *Borchers* (Chair)
US NAS panel on impacts of anthropogenic stressors on marine mammals: *Thomas*
International Commission for History of Mathematics: *I.Falconer* (IMU-elected rep.)
British Society for History of Mathematics: *I.Falconer* (Council)
James Clerk Maxwell Foundation: *I.Falconer* (Trustee)

**Conference organisation**

School members are energetic in organising conferences, research programmes and workshops in St Andrews and elsewhere. Most are funded by substantial grants with organisers writing funding bids. Such funding is paid directly to the host institution so for external meetings does not feature in our research income.

*Major conferences at St Andrews:*
British Applied Mathematical Colloquium, 2018
British Mathematical Colloquium, 2018
International Statistical Ecology Conference, 2018
British Colloquium for Theoretical Computer Science, 2017 (CIRCA)
Big Data and Discrete Mathematics, 2016
Young Researchers in Mathematics, 2016
International Conference on Geophysical and Astrophysical Vortex Interactions, 2019

Over 25 other specialist workshops and conferences have been organized in St Andrews since 2014. Several in 2020 were postponed and/or took place online.

'Groups St Andrews', the foremost international group theory meeting, is organised by St Andrews staff every four years since 1985, including at Birmingham (2017) and Newcastle (postponed to 2022).

*Long-term research programmes organised:*
Mittag-Leffler Institute: Fractal Geometry and Dynamics (*K.Falconer*, co-principal organiser, Sep-Dec 2017)
Mittag-Leffler Institute: Mathematical Biology (*Chaplain*, co-organiser, Sep-Dec 2018)
Isaac Newton Institute: Groups, Representations and Applications (*Roney-Dougal*, principal organiser, Jan-Jun 2020)

*External conferences organised include:*
Design and Analysis of Experiments in Healthcare (INI, *Bailey*, co-organiser)
Industrial Strategy Challenge Fund and UK Mathematical Sciences (ICMS, *Bleak*, co-organiser)
Computational and multiscale mathematical modelling of cancer growth and spread (ICMS, *Chaplain*, organiser)
Thermodynamic Formalism in Dynamical Systems (ICMS, *Todd*, co-organiser)

New Perspectives on State-Space Models (Banff International Research Station, *Thomas*, co-organiser)
Extreme Value Theory and Laws of Rare Events (CIRM, *Todd*, co-organiser)
Permutation Groups and Transformation Semigroups (LMS-EPSRC Durham Symposium, *Cameron* & *Mitchell*, co-organisers)
Biennial History and Teaching of Mathematics Conference, Hungary (*Robertson** Chair since 2014)

*Special Conferences:*
K.Falconer 60th birthday (Paris-Saclay)
Cameron 70th birthday (Lisbon)

**Editorial**

Since 2014 staff have been on over 26 editorial boards including: Advances in Mathematics, Australian J. Combinatorics (*Cameron,* Hon. Ed in Chief), J. Agricultural, Biological, Environmental Statistics (*Buckland*, Ed. in Chief), Biometrics, Fluid Dynamics, Historia Mathematica, J. Atmospheric Science, J. RSS Ser.C, J. Theoretical Biology (*Chaplain*, Co-Ed. in Chief), LMS Lecture Notes, Proc. Edinburgh Mathematical Soc. (*Quick,* Board convener), Royal Society Open Science (*Chaplain*, Maths Subject Ed.), Royal Society Transactions A, Solar Physics.

All staff regularly referee journal papers, grant proposals and book proposals. *Todd* was *Reviewer of the Year 2017* for *Nonlinearity*, *Threlfell* (postdoc) was *Most Valued Reviewer 2018* by *New Astronomy*, and *Cairns** was recognised for *Extraordinary Service in Reviewing 2017* by *Physics of Plasmas*.

**Invited lectures**

Hundreds of plenary and invited lectures at international and national conferences, including:
*Priest**: Birkeland Lecture (Norwegian Academy of Science and Letters)
*De Moortel:* Lord Kelvin Award Lecture (British Science Festival), Charlotte Scott Lecture (Lincoln)
*King°, Roney-Dougal:* LMS Popular Lectures
*Cameron:* John Venn Lecture (Hull)
*Parnell:* Leon Davies Lecture (Glasgow)
*K.Falconer:* Lewis Fry Richardson Lecture (York)
*Fraser:* Opening lecture, *Fractals and Stochastics 6* (Bad Herrrenalb, Germany)
*Cameron:* Opening lecture, *From permutation groups to model theory* (ICMS)
*Chaplain:* Plenary, *Annual Meeting of Society of Mathematical Biology* (Utah)
*Borchers:* Plenary, *International Statistical Ecology Conf.* (Sydney-online)
*Bailey:* Opening lecture, *Model-Oriented Data Analysis and Optimal Design* (Slovak Acad. Sci.)