

Institution: University of East Anglia

Unit of Assessment: 10

1. Unit context and structure, research and impact strategy

1.1 Overview

The **School of Mathematics** is one of six schools in the Faculty of Science at the University of East Anglia (UEA). The University lies at the heart of the **Norwich Research Park (NRP)**, a unique collaboration of over 3,000 scientists in six institutes that also includes the **Quadram Institute** for food and health research, and the world-leading **John Innes Centre (JIC)** for plant science and microbiology.

The Unit totals **20 permanent academic staff** with 19 in the School of Mathematics and one in Engineering, which currently exists as a subgroup within Mathematics and which will launch as a School in 2021. Since REF2014 we have generated **£4.2M in research income**, hosted 21 Research Associates (including one Leverhulme Early Career Fellow, one Royal Society Newton Fellow, and one UKRI Future Leaders Fellow), and graduated 36 PhD students. We have published over **240 peer-reviewed research articles** in leading international journals. Since 2014 we have made one new appointment and eight promotions (one to a Chair, and seven to Associate Professor or Senior Lecturer).

Research in the Unit is organised into groups: **Algebra, Fluid-Structure Interaction, Industrial Mathematics, Logic, Mathematical Biology, and Quantum Fluids**. A distinguishing feature of the School is a strongly collegiate atmosphere that engenders a highly interactive research culture with joint seminars, study groups, and co-supervision of PhD students often leading to joint publications. Our research vision is outward-facing, and it encompasses numerous initiatives, projects, and synergies across the NRP and with our many national and international partners.

1.2 Research structure

Our research groups are listed in Box 1. The intersections between group members illustrate our strong tradition of working together in a supportive research community.

Box 1. Research Groupings

Algebra (Grant, Gray, Lyle, Miemietz, Siemons, Stevens)

Representation Theory, Group/Semigroup Theory, Algebraic Combinatorics

We study the representation theory of algebras using combinatorial (*Lyle, Siemons*) and homological techniques (*Grant, Miemietz*), and explore links to number theory (*Stevens*), category theory (*Grant, Miemietz*) and beyond. We are world-leaders in higher representation theory: *Miemietz* is co-creator of the burgeoning theory of 2-representations (EPSRC-funded); and *Grant* is breaking new ground in the study of higher preprojective and cluster algebras (e.g. *Compos. Math.*, 2020). *Stevens* is a world-leading expert in the theory of types for p-adic groups, and has used explicit representation-theoretic constructions to give a description of wild functoriality in the local Langlands program (*Inventiones Math.*, 2020). *Gray* works on co-growth and amenability in semigroups: in ground-breaking EPSRC-funded work he has recently proved the undecidability of the word problem for one-relator inverse monoids (*Inventiones Math.*, 2020).

Fluid-Structure Interaction (Blyth, Cooker, Korobkin, Părău, Purvis)*Hydroelasticity, impacts, sloshing*

We work on a broad range of problems including violent wave impact on coastal defences (Cooke), wave interactions with sea ice (Părău), deformable aerofoils (Blyth, Părău), and droplet impact onto elastic surfaces or porous surfaces (Purvis). Korobkin is a world leader in wave interaction with offshore structures, ship slamming, and sloshing in liquid natural gas tanks (supported by EU funding and the Office for Naval Research). A research highlight is Korobkin's work developing an analytical coupled model of lifting an elastic body from a water surface (*J. Fluid Mechanics*, 2019), and his confirmation of those predictions by experiments (Box 5).

Industrial Mathematics (Atkin, Blyth, Hammerton, Korobkin, Purvis, Whittaker)*Droplet impact and wing icing, sonic booms, boundary layers, multilayer flows.*

Our work has applications in the aerospace industry and in the chemical and manufacturing industries. We work on boundary-layer transition and low-order modelling for the design of fuel-efficient aircraft (Atkin), and landmine detection by radar (Hammerton). Blyth mentored Leverhulme Early Career Fellow Kalogirou's work on surfactant dynamics in multilayer flows. Purvis' work with AWE and the Smith Institute demonstrated how the failure of numerical models to predict detonation in reactive materials can result from small-scale localised shear banding acting as a hot-spot mechanism (*Proc. Roy. Soc. A*, 2019).

Logic (Asperó, Džamonja, Gray, Karagila, Kirby)*Set Theory, Model Theory*

We work on combinatorial aspects of set theory (Asperó, Džamonja) and on set theory without the Axiom of Choice (UKRI Future Leaders Fellow Karagila). Asperó, Džamonja, and Karagila are world experts in forcing techniques, including the development of a framework at the successor of a singular cardinal (Džamonja, *Trans. Amer. Math. Soc.*, 2017), symmetric forcing with side conditions (Asperó, *Trans. Amer. Math. Soc.*, 2015), and an iteration framework for symmetric extensions (Karagila, *J. Symb. Logic*, 2019). Kirby studies the connections between model theory and number theory and has shown that Zilber's quasiminimality conjecture can in principle be proved without first needing to prove the very difficult Schanuel conjecture (*Algebra and Number Theory*, 2018). We also study other areas of model theory (Džamonja, Kirby), and Gray's work on decidability problems is at the interface between algebra and logic.

Mathematical Biology (Blyth, Cooker, Purvis, Whittaker)*Flow in collapsible tubes, digestion and plant biology*

We work in close collaboration with NRP partners, notably the Quadram Institute and JIC. Research includes digestion in the gut (Blyth, Cooker, Purvis), self-excited oscillations in blood vessels (Whittaker), and problems in plant biology (Blyth). Highlights from this area of our interdisciplinary work are given in Box 6.

