# Unit-level environment template (REF5b)

### Institution: Durham University

#### Unit of assessment: 10 Mathematical Sciences

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

The unit of assessment is a single department of the University, one of eight departments within the Faculty of Science. It is an active participant in a variety of the wider University's Institutes and Centres, as detailed below.

Having expanded to 85 permanent Category A staff by the end of 2020, the Department is in a phase of significant growth across all of its groups, with an ambitious hiring strategy that will continue in the coming years. The decision to expand the Unit was taken by the University in 2016, following a growth plan submitted by the Department to the University's Science Faculty Meta Review in February of that year. The Unit's expansion is reflected in the rise from 54 FTE submitted (51 of them on permanent contracts) for REF2014 to 73.7 FTE for REF2021; the further increase in permanent Category A staff numbers to 85 in the period from the census date to the end of the REF period shows that growth is being sustained.

This growth involves major investment in a new building for the Department, the construction of which began in November 2018. The handover of the building was delayed by the Covid crisis but was completed in December 2020. Staff began occupation of the building at the start of January 2021, and while this process has been delayed by the national lockdown, the move will be finished by Easter 2021. More details of this important infrastructure project are given in **section 3** below.

The research activity in the Department is distributed between four broad research groups:

- Pure Mathematics
- Applied and Computational Mathematics
- Mathematical and Theoretical Particle Physics
- Probability and Statistics

Each group runs at least one weekly research seminar or colloquium during term-time.

These are further subdivided into ten more-specialised research subgroups, as shown in **figure 1** below, which also lists the University-wide Institutes and Centres with which the Department has significant interactions. Many of these research subgroups run their own seminars and/or discussion groups in addition to the main weekly seminars held in the Department. The primary assignments of category A staff to the research subgroups are shown in **table 1** below.



**Figure 1:** Research groupings in the unit, by groups and subgroups. Also shown are the University-wide Institutes and Centres with which the Unit has active links.

The boundaries between subgroups are not always sharp, and some of the associations of staff to subgroups shown in table 1, for example those within the Mathematical and Theoretical Particle Physics group, can be rather fluid.

Another example of a 'soft border' is that between the Geometry subgroup and the Analysis and Partial Differential Equations subgroup, where in particular a joint working group on Optimal Transport Theory has been active.

A further instance of cross-subgroup collaboration was the working group on block co-polymers involving members of the Geometry, Analysis and Partial Differential Equations, and Solitons in Field Theory subgroups which ran from 2015-2016; this also brought in members of the University's Chemistry Department.

More generally, members of the Department often attend seminars and colloquia beyond those of their own groups, and events such as the termly Departmental Research Colloquium encourage further interactions and foster a healthy research environment.

### Strategy and Planning

The Department is committed to the University's strategic goal of producing world-leading and world-changing research, and to enhancing the impact of this research on the academic community and beyond.

- The development, implementation and monitoring of day-to-day strategies to achieve these goals is led by the **Research Committee** of the Department, the membership of which includes the Director of Research and the Director of Impact together with research-active staff at a variety of career stages.
- The Department's **Management Board** also considers research matters. It meets fortnightly in term time, and its remit is the day to day running of the Department. It

comprises those with key responsibilities for central activities: Head of Department (HoD) (Chair), Deputy HoD, Director of Education, Director of Postgraduate Studies, Director of Research, Chair of the Board of Examiners, Chair of the EDI Committee, and Departmental Manager.

- Longer-term planning issues relating in particular to hiring strategies are considered by the Department's **Strategic Planning Committee (SPC)** which includes senior staff representatives from each research group and is led by the HoD.
- Their considerations are also informed by an external Advisory Board comprising senior academics from other universities and representatives from the private sector, meetings of which are arranged, either in person in Durham or virtually, as issues arise. A more focussed Impact Advisory Board is planned, to advise on maximising interactions beyond the academy.

## **Research Groups**

The distribution of research groups is close to that at the time of REF2014, with the main difference at the top level being the splitting of the Applied group into separate Applied and Computational, and Mathematical and Theoretical Particle Physics, groups.

This better reflects the distinct research interests and potential hiring pools of the two areas, and also marks a strategic and ongoing decision to build extra strength in the Applied and Computational group.

As a result of staffing changes and evolving priorities a separate biomathematics subgroup is no longer identified within the Unit, but a number of staff retain an active interest in the field, including Einbeck, Hryniv, Peeters, Piette, Prior, Taormina and Vernon; this is supported by their participation in the activities of the University's Biophysical Sciences Institute.

Subgroup	Members		
Algebra and number theory (8)	Abrashkin, Bouganis, Funke, Gangl, Magee, Shotton, Stasinski, Vishe		
Geometry (7)	Felikson, Galaz-Garcia, Klingenberg, Palmisano, Parker, Peyerimhoff, Tumarkin		
Topology (5)	Hunton, Lobb, M. Powell, Ramagge, Schuetz		
Analysis and Partial Differential Equations (4+1)	Boegli, Griffin-Pickering*, Mészáros, Wirosoetisno, [Straughan]		
Magnetohydrodynamics (3)	Prior, Wyper, Yeates		
Quantum Field Theory (13+1)	Bowcock, Bullimore, Cremonesi, Del Zotto, Dorey, Dorigoni, Garcia Etxebarria, Heslop, Lemos, Lipstein, Niarchos, Sulejmanpasic, van Rees, [Mansfield]		
String Theory, Gravity and Cosmology (9)	Braun, Donos, Gregory, Iqbal, Peeters, Ross, Smith, Taormina, Zamaklar		
Solitons in Field Theory (3+1)	Piette, Sutcliffe, Ward, [Zakrzewski]		
Probability (9)	Chhita, da Costa*, Georgiou, Hryniv, Menshikov, E. Powell, Rahman, Troffaes, Wade		
Statistics (14)	Aslett, Caiado, Coolen, Coolen-Maturi, Craig, Cumming, Du, Einbeck, Goldstein, Jermyn, Karagiannis, Oughton, Perrakis, Vernon		

**Table 1:** Category A staff by research subgroup as of 31 July 2020; the two Willmore Fellows in post on that date are indicated with a \*, while the three names in square brackets are emeriti.

# Recruitment

The Unit's research directions are largely set by its hiring decisions, and strategies in this regard have also evolved since REF2014, in response to the challenges and opportunities provided by the growth in staff numbers.

There is a continuing emphasis on the hiring of young and promising academics at relatively early career stages; this is reflected in our age profile as will be discussed in **section 2** below. Given the rapid growth of the Department its composition is evolving fast, and we have chosen to mention appointments taken up since the census date in the following discussion, as they serve to illustrate choices of strategic directions made by the Unit during the assessment period. These names are given in italics and are not included in **table 1**. This growth is ongoing: the Department is currently in the process of hiring 11 Assistant Professors, 9 of them new positions, with 2 replacements.

# Applied and Computational Mathematics

- A key aim since the time of REF2014 has been to create critical mass within the smaller research groups, with a particular emphasis on the Applied and Computational Mathematics group which, though active, was relatively small.
- Progress on this goal was achieved by the census date with the appointments of four academics (Boegli, Griffin-Pickering (Willmore Fellow) and Mészáros into **Analysis and Partial Differential Equations**, and Wyper into **Magnetohydrodynamics**). Three further permanent appointments into this group have taken up their posts since the census date, namely *Einav* and *Gittins* into Analysis and Partial Differential Equations, and *Townsend* into Magnetohydrodynamics, the latter marking a strategic broadening of the research interests of that subgroup towards biological applications of fluid mechanics.

# **Pure Mathematics**

- The three Assistant Professors and one Willmore Fellow appointed into the Analysis and Partial Differential Equations subgroup have been complemented by two more (Galaz-Garcia and Palmisano) in analysis-related areas just on the other side of the above-mentioned soft border with the **Geometry** subgroup. Taken together, these appointments have significantly bolstered the unit's strength in analysis, an area which was relatively under-represented compared to national norms at the time of REF2014. The Geometry subgroup has been further strengthened since the census date with the arrival of *Ducat* in October 2020 as a Wilmore Fellow.
- Changes in the Pure Mathematics group have seen the appointments of Magee and Shotton in the area of **Algebra and Number Theory**, and of M. Powell in **Topology**. A further Assistant Professor in Topology, *Fuhrmann*, joined the Unit after the end of the REF period, in January 2021, bringing the number of permanent Category A staff in the Unit up to 86, and building further links between the topology subgroup and those staff in other subgroups working in geometry, dynamics and analysis.
- The hiring in Pure Maths during the period has been strategic in design, with the choice mostly made to advertise each year within specific strategic areas either to bolster general critical mass or to reinforce particular developing areas within the group, as noted in the examples above. While within these constraints positions have been broadly targeted, the overriding aim to appoint the strongest available candidate each

time has clearly both strengthened and organically expanded the overall intellectual footprint of the group.

## **Probability and Statistics**

- Another smaller research subgroup which the Unit has aimed to grow to critical mass within the period since REF 2014 is the **Probability** subgroup.
- Five academics (Chhita, da Costa (Willmore Fellow), Georgiou, E. Powell and Rahman) were appointed into the subgroup by the census date, and four more permanent appointments (*Feng*, *Helmuth*, *Thacker* and *Zhao*) have commenced since then. These appointments have significantly increased the national and international standing, visibility and connectivity of this subgroup.
- In the **Statistics** subgroup there has also been growth since 2014: while Sayit has left the Unit, Troffaes has moved to the Probability subgroup and Wooff has retired, Aslett, Caiado, Coolen-Maturi, Cumming, Du, Karagianis, Oughton and Perrakis have been recruited, increasing the size of the subgroup from nine to fourteen.
- The further growth of strength in this research area has been emphasised by the SPC and the HoD as a strategic priority for the Unit, evidenced by the creation of a new undergraduate degree in Mathematics and Statistics, and a Masters in Data Science, both of which started in October 2020, and the Department's involvement in the University's MISCADA MSc in Scientific Computing and Data Analysis. Indeed, two further Assistant Professors in Statistics, *Ogundimu* and *Drikvandi*, took up their posts in September and October 2020, respectively.

# Mathematical and Theoretical Particle Physics

- The Mathematical and Theoretical Particle Physics Group has also seen a number of changes. As already mentioned, the divisions between the different subgroups in this Group are not strong, and so the practice in hiring has been, and is expected to continue to be, to advertise across the whole range of interests in the group as positions become available; this has consistently produced a very strong field of applicants, with the existing strength of the Group encouraging applications from the best available candidates world-wide.
- Since REF2014 Zakrzewski has retired, becoming an emeritus professor in the Unit, while Chu, Rangamani and Hubeny have left to take up prestigious posts elsewhere (Chu is now the Director of the National Center for Theoretical Science, Physics Division at the National Tsing Hua University, Taiwan, while Hubeny and Rangamani are Professors at the Center for Quantum Mathematics and Physics (QMAP) at UC Davis, California, of which they were founding members).
- In their stead, Bullimore, Cremonesi, Del Zotto, Dorigoni, Garcia Etxebarria, Lemos, Lipstein (Royal Society URF), Niarchos, Sulejmanpasic (Royal Society URF) and Van Rees have joined the Quantum Field Theory area, while the appointments of Braun, Donos and Iqbal maintain the Group's strength in String Theory, Gravity and Cosmology. The Quantum Field Theory subgroup has further grown since the census date with the appointments of *Sleight* and *Hoare*, the latter a UKRI Future Leaders Fellow.
- Staffing in the **Solitons in Field Theory** subgroup has been more stable, but it is worth noting that a number of the new hirings, including Dorigoni and Sulejmanpasic, augment the Unit's strength in this area, even if their primary assignations are with the Quantum Field Theory subgroup.

# Willmore Postdoctoral Fellowships

A new initiative taken since REF2014 has been the instigation in 2017 of the Willmore Postdoctoral Fellowships, three-year University-funded positions for candidates with between two and six years of research experience since their PhD.

One such post is advertised each year, with the research area cycling between different groups or subgroups of the Unit, so that there are normally three Willmore Fellows in post at any given time.

- The first Willmore Fellow, **Dr Shane Cooper**, worked in the Analysis and Partial Differential Equations subgroup, and two further Willmore Fellows, one (**da Costa**) in Probability and one (**Griffin-Pickering**) again in Analysis and Partial Differential Equations, took up their posts this academic year and are included in our submission.
- Looking forward, the research area of subsequent Willmore Fellowships will be settled by the HoD in consultation with the SPC on a strategic basis.
- The next Fellowship, in the area of Pure Mathematics, has already been awarded and that Fellow (*Ducat*) started in September 2020.
- This will be followed by a Fellowship in Mathematical and Theoretical Particle Physics.

#### **Institutes and Centres**

The research undertaken in the Unit is embedded within the wider University context, and an important driver for interdisciplinary activity is the network of Institutes and Centres that the University supports. **Table 2** below captures these connections.

In most cases the links come about through a shared research interest in the field of study covered by the relevant Institute or Centre and should be clear from the name of the Institute (some of these links are also mentioned explicitly elsewhere in this document).

An exception to this rule is the **Institute for Advanced Study (IAS)**, which supports a rolling programme of interdisciplinary projects tackling major research problems during which researchers are supported to visit Durham as visiting Fellows of the IAS; when appropriate these Fellows are co-hosted in the Unit and collaborate with its members.

A recent example is the interaction between Dr Iqbal from the Unit and Dr Arjun Bagchi from the Indian Institute of Technology at Kanpur in spring 2019, when the latter was visiting Durham through a programme at the IAS. In addition to scientific interaction, this led to the decision to co-organize a winter school together in Bangladesh, that is described in more detail in **section 4** below.

Particularly strong and long-standing links for the Unit are those with the **Centre for Particle Theory (CPT)** and the **Institute for Particle Physics Phenomenology (IPPP)**, both of which are joint operations with the Department of Physics (which hosts the IPPP). An MSc in Particles, Strings and Cosmology is run by the Mathematical Sciences and Physics Departments under the aegis of the CPT, while the two Departments also share the 'CPT Colloquium' which is held regularly throughout the year. Members of the Unit also assist in the organisation of the IPPP's Annual Theory Meeting (ATM), held in Durham every year just before Christmas and aimed at the whole UK Theoretical Particle Physics community, and the associated Young Theory Meeting (YTF), held just after the ATM.

Other links have led to the initiation of new interdisciplinary collaborations and funding: for example, Prof. Piette's involvement with the **Biophysical Sciences Institute** helped to foster his collaboration with Prof. Jonathan Heddle, a biochemist from Krakow, on two projects which have led to three publications, including one in Nature, while Prof. Goldstein's work with the **Durham Energy Institute** linked him into obtaining his part of the grant for the Centre for Energy Systems Integration consortium, which funded three postdoc positions in the Unit.