Quantum fluids (Proment, Salman)*Vortex dynamics, turbulence in superfluids*

We work on vortex dynamics, turbulence of ultracold Bose gases and far-from-equilibrium phenomena in superfluid systems. Salman received a Leverhulme Research Fellowship to focus on his work on the dynamics of electron bubbles on quantised vortices in superfluid helium-4. Proment's work on vortex reconnections in superfluids was recognised by the

35th APS François Frenkiel Award in 2018; and a cover page article in *Physics Review Letters* in 2020. This group also includes researchers from a growing Physics presence at UEA, and has benefitted from the recent appointments of Borgh (2016, submitted to UoA8) who works in spinor Bose-Einstein condensates, and Lander (2020, submitted to UoA8) who works on neutron stars and magnetohydrodynamics.

1.3 Research strategy and progress against REF2014 plans

Our research strategy is developed by the School's Executive Committee chaired by the Head of School (HoS, *Stevens*) and including the Director of Research (DoR, *Blyth*), who is a member of the Science Faculty Research Executive. The DoR assumes responsibility for implementing strategic decisions, managing the internal peer review of research grant applications, and conducting annual review meetings with staff (see section 2.1). They are responsible for two-way communication on research matters with the Faculty of Science, who lead the development of the Science-wide research strategy through its Pro-Vice Chancellor, its Associate Dean for Research and its Executive and Research Committees.

Although the University has focused new appointments since 2014 within the Engineering subgroup, Mathematics has benefitted from the new research synergies these have brought. A **Research Strategy Review** in September 2015 initiated the implementation of a new strategic plan. Recommendations included promoting new research fellowship applications, and planning for a Centre for Doctoral Training grant application. These two aspirations have been achieved: we've seen a step-change in our research fellowships; and we have initiated and contributed to several CDT and DTP bids with varying outcomes (see section 2.2).

The principal aims that we outlined as part of our future strategy in our statement for REF2014 are summarised in Box 2. Our main achievements since REF2014 are summarised in Box 3.

Box 2. Key goals from REF 2014

- To maintain our strength in Fluid-Structure Interaction.
- To support the development of Mathematical Physics.
- To grow our relationship with the JIC.
- To pursue our thriving international collaborations in Algebra.
- To recruit another member of faculty in Number Theory.
- To support staff to allow them to develop their research and careers.

Box 3. Achievements since REF2014

- Fluid-Structure Interaction: A key strength identified in REF2014, we've generated over 45 outputs, £1.1M in grant income, £15K in consultancy income, nine completed PhDs, and two Impact Case Studies (ICS).
- Quantum Fluids: Our specialism in Mathematical Physics has been supported through new appointments submitted to UoA8 and the vibrancy that has come with new collaborations and research strands.
- Research synergy with JIC: This has produced two joint outputs (*Blyth & Morris*, *Frontiers in Plant Sci*, 2019; *Morris & Blyth*, *J. Exp. Bot.*, 2019), a book chapter (in 'Mathematical Modelling in Plant Biology', Springer, 2018) and a 3-month research visit by Blyth to Morris' group during study leave in 2019.

- International collaborations in Algebra: We continue to strengthen our international links, evidenced by the six group members producing 41 papers with 30 international co-authors from 13 countries, the majority in leading journals in the field.
- New appointment: The departure of a number of staff working in Number Theory led to a change in our plans. The appointment of *Grant* in 2014 strengthened our Representation Theory profile.
- We have supported staff in achieving their research goals and career aspirations. This is exemplified by promotions (*Părau* to a Chair; *Kirby* and *Miemietz* to Associate Professor; *Gray* to Senior Lecturer and then to Associate Professor; and *Asperó*, *Proment* and *Salman* to Senior Lecturer; Leverhulme Fellow Kalogirou was promoted to grade 8) and by study leaves: 17 applications made by staff since 2014 for six-month periods of leave were approved at Faculty level.

1.4 Impact Strategy

The Director of Innovation (DoI, *Proment*) coordinates our impact strategy and ensures that impact from our research is maximised. The DoI manages exchanges between the School and regional, national, and international **business partners**. Staff are asked to comment on their impact activity at the annual Research Activity Planning (RAP) meeting. In this way new impact streams are identified and fostered: the DoI offers guidance and signposts resources (including dedicated UEA funding) to ensure that strong ideas are given the support they need to develop.

Candidate Impact Case Studies (ICS) are considered at an early stage. A thorough annual review process at School, Faculty and University-level provides a gateway to accessing dedicated funding from UEA's Higher Education Innovation Fund (HEIF) allocation. This is allocated to best fit the School's and UEA's impact development agenda (our HEIF income is summarised in section 3.1).

Our two ICS showcase our ability to deliver impact from research through a targeted funding strategy. 'Danger on the seas: assessing the risk to ships from wave slamming events', led by *Korobkin*, illustrates how HEIF funds were used to support impact creation. Together with 'Making a splash: the effect of droplet impacts on aircraft icing and air safety', led by *Purvis*, we demonstrate how our expertise in **fluid-structure interaction** has benefitted Bureau Veritas and Aerotex, two companies with a combined **annual turnover in excess of £5 billion**. Our technical advice has facilitated improved methodologies and predictive tools that are now used by these companies on a daily basis. These form part of a larger portfolio (comprising 15 embryonic ICS) that has been nurtured over the REF period, including, for example, *Mathematical Modelling of Scaling in Oscillating Water Column Wave Energy Devices* (*Cooker*), *Explosive Ignition Due to a Pinch* (*Purvis*), *Ocean-Climate Modelling* (D. Stevens, who is submitted to UoA7), *Filtering for Large Eddy Simulation* (*Ryan*), and *Teaching on Infinity* (*Džamonja*).

We also mention the interactions of one of our members with the **Heilbronn Institute**. For the calendar year 2018, Shaun Stevens was freed from his duties as HoS to go on secondment at the Heilbronn Institute, spending half his time contributing to their work in London and Bristol. Following on from this, he has continued with them as a consultant and, as the situation allows, he plans to increase this involvement with them over the coming years.

1.5 Future strategic goals for research and impact

Aligned with our mission to deliver world-leading research with a strong commitment to impact generation, our five-year plan comprises the objectives laid out in Box 4.