One Institute for which the connection with the Unit might not be clear is the **Institute of Medieval and Early Modern Studies.** This link has arisen through a plan to mark, in 2022, the 500th anniversary of the publication of the first printed work published in England devoted exclusively to mathematics, 'De arte supputandi libri quattuor', by Cuthbert Tunstall, before he became Bishop of Durham. Profs. Funke and Parker from the Unit are leads on this project, in collaboration with Prof. Giles Gasper from the University's Department of History. Among other activities, we are in discussions to host the annual meeting of the British Society for the History of Mathematics in Durham in 2022.

Institute or Centre	Associated members		
Institute for Advanced Study	Caiado, Einbeck, Goldstein, Hryniv, Iqbal, Jermyn, Piette, Prior, Ross, [Zakrzewski]		
Biophysical Sciences Institute	Piette (member of the executive board), Einbeck, Hryniv, Prior (member of the executive board), Vernon		
Durham Energy Institute	Coolen, Goldstein, Troffaes, Wirosoetisno		
Institute for Hazard, Risk and Resilience	Caiado (member of the management board), Goldstein, Wirosoetisno, [Straughan]		
Wolfson Research Institute for Health and Wellbeing	Caiado, Coolen, Coolen-Maturi		
Durham Research Methods Centre	Einbeck (co-director), Coolen, Coolen-Maturi		
Institute for Computational Cosmology	Vernon		
Centre for Particle Theory (CPT);	Ross (co-director of the CPT) together with all members of the Mathematical and Theoretical Physics research group		
Institute for Particle Physics Phenomenology			
Institute for Data Science	Einbeck (co-director), Aslett, Caiado, Coolen, Coolen- Maturi, Cumming, Hryniv, Jermyn, Karagiannis, Vernon, Wade, Wyper, Yeates		
Institute of Medieval and Early Modern Studies	Funke, Parker		

**Table 2:** University-wide Institutes and Centres with specific links to the Unit, and staff with particular associations with those Institutes and Centres.

### Impact

The Department has a number of strategies in place to encourage impact. There is a dedicated Director of Impact (DoI), distinct from the Director of Research, who is a member of the Research Committee and also liaises with the central Research and Innovation Services (RIS) unit to encourage and support impact-related activities.

Explicit credit is given in the Departmental work-load model for impact-related work, not only for specific work on the Impact Case Studies mentioned in the current REF submission, but also for a wider set of projects, some of which are by their nature smaller in scale, and others of which are longer-term prospects for more significant impact in the future. An Impact Advisory Board is planned, which will also offer valuable advice on our future policies in this domain.

# Funding to support impact

Various sources of funding are available to support impact. These are regularly advertised to staff in the Department by the Director of Impact.

- **UK Research Councils** provide funding through Impact Acceleration Accounts (IAAs), yielding for example £37K through 3 STFC IAAs to support the work of Dr Yeates with the Met Office that is described in more detail below.
- Innovate UK together with a partner company specific to the given project fund Knowledge Transfer Partnerships (KTPs). In the current REF period, our Department has been awarded 4 KTPs with a total value in excess of £800K.
  - Two of these are for projects with Atom Bank and have provided vital support for our Atom Impact Case Study (ICS). One of these two was led by Dr Caiado and Prof. Wooff (now retired), the other jointly by Drs Caiado and Aslett together with Prof. van Moorsel and Dr Ezhilchelvan (both from Newcastle). Atom is an exclusively app-based digital bank, and in collaboration with the Unit has developed a Digital Twin, a real-time statistical model to enable the bank to optimise its strategy, including marketing and productivity.
  - The other two KTPs are for a project with Clicksco (UK) Ltd. led by Dr Cumming. Clicksco is a digital marketing technology company and the collaboration utilises the Unit's statistical modelling expertise along with the digital data specialism of Clicksco to create new digital tools to enable organisations to better understand consumer behaviour.
- Durham University also provides Research Impact Funding (RIF) grants, typically in the range £1K £15K; each year there are four calls for applications. This has been utilised for example by Dr Einbeck to support the Dosimetry ICS, enabling him to travel and host a visitor to collaborate on generating and evidencing impact.

# **Raising Awareness of Impact**

A long-standing goal of the Unit has been to spread work on, and awareness of, impact-related activities to all research groups. While it is still the case that the most significant specific pieces of impact, which are the subjects of our Impact Case Studies, have come from our Statistics subgroup, the following sets of examples from each of the three other top-level research groups in the Unit show how the target to broaden impact engagement has been achieved over the assessment period. We also include two further examples of impact-related activities from the Statistics group to illustrate the breadth and reach of this group's work in this area.

# Pure Mathematics

a) In the **Pure Mathematics** group, Prof. Peyerimhoff was instrumental in setting up the Northeast Organisation of Discrete Structures (NODES), bringing together mathematicians and computer scientists from Durham and Newcastle Universities with common interests in discrete structures, in order to foster collaborative links aimed both at real-world applications and engagement with interdisciplinary training and fundamental research.

Among its activities have been seminars, two academic speed dating events, and two industry days with speakers from industry and former PhD students talking about their careers outside the university sector.

As a direct consequence of the industry days, Prof. Peyerimhoff is now supervising a PhD student, Laura Midgley, funded by the European Regional Development Fund. She is working on 'Mathematics in Crystallography' in close interaction with Olex2, a company based in Durham University providing software for small crystal determination.

b) Dr Gangl has been developing an innovative application of his work on hyperbolic polytopes to the design of jewellery using 3d printing techniques. The Department recently funded his attendance at the Inhorgenta Munich Trade Fair, 14-17 February 2020. Inhorgenta Munich claims to be "Europe's leading platform for jewellery, watches and gemstones" and Dr Gangl participated with one of the booths in the British Pavilion.

#### Applied and Computational Mathematics

- a) In the Applied and Computational Mathematics group, Prof. Yeates has been developing a relationship with the Met Office Space Weather Operations Centre, where the lead scientist is Prof. David Jackson. Most recently, he has been assisting them in applying for a European Space Agency contract related to the proposed ESA L5 satellite mission. His role is to provide hypothetical magnetic field models, so that the Met Office can demonstrate the expected improvement to their operational solar wind predictions that would arise from including a magnetograph instrument on the new satellite. This project was supported by the 3 STFC IAAs, to a total value of £37K, mentioned earlier.
- b) Also from this group, Dr Prior has been conducting an ongoing project to develop a novel method and code to interpret protein structures using small angle x-ray scattering. This is in collaboration with Prof. Ehmke Pohl of the Durham Biophysical Sciences institute and Dr Owen Davies of Newcastle University's Institute of Cell and Molecular Biosciences.

The major result of the project so far has been to provide a realistic prediction of a crucial component of the human synaptonemal complex, which is a vital part of mammalian meiotic recombination. They are now working on various other structures developed in Dr Davies' lab and Dr Prior is scheduled to speak at a number of experimental meetings in order to promote the code.

The long-term goal is to set up a web server on which users can deposit their experimental data and receive automated structure predictions. This will help the project achieve maximal impact, with the method being widely available to researchers in both the public and private sector.

#### Mathematical and Theoretical Particle Physics

a) In the Mathematical and Theoretical Particle Physics group, Prof. Piette organised the 2016 European Study Group with Industry (ESGI), hosted by the Unit in Durham in April 2016. The aim of these study groups is to allow industrial partners to present specific problems and ask mathematicians to work on these problems for a week. While full solutions are not always found in such a short time, the study groups always make good progress, often leading to further collaborations between the parties involved. The event was attended by members of all groups within the Unit, as well as the external participants.