Box 4. Objectives

- To continue:
 - to support our staff in developing their research and careers, and to promote the best interests of our students.
 - grow our internationally excellent research activity and to seek new research collaborations.
 - to strongly promote interdisciplinary research.
 - to attract high calibre PhD students and Research Fellows.
- To re-establish our historic core strength in Number Theory.
- To target resource and support at key points of strength in our developing impact portfolio.
- To maintain our commitment to EDI and to apply for Athena Swan Silver status.

These objectives form part of a strategy that will enable us to continue to produce high impact research, and to win external financial support from UKRI and other national and international funding bodies and industry. To fulfil these goals, we will:

- create a new *Impact Working Group*, to be led by the DoI and the DoR, with a remit to identify and grow impact from our research and to leverage new opportunities with business and industry. Study leave will be used strategically to support impact creation.
- continue to seek and target PhD funding at the highest quality applicants. We will be hosting the *LMS Prospects in Mathematics* meeting in September 2021 which will help us to ensure that UEA is at the forefront of activity in national PhD recruitment. We will continue to use and create national and international networks to support current PhD students and to increase graduate training opportunities at UEA, through co-tutelles, potential CDTs and increased EPSRC DTP allocation (e.g. we have been awarded three studentships from the 2021 Additional Funding Programme for Mathematical Sciences).
- continue with our successful strategy for encouraging strong fellowship applications to the School.

We anticipate two future appointments from post releases frozen during the pandemic. Working to grow our student numbers will put us into a strong position to seek a third new appointment. Two posts will be targeted at Lecturer level in Number Theory: one to align with our Algebra and Logic groups (e.g. Number Theory with connections to Model Theory); and one seeking a researcher with interests in Cryptography and associated impacts (e.g. via GCHQ or private industry such as Google). A further post will be targeted at Associate Professor level, specifically at someone with a strong track record of impact-creation from applied mathematics, in order to capitalise on our core strengths and diversify our impact activities.

1.6 Approach to Interdisciplinary Research

Interdisciplinary research is strongly supported within the School and is aided by our proximity to key partners on the NRP. For example, *Părrău* and *Korobkin* were granted study leave in 2017 to run an interdisciplinary programme on sea ice phenomena at the Isaac Newton Institute (section 4.6); and *Blyth* was given financial support in 2020 to visit Prof. Ted Farmer in the Dept. Molecular Biology, University of Lausanne, Switzerland. Financial support is provided through School funds. We host interdisciplinary seminars and staff regularly participate in seminars across the NRP (e.g. the Tensor Lab group seminars in the School of Medicine). Our Quantum Fluids group has an interdisciplinary streak with outputs returned to the Mathematics, Physics and Chemistry panels. Prof. Morris, Head of the Computational and Systems Biology group at JIC, is an Honorary Professor in the School, is actively engaged in joint research with us, and contributes to our teaching. Exemplars of our success in interdisciplinary research are shown in Box 6.

1.7 Research integrity and an open research environment

We promote the open and free exchange of advice, expertise and ideas. Our UKRI Future Leaders Fellow *Karagila* has posted over 6100 answers to technical questions on the Mathematics Stack Exchange website. Staff conduct research according to the University's principles and Guidelines on Good Practice in Research (UEA is a signatory to the Concordat to Support Research Integrity). Our research outputs are all made widely accessible via the UEA Open Digital Repository and through Open Access Journals in line with UEA's institutional Open Access Policy.

2. People

The 20 staff included in the Unit make up 19.27 FTE and are all on indefinite contracts. The fractional FTE results from three members of staff having chosen to benefit from the University's part-time and flexible working package.

2.1 Staffing strategy and staff development

Our staffing strategy aims to sustain our thriving research environment through staff development and by recruiting internationally excellent new staff. Responsibility for the strategy rests with the School's Executive Committee, chaired by the HoS (Head of School), and includes the DoR (Director of Research) and DoI (Director of Innovation), who also sit on Faculty-level research committees. New appointments with research and teaching responsibilities (known as ATR posts) are aligned with the School's research priorities set by the Executive Committee.

Recruitment processes conform to the University's Equality, Diversity and Inclusion (EDI) regulations. Job adverts display the Athena SWAN logo, have an EDI page in the further particulars, and a positive action statement to encourage those with protected characteristics to apply. Recruitment panels must complete UEA's 'Recruitment and Selection training' which includes unconscious bias training. We benefit from the University's **relocation assistance** package for academic staff (and, since April 2019, for research staff) which covers removal costs up to the equivalent of one month's gross salary.

New staff appointments are made to maintain, broaden and strengthen our research profile. Successful applicants must have an **internationally excellent research profile** and have potential to undertake future senior leadership roles. New ATR appointments are made to indefinite contracts with a five-year probationary period. To free up research time for ATR staff, we strategically hire a small number of staff on teaching-only (ATS) contracts (currently roughly 8% of staff by FTE).

Since at least 1998 we have operated a **workload model** to balance staff time and to ringfence research time. We are moving across to a new Science Faculty model that allocates **30% of staff time to core research activities** (e.g. proposal writing, grant and output writing, and impact development) and that protects grant success by including all awarded Investigator time as workload. New early-career staff have a reduced load: teaching and administration occupy at most 0.3 FTE in year 1, 0.4 FTE in year 2, 0.55 in year 3, and 0.65 FTE in year 4. All new faculty receive £7.5K/year start-up funding for the first two years. School funds of roughly £18.5K/year for research travel are available for all staff to bid to: this is used strategically to support speculative research visits to/from UEA, dissemination via conferences, and attendance at workshops.

All new early-career staff have a School-based mentor. The mentor helps with the transition to UEA and offers research support: helping with grant proposals, potentially collaborating, and advising on research student supervision. The mentor also advises on career progression and promotion. Annual Research Activity Planning (RAP) meetings with the DoR and the HoS encourage **self-reflection and planning** and are compulsory for all ATR staff (optional for other researchers). Advice is offered and resources for research and impact activities are signposted.