Such was the success of this event that the Unit will host a further iteration in 2021, this time associated with a training event of the SAGEX (Scattering Amplitudes: from Geometry to Experiment) Marie Skłodowska-Curie Innovative Training Network (ITN) funded by the European Commission, with which the Unit participates as a beneficiary (SAGEX will be described in more detail in **section 4** below). This will bring in the industrial partners of SAGEX, namely Wolfram Research, Maplesoft, Danske Bank,

DreamQuark, Maersk Tankers, Milde Marketing Science Communication, and Ekaterina Eremenko Films. Even before this event, these industrial partners were involved in other events and training activities of the SAGEX network; in particular the two SAGEX PhD students based in the Unit took three-month private-sector secondments, one with Wolfram Research and one with Maplesoft, during the REF assessment period.

b) In response to the Covid-19 crisis, Dr Iqbal joined the National Data Analytics Task Force for the government of Bangladesh (his home country), providing mathematical support to the epidemiology team and working on the algorithm for the real-time monitoring of the effective reproduction number R(t) for the government dashboard. He also co-authored the guidelines for the rollout of the country's antigen testing programme.

## Probability and Statistics

In addition to the work undertaken by the **Statistics** subgroup that is described in our Impact Case Studies, a great variety of other impact related activities are underway in that section of the Unit. To give two further examples:

- a) Dr Aslett has had significant engagement with the Alan Turing Institute (Turing). He was seconded at 0.5 FTE to Turing for 10 months in 2018-19, which dovetailed into a 0.4 FTE Health Programme Fellowship for 18 months in 2019-20. His work has been primarily around SPARRA (Scottish Patients and Risk of Readmission and Admission), a risk model of the whole Scottish NHS population for use nationally by general practitioners, and assisting in the development of potential future strategic engagement between NHS Scotland and Turing.
- b) Prof. Goldstein and Dr Vernon have a long-running link with Prof. Daniel Klein of the Institute for Disease Modelling (IDM) in Seattle, contributing to the modelling done by the IDM for the decision-making processes of the Bill and Melinda Gates Foundation. This work employs the award-winning Bayes linear emulation and History Matching techniques designed by Goldstein and Vernon for application to complex epidemiology models and has already been used by the Foundation to advise a number of African Governments regarding their strategies for reducing HIV incidence.

# **Open Access**

Staff are regularly reminded to deposit their papers with Durham Research Online in accordance with the open access requirements and are also encouraged to place them on online resources such as the arXiv, in addition to submitting them to academic journals for publication.

Combined with our regular engagement with academic conferences this ensures the maximum visibility for our research outputs within the academic community; further outreach activities beyond that community are outlined in **section 4** below.

As a part of Durham University, the Unit is committed to the Concordat to support research integrity, as described at <u>https://www.dur.ac.uk/research.innovation/governance/integrity/otherorgs/</u>.

# Section 2. People

Ongoing growth in staff numbers has provided the opportunity to bolster numbers in smaller research subgroups to attain critical mass, and to grow strategically in other areas such as analysis that were recognised as being underrepresented in the past.

Given such considerations the Unit aims to look at a wide pool of applicants for each post and to select an outstanding candidate whose work shows individuality and originality, while fitting with existing activities.

All posts are advertised internationally and attract an international field of applicants. This is reflected in the international diversity of the current staffing list, with nineteen different nationalities represented.

The Department implements the Concordat to Support the Career Development of Researchers, as set out in the University's letter of commitment to the concordat at <a href="https://www.vitae.ac.uk/policy/concordat/Durham-University">https://www.vitae.ac.uk/policy/concordat/Durham-University</a> commitment-letter concordat2020.pdf

## Equality, Diversity and Inclusion

The Department is committed to upholding the principles of EDI and is working to improve its diversity and culture. The Unit currently holds Athena Swan Bronze status and is planning to apply for Silver. EDI is monitored by the Unit's EDI Committee, and the Chair of the Committee is a member of the Management Board.

The Unit implements the recruitment policies set by the University. These now stipulate: appointment panels must contain at least #F/#M = 2/2 and;

- Standard advertisement text on flexible working, job shares, and EDI;
- Text encouraging applications from women and black and minority ethnic candidates, and encouraging applicants to disclose career breaks so that they may be allowed for;
- Mandatory search training, including EDI issues and attracting a diverse pool;
- Standard provision to search committees of gender and ethnic balance information for UK application pools;
- EDI champions on each search committee;
- Monitoring to ensure that applicants and longlists are sufficiently diverse insufficient diversity may lead to re-advertising.

The University supplies recruitment packs to search committees and appointment panels for scoring and evaluating candidates. The search committee provides scores and commentary for each candidate; publications are read, scored, and commented on by the search committee or chosen experts. Reports are completed at each stage and are approved by the Provost before the next stage. Particular attention is paid to gender balance in this process. Further actions taken by the Unit include Departmental workshops on EDI issues including unconscious bias, mandatory EDI training for all appointment panellists, and a target of at least two female candidates on each shortlist.

Starting from the 2017-18 academic year, the University has implemented a more robust criterion-based system for promotions that considers all academic staff. The result has been that more women and staff from minority ethnic groups have been promoted across the University, and in particular in our Department.

**Table 3** below shows that the Department has been consistently moving larger percentages of women through the recruitment process than men. This is reflected in an increase in the female percentage of staff over the assessment period, with recruitment in the two most-recent academic years surpassing the University's overall target that at least 30% of new appointments should be female: of the 12 appointments in the 2018-19 academic year (10 permanent + two Willmore Fellows), four are female and two are BAME (plus one female Executive Dean who is 0.2FTE in our Department); and of the 14 appointments in the 2019-20 academic year (13

permanent + one Willmore Fellow), five are female and five are BAME (this includes two who are both).

In the selection of outputs for REF, the Unit's selection profiles are close to its staffing profiles (the numbers are rounded, with U in each case signifying blank / unknown / prefer not to say returns):

- by gender the M/F/U percentage splits are 83/16/1 (UoA) vs 82/15/3 (selection);
- by Early Career the No/Yes/U splits are 96/3/1 (UoA) vs 95/2/3 (selection);
- by Ethnic Origin the non-BAME/BAME/U splits are 83/16/1 (UoA) vs 77/20/4 (selection).

The rapid growth of the Unit combined with the already-mentioned strategic focus on the hiring of staff at early career stages means that we have a relatively young age profile, and these younger members of staff are contributing strongly to our output selection: 35 of our 75 Category A staff (46.7%) were aged 40 or younger on the census date, and this group is responsible for 103 out of 184 (56%) of our selected outputs.

	2016-17	2017-18	2018-19	2019-20
% of applicants shortlisted	9/9/12	13/14/0	10/19/14	10/13/8
% of applicants accepting offers	2/2/0	2/3/0	2/8/0	2/7/0

**Table 3:** Percentages of male / female / unspecified applicants shortlisted and accepting offers for Departmental academic posts in the last four recruitment campaigns.

### Induction

All new staff go through University induction, which covers key policies and procedures. In particular, there is mandatory training in EDI, Data Protection, and Health and Safety. All staff also have access to focused training, described in more detail below.