Achievements and readiness for career advancement are praised. RAP data on outputs, grant activity and PhD supervision informs the School's **annual research review**, which feeds into Faculty-level strategy and maintains focus on research as a priority against other commitments. In addition there is an **annual appraisal**, compulsory for all staff, that covers all aspects of the academic role.

We reward staff for research and impact activity through the **promotions process** including via applications for salary increments. All staff are considered for promotion by the School Promotion Committee (whether they have applied or not) and the HoS makes appropriate recommendations to the Faculty Promotions Committee. We have implemented a number of actions to stimulate promotion applications, including a prompt in the annual appraisal checklist, and a *Demystifying Promotion* workshop.

The School encourages researchers to apply for **study leave** to give time to focus on research. ATR staff can apply for a six-month study leave every three years. Leave has been granted for 14 of our UoA members during this REF period (some more than once), with a total of 17 leave periods, representing a comparatively high uptake for UEA.

2.1.1 Contract Research Staff

We are committed to recruiting excellent research staff. We support the development of all research staff and nurture our early career researchers (ECRs). UEA's **Code of Practice** for the Management of Research Staff provides guidance to research staff and research managers and is informed by the **UK Concordat to Support the Career Development of Researchers**. We use indicative research job descriptions to ensure that Research Associate (RA) jobs are costed at the correct level on grant applications and that appointments are made on an appropriate salary grade to reflect the level of knowledge and expertise required in the role. With effect from April 2019 the University introduced relocation assistance for research staff as well as (from summer 2020) a **merit-based promotions process for RA staff** which accords with expectations under the revised Concordat for the Career Development of Research Staff. The Faculty funds any shortfall in funding for merit-based promotions and salary progression awards.

The DoR acts as the Research Staff Coordinator and is a direct point of contact between the research staff and the Faculty. The DoR offers advice and facilitates a dialogue between the research staff and the School's Executive Team, and signposts available advice and support from the University (e.g. the Researchers' Working Group) and the School. The DoR also offers individual advice on grant proposals (e.g. fellowship applications) and completes the final sign-off. A representative of the research staff sits on the School Board, which convenes once a semester.

Research staff must complete an annual appraisal with their line manager (they can request an alternative appraiser if they wish), are offered the opportunity for a RAP, and have the same opportunities for training as permanent staff.

We recognise that delivering research excellence depends on attracting and supporting high-achieving research staff. We welcome new research fellows and we **encourage and support fellowship applications** through mentoring from senior research leaders and help from administrative staff. Opportunities are advertised on the Science Faculty's Fellowships webpages and colleagues are encouraged to help identify strong candidates. School and Faculty-level sift processes are used for schemes demanding significant financial input (e.g. Leverhulme Early Career and UKRI's Future Leaders Fellowships). Successful fellows are carefully integrated into the School, assigned a mentor, and offered training and personal development. They can access further funding opportunities such as our early-career PhD studentship competition. Long-term (five year) fellows are considered for transition to a permanent contract at the end of their fellowship.

Since 2014 the unit has mentored **four successful fellowship applications** (a significant number given the size of the School) including Kalogirou (Leverhulme Early Career Researcher 2017-2019) and Soukup (Marie Curie Fellowship; he ultimately accepted a position outside of Mathematics). *Karagila* held a Newton International Fellowship with us (2018-2020) and was subsequently awarded a highly prestigious **UKRI Future Leaders Fellowship** (July 2020-). We have been successful with the EPSRC Doctoral Prize: in a Faculty-wide competition this was won by Mathematics candidates both times the scheme was run (in 2014, 2016), and both of these achieved further success, gaining a UKRI Future Leaders Fellowship and a Nottingham Research Fellowship respectively.

2.2 Research Students

A flourishing cohort of postgraduate research (PGR) students is fundamental to our research vitality. During this REF period we **awarded 36 doctoral degrees** compared with 33 in REF 2014. These students subsequently accepted posts in industry or other professional positions, or else continued in academia (18 took up postdoctoral posts in Mathematics or closely related areas, and seven accepted junior university positions).

Our students were supported by **funding** from EPSRC and NERC, including via an iCASE award and co-tutelle arrangements with overseas institutions. We attracted seven self-funded students. The Science Faculty funded nine studentships demonstrating its continued commitment to Mathematics. Science Faculty funding is also used strategically to help support new faculty in supervising PGR students

A rigorous annual **student recruitment** drive is overseen by our PGR Director (*Miemiętz*). Successful applicants are selected for their strong research potential and academic record, and their relevant skills/knowledge. The recruitment panels undergo EDI training to ensure a fair and transparent process, and are independent of the project supervisor.

New students attend an induction session, complete a Training Needs Analysis (TNA) and have a formal supervisory meeting to map out a **Training Pathway (TP)** and **Personal Development Plan**, and all of these are updated annually. Available training includes specialist skills (e.g. High Performance Computing), broader research skills (e.g. oral presentation), and life skills (e.g. leadership). All training adheres to national standards including the Roberts 'SET for Success' report, the Vitae Researcher Development Framework, and the expectations of RCUK.

A formal progress meeting takes place every four months and progress is further evaluated at an annual review meeting. A formal probationary review takes place after 8-10 months and we have a near perfect record of students meeting the progression requirements. This **careful scrutiny of students' progression** has led to a 100% completion rate for most of our cohorts (and never less than 80%) over the past decade. PGR students nearing the end of their PhD are encouraged to discuss their career options with their supervisors and to join careers workshops (run by Careers Central and the School) offering interview practice, advice on fellowship applications and academic careers, as well as training and advice targeted to non-academic careers. Some of this training is aimed specifically at female PGRs.

We follow UEA's Code of Practice for Research Degrees in ensuring that all supervisors undertake **Best Practice in Research Supervision** training every three years. New faculty are helped by their mentors to achieve success as PGR supervisors. Supervisors usually meet with their students at least once a week, but they also keep in regular informal contact on a day-to-day basis as the need arises.

All PGR students have allocated **funds to support conference travel** (e.g. £1000/year for those funded by EPSRC or the Science Faculty), and additional money is available if necessary (overall around £3000 additional funds are available per year). An annual budget is dedicated to **postgraduate cohort-building activities**, and this is typically used to fund external speakers for

the PGR seminar series and for social events. Students have access to the remote taught course MAGIC network, and are expected to complete 100 hours of advanced mathematics courses by the end of their second year.

The PGR Director manages postgraduate student wellbeing and support. PGR representatives sit on the School Board and on the Faculty-level Science Postgraduate Research Committee, which informs higher committees, giving our PGR students direct influence over policy. We record strong scores in the **Postgraduate Research Experience Survey (PRES)**, beating the sector average for overall satisfaction in 2017 and 2019, with 100% overall satisfaction in 2017.

Following our strategic research review in 2015 we made several drives to secure **large-scale funding for PhD research** via CDTs or ITNs, and contributed to successful UEA-wide bids to NERC (the EnvEast and ARIES DTPs awarded in 2013 and 2019) and BBSRC (DTP2 and DTP3 awarded in 2019). We spearheaded networked collaborations with other institutions over a number of years to steer EPSRC CDT bids: with three other institutes in Pure Mathematics and with two others in Applied Mathematics. Ultimately, strategic realignments foreclosed the Applied bid, while the Pure bid made it to the outline stage but was not funded (only one CDT in Pure was funded, illustrating the low success rates). We led a bid for a Leverhulme Doctoral Training Centre in Mathematical Logic, and for a Horizon 2020 Innovative Training Network. While both were unsuccessful, we recognise the value gained from establishing new connections and collaborations.

2.3 Equality, Diversity and Inclusion (EDI)

We promote an inclusive, flexible and supportive working environment with core hours, informal and formal flexible working, and study leave, to accommodate personal need. EDI is fully considered when assessing promotion and study leave applications, appointment to leadership roles, and providing funding for conference attendance. We are well known at UEA for our supportive community atmosphere. A large contingent of faculty, postdocs and PGR students have lunch and coffee together daily. During the pandemic these morphed into daily online 'coffee and chats' and social gatherings online.

All staff must complete *Diversity in the Workplace* training every two years, and reminders are sent out to maintain 100% compliance. Our Director of EDI (*Purvis*) sits on the School Promotions Committee and chairs our **EDI committee** (attended by the HoS) that meets twice a semester, is informed by a range of data and feedback from students and staff, and reports to the School Executive Committee. One meeting per semester is open to all. This committee has made a positive difference: on its recommendation, to raise awareness of **flexible working opportunities**, an anonymised spreadsheet showing active arrangements in the School was publicised to all staff. Several staff have adopted flexible working arrangements during the current REF period. We have three staff working part-time at 0.8FTE, 0.8FTE and 0.67FTE.



We were awarded a Bronze Athena SWAN (AS) Award in October 2015, and this was renewed in May 2019. In particular the AS Panel noted our sound processes for **flexible working** and the management of **career breaks**; the increasing number of **senior positions held by women on committees**; and examples of good practice in our evaluation of outreach and in offering **shadowing opportunities**. The panel rated our action plan strong with realistic goals and success metrics, including:

- production of role-model male/female career-path posters,
- promoting 'Women in Mathematics' day,
- emphasising available support prior to the annual promotions cycle,
- appraisal checklists,
- reviewing the wording used in adverts for new posts/PhDs to promote inclusivity.

We use plasma screens and hard copy to publicise inclusivity support (e.g. the Ofsted-rated 'Outstanding' on-site Nursery, parental and flexible leave, and baby-change facilities). We use our social media accounts to promote EDI events and campaigns (e.g. #womeninscience). Staff in the School have benefitted from the Science Faculty's £10K/year fund for **career development and/or to aid transition back to work** and have used it to support conference attendance and accompanying person costs. The School's Research Travel Fund has also been used to provide financial support for caring responsibilities. Our UKRI fellow Asaf Karagila used the Faculty's **Bridging Fund** to manage the gap between his fellowships.

We continually monitor **gender balance** in the School, for example in our research seminar series. Before Ryan's departure in 2019 the staff gender balance was 19% female to 81% male. Since REF2014 the School's proportion of female postdoctoral researchers has risen from 11% to 29%, and the proportion of female PhD students has remained at around 20%. We also have an **internationally diverse** staff profile with 12 different nationalities among the 21 RAs in the School since 2014, and eight different nationalities among our permanent staff.

2.4 Selection of REF outputs

Following the UEA REF Code of Practice, outputs from all ATR staff were considered for possible selection. Staff ranked their best (up to five) outputs and internal reviews were conducted by a School panel who scored outputs on a 13-point scale and provided detailed comments. The panel included male and female members, all of whom underwent unconscious bias training. To help calibrate the scores, and to help in cases of uncertainty or divergence of opinion, reviews on a subset of outputs were sought from external expert evaluators. All scores were carefully analysed by the DoR and the HoS (both of whom had served on the review panel) to inform a portfolio selection that showcases the best research from the Unit. Our 48 outputs include 14.6% attributed to women authors compared to a fraction of 14.5% women FTE for the Unit.

3. Income, infrastructure and facilities

3.1 Income

A supportive and inclusive culture underpins our **strategy for generating research income**. We mentor and support staff to develop their individual research agenda. We promote funding opportunities via weekly email bulletins, and staff can create personalised funding alerts using the University's subscription to Research Professional. The annual RAP meetings offer further support for planning, and study leave is used to give time for the preparation of major grant applications (e.g. fellowships). Changes to the workload model made since REF2014 have recognised time spent in grant writing and impact development and these will be carried forward in the new Science Workload Model. All proposals undergo a rigorous internal review process involving detailed feedback and comment from at least two colleagues as well as from the DoR with technical support provided by the University's Research & Innovation Services. Early career staff are closely mentored and are encouraged and helped with proposal drafting. We are mindful of avoiding unconscious bias in all decision-making for resource allocation and strive to achieve a fair system for research grant support that conforms with our EDI principles.