New staff are given a Departmental induction by the Department Manager, covering day-to-day knowledge of how the Unit functions, meeting key colleagues, and ensuring that administrative tasks such as mailing list memberships are dealt with. The University's central HR department provides a standard checklist to make sure that all key information is covered. New colleagues also meet with the HoD, who explains their role and responsibilities, and they are assigned a mentor. The mentor's responsibilities include regular meetings and help when requested.

In September 2018, the Department sent all new lecturers on the 'Induction Course for New Lecturers in the Mathematical Sciences' run by the Isaac Newton Institute with support and endorsement from the Institute for Mathematics and its Applications (IMA), the London Mathematical Society (LMS), and the Royal Statistical Society (RSS).

New staff are formally introduced at the first BoS following their arrival, and more informally at a Welcome Party during the Autumn term.

# **Probationary Period**

All new staff have a one-year probationary period. Together with their mentors, and approved by HoD, they develop a tailored probation plan, with goals and success measures defined by job type. The Unit has developed its own 'Probation Journey' form, to document and encourage regular meetings with mentors to discuss progress, and to record that progress. In a staff survey recently undertaken in connection with the Unit's Athena Swan Silver award application, most respondents (%F/%M = 86/88) felt that the probationary criteria were clear. Members of staff are given a lighter teaching load in their first few years and little administration, so they may dedicate more time to establishing their research profile and developing impact. They are also encouraged to apply for grants at an early stage.

The Unit provides new staff with a handbook describing many issues relating to teaching, research, impact, and departmental administration, as well as practicalities such as printing and health and safety. There is also a section on EDI, describing Athena Swan, providing links to policies, and describing help with caring responsibilities. Help with grant application writing is described in an annually-updated grants handbook, the upkeep of which is the responsibility of the Unit's Research Committee.

## Training and development

The majority of training to staff at all levels is through centralised courses provided by the University. New staff are enrolled on the Post Graduate Certificate in Learning and Teaching in Higher Education (PGCLTHE) as part of their probation, with successful completion resulting in Fellowship of the HEA.

The University offers a wide variety of other in-person and online training courses, including an award-winning **Researcher Development** programme for PGR students and staff (principally aimed at PDRAs), covering research skills and techniques; research environment; research management; personal effectiveness; communication skills; networking and team working and career management.

These courses are advertised via University emails to relevant groups and via Dialogue, the weekly University newsletter. HoD or relevant committee Chairs may also send emails to individuals to encourage them to sign up.

**Training in EDI issues**, including unconscious bias, is mandatory for members of search committees and appointment panels, and EDI issues are also included in the Recruitment & Selection Chairs' Briefing.

The Unit's EDI and research committees have reciprocal standing agenda items to discuss research-related and EDI issues respectively. A particular concern has been to ensure that all seminars and colloquia are timetabled in core hours so as not to exclude those with, for example, child-care duties from the research life of the Unit.

All staff are encouraged to engage with the wider research community through attendance at national and international seminars, workshops and meetings, and funds are available to support such visits. The Unit takes as flexible a view as possible as to the rearranging of teaching commitments so that opportunities to attend important conferences and make new contacts are not missed. Further to this it is Departmental policy for all members of staff to take on average, one full term of Research Leave in nine. The Unit is also open to grant applicants applying to buy out fractions of their teaching time, subject to agreement from the HoD.

# Grant application assistance

The University offers specific **training in grant application writing**. The Unit's website has a page dedicated to grants, with links to the annually updated 'Guide to Grants', which includes advice on grant writing, and a guide to submitting applications.

The University's Research and Innovation Services unit holds drop-in sessions in the Department (or, more recently, virtually) at least twice a month to aid in proposal preparation, particularly on the financial and administrative aspects.

Seedcorn funding is also available, e.g., for network formation.

Within the Unit, all proposals are internally peer-reviewed, and mechanisms exist to put successful grant-holders in touch with new grant-writers to offer them advice; in addition, mock interviews are arranged for candidates who make it through to interview for larger grants such as science council fellowships and ERC awards. These tactics are bearing fruit: for example, in 2019 Drs Bullimore and Chhita were awarded EPSRC Early Career Fellowships, and in 2020 Dr Magee was awarded an ERC Starting Grant.

# **Postgraduate Students**

Turning now to the PGR students within the Unit, Durham was the originator of the '**Prospects in Mathematics' conference series** for the encouragement of PhD recruitment into mathematics on a nationwide basis. These events have now become peripatetic, the last one to have been held in Durham being in 2013 (before the current assessment period). Nevertheless, the Unit continues to be active in advertising its postgraduate opportunities, arranging open days and advertising posts as they become available.

There have been successful efforts to broaden the support base for studentships during the assessment period, for example a project involving Dr Caiado, Prof. Goldstein and Dr Vernon from the Statistics subgroup in collaboration with Shell Brazil, CNPq (a Brazilian funding council) and the University of Campinas to bring 3 PDRAs and 4 dual-degree PhD students to Durham, and others joint with Sao Paulo, UNAM (Mexico) and UPMC Paris.

A locally-funded initiative has been the **Master's Scholarship for students from Africa**, supported by the Unit together with Trevelyan College and alumni donations, with the parallel use of Commonwealth MSc Scholarships. This has been inspired by the Department's engagement with the African Institute for Mathematics Sciences (AIMS), which is described in **section 4** below. To date, four students have graduated through this route, two from Madagascar, one from Nigeria and one from Zambia. Three of these graduates (two of whom are women) are now pursuing their PhD studies, two in Germany and one in Austria. Stable funding for the coming three years of this scheme, which will be widened to allow applications from all countries on the OECD's DAC list of countries eligible to receive Overseas Development Aid (ODA), has been secured through a generous donation from Scott Logic, a Newcastle-based software development company.

All postgraduate research students (PGR) have two supervisors, who help them with the skills needed for career progression. There are frequent (normally weekly) meetings between the student and one of the team, to encourage and monitor progress. The students are strongly encouraged to attend relevant seminars, and there are several PGR-organised seminar series. In addition to annual academic progression interviews, PGR students have a pastoral interview with independent academic members of staff, at which all topics are open for discussion, including career choices and advice. PGR students are given specific training via the Next Steps in Academia initiative, and further discussion and advice, and peer support, via the PDRA Forum and the Women's Lunch.

Each research group also provides targeted lecture courses and seminars to bridge the gap from undergraduate level to postgraduate. These include:

- Lectures on Particles, Strings and Cosmology for Masters and first-year PhD students in the Mathematical and Theoretical Particle Physics group, divided into 24 topics and delivered in around 300 hours of lectures (the precise number varying from year to year). These are run jointly with the Department of Physics under the umbrella of the Centre for Particle Theory and are accompanied by supporting tutorial classes.
- Lectures of the MAGIC consortium: the Unit is a member of this consortium and has a specialised facility providing the necessary videoconferencing technology. This programme delivers approximately 500 hours of postgraduate lectures per year over 21

universities, consisting of 10- or 20-hour courses in selected topics in mathematics. Durham itself typically contributes three courses per year to the consortium.

- 24 20-credit modules from the MSc in Mathematical Sciences.
- Intensive one-week courses in statistics run by the Academy of PhD Training in Statistics (APTS; <u>http://apts.ac.uk</u>) of which Durham is a member institution, with Dr Einbeck a member of the Executive Committee.
- Student-only seminar series and journal clubs.

Students also participate in further events organised by the LMS, EPSRC, STFC (including the British Universities Summer School in Theoretical Elementary Particle Physics), and the RSS.