This strategy maintains a steady stream of applications, many with partner institutions, ranging from responsive mode and targeted calls to fellowship opportunities. It has yielded **£4.2M in research grant funding for new projects** starting during the current REF period (and £2.96M research income spent during the REF period). New large grants total £3.5M from UK sources (including UKRI, the Royal Society, the Leverhulme Trust, GCHQ and AWE), £0.4M from the EU (Framework 7), and £0.4M from non-EU sources (including the US Office of Naval Research and the US Air Force). Small grant (<£50K) income totals £354.5K from sources including EPSRC, the London Mathematical Society, the QJMAM fund, and the Royal Society. Grant-funded research produces outputs in internationally leading journals (e.g. Gray's 2020 work on the word problem

in *Inventiones Mathematicae* was supported by an EPSRC New Investigator Award) and underpins our impact activity (e.g., *Korobkin's* ICS was partly supported by a grant from the US Office of Naval Research).

To inform and encourage new applications, the Faculty regularly host **research and funding workshops**. For example, we had an EPSRC theme day in 2018 with a programme leader giving a keynote talk, presentations giving tips to winning funding, a Q&A panel and a networking poster event. Such events provide an excellent way of developing a **positive research culture**: one that is looking ahead strategically for future opportunities for success.

We have leveraged funds from the **Higher Education Innovation Fund** (HEIF) to support and underpin our ongoing impact-generating activities. This includes: *Cooker*, £600; *Džamonja*, £12,092; *Korobkin*, £12,990; and *Ryan* (who left in 2019) £36,300. Ryan also received around £3.3K from the Associate Dean for Innovation Fund (which supports innovation activities at an early stage) to visit Edwards Air Force Base in California.

We recognise the value of consultancy work for building relationships with business to develop impact opportunities. The DoI spearheads our consultancy activity. Changes made to the internal workload model that we reported for REF2014 have facilitated undertaking consultancy work, and we have leveraged a **steady consultancy income** amounting to around £8500/year over the last seven years.

UEA has **strongly supported postgraduate research** in the School by providing nine Faculty PhD studentships. The Science Faculty has been recently awarded an EPSRC Doctoral Training Grant to fund six PhD studentships (three/year for two years), and two dedicated Mathematics studentships supported by the 2020 Additional Funding Programme for Mathematical Sciences with UEA top-up funds provided as part of its commitment to support training in Mathematics. We have also been successful in attracting external funding for PhD studentships, usually with 50% UEA matched funding (e.g. co-tutelle partnerships with the University of Adelaide and the Université Panthéon-Sorbonne).

3.2 Infrastructure and facilities

The DoI is responsible for **enabling and driving forward our impact agenda**. He is supported by UEA's Engineering and Applied Mathematics Relationship Manager, who helps to identify new business contacts and consultancy opportunities (for example, this recently led to a new working relationship with Anglian Water including a co-funded student project in summer 2019). Our drive toward impact generation is supported by UEA's Impact Team, who oversee portfolio development, offer training, coordinate workshops, and assist with evidence gathering.

Achievements in impact are rewarded by invigorated promotion opportunities and by recognition in the workload model. Study leave applications are encouraged to give time and space to develop impact potential. Relevant resources are signposted, including promotional events (e.g. UEA's *Innovation Capacity Workshops* and the *NRP Translation and Innovation event*), and internal and external funding streams.

We update IT equipment in the School (e.g. Wi-Fi, software and hardware) on a three/four year cycle. Laptop provision enables staff to work effectively off campus. We are among the most regular users of the University's state-of-the-art **High Performance Computing** (HPC) facilities, e.g. for quantum fluids simulations. The HPC has seen a £520K investment year-on-year since 2014. It has 425 computer nodes, 10 GPU nodes and six huge memory nodes, providing 8312 CPU cores all powered by Intel Xeon processors, all supported by several dedicated staff. A **new Nvidia GPU farm** has been funded from a UKRI capital award (£276K) in 2020.

All research-active staff have their own private office in the School. RAs and PGR students share open-plan office spaces with individual desks and computers. We have made continual investment

in office infrastructure with **workplace ergonomics and staff welfare a priority** (e.g. height-adjustable desks and ergonomic mice are provided according to need).

A large common space in the School that allows staff, RAs, PGR students, and Masters-level undergraduates to interact is crucial to the **vitality of our research culture**. It has state-of-the-art audio-visual equipment, two computers, a well-stocked Mathematics library, and coffee/kitchen facilities. It is regularly used for research seminars, graduate-level teaching (via the MAGIC network) and formal meetings, as well as informal chats about research problems – whiteboards and glass tables are used to discuss ideas.

Staff have collaborated with **international partners** to leverage experimental expertise and laboratory infrastructure that is not available on the NRP. Examples are given in Box 5.

Box 5. Use of laboratory facilities beyond the NRP

- *Korobkin*: lifting-discs with the Fluid Mechanics Group at Universidad Carlos III de Madrid funded by the Spanish Ministry of Economy and Competitiveness, 2016-2019.
- *Korobkin and Purvis*: splashing on flexible substrates funded by the Royal Society and the National Science Council of Taiwan, 2016.
- *Părrău*: sea ice dynamics at HSVA, Hamburg funded by the Horizon 2020 Research and Innovation Programme Hydralab+, 2018.
- *Salman and Proment*: rogue waves at Dipartimento di Fisica, University of Turin, Italy, funded by the FP7 program *European High Performance Infrastructures in Turbulence* (EuHIT), 2014.

These all involved visits by the UEA collaborator to the host institution where the experiments were carried out in the year stated. All led to outputs, including in *Chemical Engineering Science*, *Experiments in Fluids*, *Geophysical Research Letters*, *Journal of Fluid Mechanics*, and *Physical Review Letters*.