Regional one-day conferences that the Unit champions such as the LMS-funded North British Mathematical Physics Seminar (NBMPS) series also have regular dedicated slots in their programmes for PhD students to speak and explain their work in a supportive environment. The University provides a comprehensive programme of key-skills development for postgraduate students, with topics including the giving of presentations, academic writing, use of online information sources, time-management and preparing for PhD examinations.

Research students are strongly encouraged to take the opportunity to be involved in teaching undergraduate modules, and in their second and third years can develop their teaching skills by delivering small group tutorials and computer classes. For these teaching activities they are first required to undergo University training sessions and specialised Departmental training sessions for subject-specific advice as to best practice and expected standards.

Each student prepares an annual report on his/her activity and progress during the preceding year, and is interviewed by two members of staff, neither of whom is the student's supervisor. The Department also operates a formal procedure for assessing whether first-year students may progress to their second year. The Department encourages research students to attend conferences and summer schools which will benefit their development, and gives full financial support; in practice, most students attend at least one such activity each year. The result of such conference attendance is discussed with the supervisory team, to make sure that active participation is maximising the impact of this activity.

Students from the Unit are also involved with wider initiatives beyond their research projects including, but not limited to, conference organisation where Durham hosts events such as the annual **Young Theorists Forum** associated with the Annual Theory Meeting, or the first of what is now a Europe-wide series of **Young Researchers Integrability Schools**, which was organised in Durham in July 2015 as part of the GATIS (Gauge Theory as an Integrable System) European Innovative Training Network. The Department is also a participant in the University-wide **First Generation Scholars Network**, which aims to celebrate and promote the achievements of people who are the first generation in their family to go to University, providing the extra support First Generation Scholars may need to negotiate University life and get the most from their time at Durham.

### Section 3. Income, infrastructure and facilities

### The New Building

The most significant infrastructural development for the Unit over the REF period has been the construction of the new building, which began in November 2018 following decisions taken in the Faculty of Science's 2016 Meta Review. The building, shown in **figure 2**, is shared with the Department of Computer Science, and at a cost of £42M it represents a major financial commitment by the University to the future development of the two departments and their planned growth through to 2027. Completion of the building was delayed by the Covid crisis,

and the move to the new building, originally scheduled for August 2020, was finally accomplished by late December 2020. While final staff occupancy has been further delayed by the national lockdown, it is expected to be in full operation by Easter 2021.



Figure 2: The new Mathematical Sciences and Computer Science building (photo: P. Heslop).

**Mathematical Sciences** occupies the top floor and half of the second floor of the building and shares the use of common areas such as a 120-seat lecture theatre and an adjacent catering space. The design has been made with the conscious aim of facilitating research discussion within and between the different subgroups of the Unit, with a variety of meeting rooms and 'breakout spaces' equipped with writing boards distributed throughout the building. Many of the breakout spaces are adjacent to shared PhD offices, so as to provide a way to integrate PhD students into the vibrant research environment of the Department.

The blurring of boundaries with colleagues in Computer Science, such as the ACiD (Algorithms and Complexity in Durham) group which already has links with some members of the Unit, will be another benefit of the Department's new setting.

An upgraded MAGIC room will double-up as a virtual research space for zoom-like group discussions with collaborators worldwide, while the lecture theatre combined with a further seminar room will enhance the Unit's ability to host national and international conferences. Two further meeting rooms equipped with state-of-the-art videoconferencing facilities will be available for research collaborations.

### The Condor Cluster

The centrepiece of the Department's research infrastructure is its suite of computing facilities, and in particular the high performance computing capabilities provided by the so-called Condor

cluster. Created in 2003, it has received investment from the University's Capital Infrastructure Fund since 2010 to the tune of £252K (including £114K since 2014), in addition to regular financial support from Departmental sources and EPSRC. This has brought the cluster to its current strength of 113 six-core computers and over 90 quadcore computers all with 32GB RAM. This hybrid cluster of high-performance graphical computers provides the specialized facilities required to perform intensive state of the art computations, both algebraic and numerical.

# Hamilton High Performance Computing Service

Members of the Department needing significant parallel computing have access to the "Hamilton" High Performance Computing service. The current setup comprises two computer clusters, Hamilton 6 and Hamilton 7, which were commissioned in 2014 and 2017 respectively at costs of £750K each time, with a total of approximately 4,700 cores. Hamilton 8 is due for delivery by summer 2021, and with 15360 cores and a cost of £1.2m it represents a significant further upgrade to the service. Hamilton is operationally run by Advanced Research Computing (ARC), a dedicated computing support unit within the Research Division of the University, and overseen by an academic steering group. ARC also supports academics in the use of other intensive computing facilities in their research.

# **External Computing Facilities**

Members of the Department also make use of external computing facilities as appropriate. A recent example is the award of 40 million CPU hours by the PRACE consortium (Partnership for Advanced Computing in Europe) to the EAGLE galaxy formation project involving Dr Ian Vernon from the Unit along with Profs Richard Bower and Carlos Frenk from the University's Department of Physics, and several other international researchers.

This is part of a long-standing collaboration between the Mathematical Sciences and Physics Departments that exists under the aegis of the Institute for Computational Cosmology, and is an example of the significant benefits provided by the University's structure of institutes in facilitating cross-departmental interdisciplinary work.

# **Departmental Visitors Programme**

A new development since REF2014 has been the instigation of a Departmental Visitors Programme, encouraging distinguished scholars who share a research interest with at least one member of the Department to visit for periods ranging from one week to three months. Typically, visitors under this new programme collaborate with members on a topic of current interest, participate in the research environment of the Department, and give a seminar during their visit.

A key part of this programme is provision of free accommodation to visiting scholars and their families in the recently-refurbished Departmental Flat, which belongs to Teikyo University of Japan in Durham and is allocated to the Unit for its long-term use. The flat is located in the grounds of St Mary's College, a short walk from the Department.

# **Income Generation**

Income to the Unit comes from a wide variety of sources, as illustrated by the following examples of funding awarded during the assessment period. We note that a number of the larger research grants, such as the EPSRC Early Career Fellowships for Drs Chhita and Bullimore, the ERC Starting Grant for Dr Magee, and the significantly increased value of the most recent STFC rolling grant, were made late in the assessment period and so are not fully reflected in the research income data.

• European Commission: transferred funding from the GATIS to GATIS+ network, £63K; NUTS (Nuclei Using Topological Solitons), £122K; SAGEX, £343K; UTOPAIE, £370K;

SPIN (Symmetry Principles In Nature):  $\pounds$ 1M, ERC Starting Grant awarded to Dr Magee,  $\pounds$ 1.1M.

- The Department of Health: £147K for the project 'Connected Health Cities'.
- Roxar Software Solutions (now Emerson): £150K and £157K.
- IBEX Innovations Limited: £51K.
- Atom bank: £211K.
- STFC: £741K, £493K and £1.1M for the Particles, Fields and Spacetime rolling grant, and £363K for the Dundee-Durham Solar and Astrophysical consortium.
- EPSRC: £770K and £740K for two early career fellowships, awarded to Drs Chhita and Bullimore in 2019, along with a variety of first and standard grants.
- The Simons Foundation: £315K for the Simons Collaboration on the nonperturbative bootstrap.
- The Leverhulme Trust: £260K for SPOCK: Scientific Properties of Complex Knots.
- The Royal Society: £421K and £621K for the Royal Society URFs of Drs Lipstein and Sulejmanpasic.

Structures are in place to facilitate the generation of income and impact, some of which were already mentioned in **section 1**. Working together with the Unit's Director of Research, Director of Impact, Finance Administrator and full-time Senior Research Administrator, central support for all aspects of research and impact development and management is provided by Research and Innovation Services (RIS):

- Regular communications ensure all staff are aware of internal and external funding opportunities, as well as the support available to develop research and impact.
- Three RIS staff members have specific responsibilities to support research in the Unit from advertising research grant opportunities, supporting application preparation and submission, through to grant management.
- Regular drop-in sessions, open to all staff, are held in the Department so all potential developments can be explored, and support is readily available. During the Covid crisis these have switched to on-line sessions on Teams.
- In addition, a Senior Impact & Engagement Officer actively supports impact within the Unit, working with all staff engaged in impact activities. Where required, further specialised support is available in RIS, such as for business development and knowledge transfer.

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

### National and International Collaborations

Given the wide range of nationalities represented in the Unit, it is not surprising that its members participate in many international collaborations. Over the course of the assessment period collaborations have involved other researchers based in Australia, Belgium, Brazil, Canada, China, France, Italy, Japan, South Korea, Taiwan, Poland, Portugal, Russia, Spain, and the USA.

These links have been fostered by the Unit's support for its academics to visit other institutions, its various visitor programmes, and the active participation of the Unit in a wide variety of national and international networks, including the following during the assessment period:

- LMS funded networks: the North British Mathematical Physics Seminar; the North British Geometric Group Theory Seminar, and the Yorkshire and Durham Geometry Days.
- The annual UK Integrable and Conformal Field Theory (UKICFT) meetings, last held in Durham in 2015.
- The GATIS European FP7 network <u>https://gatis.desy.eu/</u>, which ran from 2013 to 2016 and then morphed into GATIS+ <u>https://gatisplus.desy.de</u>.

- The UTOPIAE (Uncertainty Treatment and Optimisation in Aerospace Engineering) European Innovative Training Network <u>http://utopiae.eu</u>, from 2017 to 2021.
- The SAGEX (Scattering Amplitudes: from Geometry to Experiment) European Innovative Training Network <u>https://sagex.ph.qmul.ac.uk</u>, from 2018 to 2022.
- The Simons Collaboration on the Nonperturbative Bootstrap.
- The Durham Symposia, described in more detail below.

## Meetings and Conferences

Members of the unit have given 120 invited keynotes or talks at international conferences during the assessment period, including plenary talks at the main annual conferences in the research areas of the subgroups.

These conferences include:

- Strings
- String Math
- Amplitudes
- The Spring Meeting of the German Physical Society
- The American Astronomical Society Meeting
- Computational and Methodological Statistics (CMStatistics)
- The Summer Conference on Topology and its Applications
- The Annual Congress of the Chinese Mathematical Society

Members have also delivered talks at workshops and conferences at major research institutes worldwide including:

- The Steklov Institute
- The Galileo Galilei Institute
- The Simons Center for Geometry and Physics
- CERN
- The Aspen Center for Physics
- The Erwin Schroedinger Institute in Vienna
- CIRM Luminy
- Oberwolfach
- CRM Montreal
- The Institute for Advanced Study, Princeton
- The Banff International Research Station
- The Fields Institute
- The Max Planck Institute for Mathematics
- The Perimeter Institute

### Meetings hosted in Durham

Many meetings have been hosted in Durham. **The Durham Symposia**, formerly known as the LMS-Durham Symposia, (<u>http://www.maths.dur.ac.uk/symposia/</u>) have been a regular item on the UK and international mathematical calendar since 1974, and eleven such meetings have been hosted by the Unit during the assessment period. National funding for these Symposia moved elsewhere in 2020, but the Unit is committed to maintaining the tradition of Durham Symposia and will continue to host at least one Symposium per year into the future. The first of the newly-named Durham Symposia, on the Mathematics of Constraint Satisfaction, was due to be held in July 2020 but has been delayed by the coronavirus outbreak to summer 2021.

The Unit, in conjunction with the Physics Department, also hosts the **STFC-funded Annual Theory Meeting**, which gathers together the UK Theoretical Particle Physics community.

In addition to the many other specialised conferences and workshops that have been held in Durham over the assessment period, the Unit organised the **2017 British Mathematical Colloquium,** the major annual meeting of the UK Mathematics community.

The Unit also organises an annual **Collingwood Lecture**, with the lecturers in the assessment period being Prof. Wendelin Werner (Fields Medallist, Zurich), Prof. Martin Hairer FRS (Fields Medallist, Warwick, now Imperial), Prof. Ray Goldstein FRS (Cambridge), Prof. Pierre Cartier (IHES, Paris), and Prof. Gwyneth Stallard (Open University).

### **Pascal Fellowships**

In addition to the meetings hosted in Durham, the Unit's programme of Pascal Fellowships brings eminent mathematicians to Durham. In the assessment period, the Pascal Fellows have been Prof. Gary Gibbons FRS (Cambridge), Prof. Dimitri Petritis (Rennes), Prof. Caroline Series FRS (Warwick), and Prof. Peter Diggle (Lancaster).

## International journals

Members of the Unit sit on the editorial boards of 18 international journals. Amongst them, Prof. Parker is joint Editor-in-Chief of Geometriae Dedicata. Prof. Hunton is the Publications Officer of the London Mathematical Society, in charge of running the LMS books and journals portfolio, which includes managing contracts, setting long-term strategy, appointing and overseeing editorial boards, and has represented the UK Mathematical Learned Societies at UKRI consultations on Open Access. He has also been the Managing Editor of the Open Access Transactions of the LMS.

## Panel membership

In addition to editorial board memberships and refereeing duties, members of the Unit sit on many panels and committees, both in the UK and abroad. These include EPSRC Fellowships, New Horizons, Programme Grant and Responsive Mode panels, STFC, NERC and ESRC panels, the UKRI Future Leaders Fellowship Panel College, the Leverhulme Trust, the Royal Society Research Grant and URF Schemes, and the Research Grants, Research Meetings and Prizes committees of the LMS within the UK; and panels for the European Research Council, the Irish Research Council and Science Foundation Ireland, the Research Foundation – Flanders in Belgium, the Swiss National Science Foundation, the Swedish Science Council, KAUST Saudi Arabia, the Czech Science Foundation, the Australian Research Council, the Royal Society of New Zealand, NSERC Canada and the Fund for Scientific and Technological Research in Argentina.

The work of the Unit's members has been recognised in a variety of international awards and prizes during the assessment period, including the following:

- Prof. Yeates was awarded the 2019 Karen Harvey prize of the American Astronomical Society (<u>https://spd.aas.org/prizes/harvey/previous</u>) and delivered the prize keynote lecture at the 234<sup>th</sup> AAS meeting in St Louis, in June 2019 (<u>https://aas.org/meetings/aas234</u>). His talk was entitled 'Where do solar eruptions come from?'.
- Prof. Goldstein and Daniel Williamson (a former Durham PhD student, now at the University of Exeter) were awarded the 2015 Lindley Prize for their paper 'Posterior Belief Assessment: Extracting Meaningful Subjective Judgements with Bayesian Analyses of Complex Statistical Models', published in Bayesian Analysis, 10, 877-908, 2015.
- Prof. Coolen, with Tien Thach and Radim Bris, won an IEEE Best Paper Award for their paper 'Mixture Failure Rate: a study based on cross-entropy and MCMC method' in Proceedings of the International Conference on Information and Digital Technologies 2017, Zilina, Slovakia, July 2017. IEEE, pp. 388-397. He also received the 2020 Donald Julius Groen Prize from the Institution of Mechanical Engineers (IMechE, UK) – Safety

and Reliability Group, for the paper 'Extending the survival signature paradigm to complex systems with non-repairable dependent failures' (Journal of Risk and Reliability, 233 (2019), 505-519), with H. George-Williams, G. Feng, M. Beer and E. Patelli.