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

4.1 Collaborative research

We collaborate widely with national and international partners in academia and in industry, and the School strongly encourages interdisciplinary research. Collaborative research is supported via funds for travel (about £18.5K/year is available), via study leave provision, and via external funds, where we have a strong record of success (see section 3.1).

International collaborations

In this REF period we have worked with collaborators in 26 different countries. We have hosted 85 international visitors from 16 countries, including 29 visits of longer than one month. We have made numerous extended visits to international collaborators including, for example, in Australia, China, Finland, France, Germany, Sweden, and the USA. This activity has produced many outputs in leading journals (e.g. Dinvey [Norway], Kalisch [Norway] & Părrău, *J. Fluid Mech.*, 2019; Dolinka [Serbia], Gray & Ruskuc, *Proc. London Math. Soc.*, 2017), and collaborative research grants (e.g. *Korobkin*, Office of Naval Research Global, £187,641, with partner Maki, University of Michigan, USA; *Părrău*, Royal Society, £11,780, with partner Wang, Chinese Academy of Sciences, China; *Proment*, Royal Society, £9,140, with partner Krstulovic, Observatoire de la Côte d'Azur, France).

We hold/have held visiting professorship/fellowship positions including *Džamonja* (Associate Member of IHOST and a member of the Ecole Doctorale at the Université Panthéon-Sorbonne,

Paris, France), Gray (visiting Professor in Algebra and Mathematical Logic, University of Novi Sad, Serbia), Korobkin (Chair in Excellence, Universidad Carlos III de Madrid, Spain; visiting Professor, Harbin Engineering University, China), and Korobkin and Părau (Simons Fellowship, Isaac Newton Institute).

Examples of longer-term visits by international collaborators include a one-year visit by Fenjin Liu (Chang'an University, China) funded by the China Scholarship Foundation, and a two-year visit by Yannis Chatzigeorgiou (National Technical University of Athens, Greece) funded by an FP7 Marie Curie Actions grant.

4.2 Exemplars of interdisciplinary research and contribution to the research culture

Interdisciplinarity is central to our research vision. We make a strong contribution to the research base on the NRP and have established numerous long-term partnerships with collaborators in other UEA Schools, notably Biology, Environmental Sciences, Medicine, and Pharmacy, and the other NRP institutes, e.g. Quadram Institute and the John Innes Centre (JIC). Box 6 showcases the range of our interdisciplinary work since 2014.

Box 6. Interdisciplinary collaborations

UoA member	Partner	Example Output	Details
Atkin	City University, University of Toulouse, France	Veerasamy & Atkin (2020) <i>Exp. Fluids</i> , 61.	Drag reduction; boundary-layer transition.
Blyth	JIC	Blyth & Morris (2019), <i>Frontiers Plant Sci.</i> , 10:1393.	Wound signalling in plants.
Blyth	School of Pharmacy, UEA	Hamdallah et al. (2020) <i>Int. J. Pharma.</i> , 584, 119408	Nanoparticle fabrication.
Blyth, Cooker, Purvis	Quadram Institute, NRP	Rickett et al. (2015) <i>IMA J. Appl. Math.</i> , 80, 1582-1618.	Digestion modelling in the gut.
Cooker	School of Environmental Sciences, UEA	Alexander & Cooker (2016) <i>Sedimentology</i> , 63, 1582–1595.	Boulder motion in flash floods.
Džamonja	Dept. of Philosophy, University of Konstanz, Germany; Paris-Sorbonne University, France; Chapman University, USA.	In <i>Reflections on the Foundations of Mathematics</i> , Springer, 2019; and in <i>Contradictions, from Consistency to Inconsistency</i> , Springer, 2018.	Philosophy of set theory.
Părau	Newcastle University, HSVA, Hamburg	Carr et al. (2019), <i>Geophys. Res. Lett.</i> , 46, 12230-12238.	Solitary waves in ice-covered water.

4.3 Engagement with research beneficiaries and wider impact activities

Our research portfolio encompasses numerous impact-generating activities including engagement with academics, industry and stakeholders, and delivery of graduate-level teaching. *Džamonja* has sought to accelerate impact from her research in mathematical logic through the delivery of graduate-level courses in **Africa, Bosnia and Herzegovina, and Iran**. *Hammerton's* work on **landmine detection** with Cobham Technical Services yielded an output in *IEEE Transactions on Geoscience and Remote Sensing*. *Korobkin's* project with the aerospace, defence and security specialist company **Leonardo** on high speed liquid impact modelling employed two research assistants in the School. *Purvis's* connections with **AWE** and the **Smith Institute** led to a successful PhD completion on shear banding in reactive materials via an **EPSRC iCASE award**. With her PhD student Docampo, *Ryan* acted as a developer of the spectral/hp element package **Nektar++** suitable for industrial end-users (e.g. Formula 1). *Ryan* engaged with workers at **Edwards Air Force Base, California**, including delivery of a short course on wave propagation. *D. Stevens'* (submitted to UoA7) ocean/climate work (included in our portfolio of potential ICS, section 1.4) involved direct engagement with the **UK Meteorological Office** and the Centre for Environment, Fisheries and Aquaculture Science (**CEFAS**), the latter via a **NERC CASE studentship**. *D. Stevens* co-authored two 2019 Marine Climate Change Impacts Partnerships (**MCCIP**) report cards, concise summaries for policy advisors, decision makers, Ministers, Parliament and the devolved administrations. A figure from one of four referenced co-authored papers was reproduced in the chapter 'Evaluation of Climate Models' in the **IPCC 5th Assessment Report**.

4.4 Editorial positions

Members of the UoA are, or have been, on editorial boards of prestigious journals including

- *Atkin*: The Aeronautical Journal (2011-).
- *Džamonja*: Proceedings of AMS (2013-2016).
- *Gray*: International Journal of Algebra and Computation (2020-).
- *Kirby*: London Mathematical Society Journal, Bulletin and Transactions (2020-).
- *Korobkin*: J. Engineering Mathematics (2004-), J. Fluids and Structures (2011-).
- *Părrău*: Water Waves (2019-).
- *Siemons*: J. Design Theory (1998-2018).

4.5 Plenary lectures and keynote talks

We routinely give research seminars at universities in the UK and abroad, and present talks at national and international conferences. Plenary and keynote talks include:

- *Asperó*: KNAW Colloquium on Generalised Baire spaces, Holland (2018).
- *Korobkin*: Lavrentyev Readings on Mathematics International Conference, Russia (2015).
- *Grant*: Hausdorff Research Institute, Germany (2017).
- *Gray*: AAA90, 90th Workshop on General Algebra, Serbia (2015).
- *Părrău*: International Symposium of High-Fidelity Computational Methods and Applications, China (2019).

We have been invited to participate at meetings at international research stations, for example *Oberwolfach Research Institute for Mathematics*, Germany, *Schloss Dagstuhl – Leibniz Center for Informatics*, Germany, *Centre International De Rencontres Mathematiques*, Luminy, France, and *Mathematical Sciences Research Institute*, Berkeley.

4.6 Conference/meeting organisation and research network activities

We regularly organise national and international research programmes, conferences and meetings. We have taken leading roles in promoting nonlinear waves, sea-ice dynamics, set theory, and representation theory. Examples are:

- *Asperó*: Workshop on 'Methods in Higher Forcing Axioms', UEA, (2019).
- *Džamonja*: Isaac Newton Institute programme 'Mathematical, Foundational and Computational Aspects of the Higher Infinite' (19/08 - 18/12/2015).
- *Korobkin, Părau*: Isaac Newton Institute programme 'Mathematics of Sea Ice Phenomena' (21/08 - 20/12/2017).
- *Gray*: Winter One-relator Workshop, UEA (2018).
- *Lyle*: 'Representations of p-adic groups and finite groups of Lie type', Centre International De Rencontres Mathématiques (CIRM), France (2016).
- *Miemietz, Stevens*: 'Categorification and p-adic groups', UEA (2016).
- *Părau*: 'Nonlinear Waves: Theory, Computations and Real-World Applications', Tsinghua Sanya International Mathematics Forum (TSIMF), China (2019).

We proactively devise and lead specialist research networks including a number of **UK Fluids Network Special Interest Groups** ('Evolving Interfaces in Complex Fluids' led by *Blyth*; 'Quantum Fluids' led by *Salman*; 'Wave Turbulence' co-led by *Proment*). In 2015 *Proment* created the **Eastern Arc Conference on Topological Solitons and Quantum Fluids**, a partnership between UEA, University of Essex, and University of Kent; and *Kirby* founded the network **SEEMOD** (South and East of England Model Theory) involving UEA, Oxford, QMUL, Imperial, and Cambridge.

4.7 Examples of engagement with national and international funding bodies

We regularly engage with funding bodies through proposal reviews and panel meeting participation. Nine of us are members of the EPSRC Peer Review College (*Atkin* and *Kirby* are associate members; and *Blyth*, *Džamonja*, *Gray*, *Părau*, *Proment*, *Salman*, and *Stevens* are full members). *Proment* is a member of the UKRI Future Leaders Fellowships Peer Review College, and *Whittaker* is on the Royal Society Newton International Fellowships review panel. We regularly review research proposals for funding bodies in numerous countries, including Austria, Chile, France, Japan, and The Netherlands. *Blyth* sat on the interview panel for the La Caixa-Marie-Curie-Horizon2020 InPhiNit International PhD Fellowships in 2017. *Džamonja* and *Proment* are European Commission H2020 experts.

4.8 Awards

In 2018 *Proment* (with PhD student Villos) received the prestigious **35th François Naftali Frenkiel Award** for Fluid Mechanics. *Proment* also received the **Euromech Young Scientist Award** at the European Turbulence conference 2019.

4.9 Public engagement

We regularly give talks in schools and colleges (regionally and nationwide) to promote our research, and Mathematics generally, and we frequently contribute talks and presentations to local STEM events, as well as hosting numerous outreach events. Our annual 'Explore Maths Day' and 'Discover Maths Day' events for school students are highlights. Since 2014 *Proment* (part-funded by EPSRC) has had stands explaining vortex dynamics and Chladni patterns at the annual **Norwich Science Festival**. *Proment* also received publicity (articles in SciNews and Atlas of

Science, and a local newspaper) for his work on the Fermi-Pasta-Ulam-Tsingou problem (*PNAS*, 2015).

4.10 Wider contributions to the discipline

We serve on numerous research and conference **committees and councils** including:

- *Atkin*: Fellow of the Royal Academy of Engineering (2018-); President (2016-17) of the Royal Aeronautical Society.
- *Kirby*: British Logic Colloquium committee (2017-).
- *Korobkin*: Russian Committee on Theoretical and Applied Mechanics (2001-).
- *Siemons*: Scientific Board of the Shanghai Conference on Combinatorics (2011-).
- *Stevens*: London School of Geometry and Number Theory (LSGNT) Strategic Advisory Board (2019-).
- *Whittaker*: European Study Group with Industry UK Standing Committee (2014-2018).

We have written/edited four **books** with an emphasis on highlighting recent research:

- *Džamonja*: *Fast Track to Forcing* (Cambridge University Press, October 2020), *Théorie des Ensembles pour les Philosophes* (Europe. Univ., 2017).
- *Kirby*: *An invitation to Model Theory* (Springer, 2019).
- *Părau*: (co-editor) *Nonlinear water waves* (Springer, 2019).

We have taught numerous **graduate level courses**, including (in the UK) 13 courses for the MAGIC Consortium, and five courses at LMS Undergraduate Summer Schools; (and abroad) numerous taught courses including 'Nordic Logic Summer School' (*Džamonja*, Sweden), 'XXIV Brazilian Algebra Meeting' (*Gray*, Brazil), and a course on hydroelasticity at Harbin Engineering University (*Korobkin*, China).