- The Innovate UK / KTP award for 'Best Future Innovator' was won by Ryan Jessop, a Durham graduate, for his work with Dr Cumming on the Unit's KTP project with Clicksco mentioned earlier.
- Dr Garcia Etxebarria won the Martin and Beate Block Winter Award (2017) from the Aspen Center for Physics, USA.

### **Dissemination to public audiences**

On the national stage, members of the Unit have been active in the general dissemination of research to public audiences, from talks and media appearances on programmes such as *In Our Time* on Radio 4, through to participation in more-local events such as the Café Scientifique, Science Saturdays (<u>https://www.dur.ac.uk/physics/satmornscience/</u>) or the University's annual Celebrate Science event (<u>https://www.dur.ac.uk/celebrate.science/</u>), during which school children (mainly aged 7-11) are given the opportunity to engage over the course of three days with exciting scientific ideas with practical demonstrations and exhibits. The Unit also maintains significant links with schools in North-East England, with members giving outreach talks, and leading Coding Clubs and Hackathon events.

## **International Outreach Activities**

The Unit is also involved in outreach activities at an international level. Three examples are as follows.

### • The African Institute of Mathematical Sciences (AIMS)

This is an Africa-wide network of Institutes whose primary function is the teaching of a one-year Masters Programme in the Mathematical Sciences to students from all over the continent, all of whom are supported by full scholarships.

Members of the Unit have taught at AIMS centres in Cameroon, Ghana, South Africa and Tanzania, and Durham University signed a partnership with the AIMS network in 2017, building on a previous MoU with AIMS Ghana.

The Unit has also set up a scholarship to enable students from Africa to study for an MSc at Durham, which has so far seen three students from AIMS (plus one further AIMS student supported by a Commonwealth Scholarship) graduate, three of these four proceeding to PhD studies. As described in **section 2**, the scope of this scholarship has now been widened and in future, applications from all countries on the DAC ODA list will be considered.

### • Annual Palestinian Advanced Physics School, West Bank

Since 2016, the Unit has been involved in organising and teaching at this school, providing lectures for Palestinian Physics students. Schools have been held in 2016, 2017, and 2019. The goal of the programme is to introduce Palestinian Masters and advanced undergraduate students to contemporary topics in physics research through lectures delivered by international leaders in the field.

The schools also have interactive problem solving sessions, discussions on life in academia, and opportunities for networking; each school is attended by students from the major universities in the West Bank.

## • The India-Bangladesh Winter School

The Unit has helped organise and teach at the first India-Bangladesh Winter School, designed to build connections between emerging theoretical physics research groups in Bangladesh and established research programmes in neighbouring India. The first school was held in the winter of 2019 at the International University Bangladesh in Dhaka. International experts from India, the USA, and the Durham Unit delivered lectures on topics in high energy physics, which were attended by Bangladeshi Masters students.

# Response to the Covid pandemic

The Unit's long-term strategy to extend impact-related activity across all groups has been described, along with a range of examples of this work, in **section 1**; this material will not be repeated here. However, it is also important to be able to respond to more immediate national and international priorities, of which the Covid crisis is a prime example. This has posed many challenges to mathematicians, and members of the Unit have been active in addressing a variety of them. The work of Dr Iqbal for the government of Bangladesh was already mentioned in **section 1**; and within the University itself, Dr Caiado and Prof. Ramagge, together with Sophie Daniels from the Strategy Development Unit, led the Durham University Mass Testing Initiative, working with Public Health England, the Department of Health and Social Care and Deloitte to enable 18,000 people to self-administer SARS-CoV-2 tests using Lateral Flow Devices on a regular basis. This pioneering project, still ongoing, attracted extensive media coverage and interest from other universities. In the following we highlight three further examples of the Unit's activity in response to the pandemic.

## • DECOVID: EHR data to inform clinical practice during the pandemic

Dr Aslett is a member of the leadership team of DECOVID, a project founded by University Hospitals Birmingham NHS Foundation Trust, University College London Hospitals NHS Foundation Trust, the Alan Turing Institute, University College London and the University of Birmingham. DECOVID brings together high-resolution patient level electronic health record (EHR) data from major NHS foundation trusts both for external data requests and for analysis by the DECOVID analytics workstream (co-led by Dr Aslett), which consists of 7 teams of world leading experts in intensive care, EHR and health analytics, to address questions prioritised by a panel of expert clinicians and approved by the Data Trust Committee of patient representatives. The 4 core questions being analysed at the time of writing are around increased incidence of thrombosis in Covid-19 patients; the effect of different respiratory support strategies (CPAP/IMV) for severe Covid-19 patients; additional risk factors for COPD patients who experience exacerbations or complications due to Covid-19; and to understand (and possibly update) commonly used early warning scoring systems mandated in hospital use.

### • Statistical modelling and advice to the Local Resilience Forum

County Durham and Darlington Local Resilience Forum (LRF) is the leader of the local area strategic response to the COVID-19 pandemic. In response to a request made in April 2020 by the Chief Fire Officer of County Durham and Darlington (and LRF Chair) for support from Durham University for the work of the Data Cell in statistical analysis and modelling to support the COVID response, Dr Caiado joined the Data Cell as the University representative.

Testimonial from Jenny Haworth, Head of Strategy for Durham County Council and Chair of the County Durham and Darlington Data and Intelligence Cell, describes Dr Caiado's input to the Data Cell as "outstanding", providing a sounding board for epidemic modelling and scenario planning of epidemic spread and directly leading, for example, to the development of a local COVID epidemic heat map ahead of the second wave and ahead of any national work. This heat map was presented at national level within Public Health England, and also across the

North East and Yorkshire region, thereby driving improvement in surveillance regionally and nationally. The work included the adaptation of the Durham University COVID simulation model to the Durham and Darlington footprint, informing the understanding of epidemic spread and intervention measures, and also provided "critical support and challenge in developing understanding of epidemic spread and infection control in care homes". Dr Caiado was described as a role model in what good collaboration between university research departments and local agencies looks like, and how research such as the simulation model can be translated into practice.

### • Modelling the epidemic: the JUNE simulation

In order to understand, analyse and predict the global development of the Covid-19 pandemic, increasingly sophisticated models are required. These must be of sufficient granularity to capture the details of home, work, travel, socialising, and behavioural responses to government lockdown strategies. Working in collaboration with a group from the Physics Department led by Prof. Krauss (a member of the Institute for Particle Physics Phenomenology and the Director of the Institute for Data Science), Dr Vernon helped to develop the JUNE model<sup>1</sup>, making use of his previous experience applying statistical techniques to epidemiology in other contexts. These contexts include the work with the Institute for Disease Modelling in Seattle for the Bill and Melinda Gates Foundation that was mentioned in **section 1**, and previously MRC and currently Welcome Trust funded work with collaborators at the London School of Hygiene and Tropical Medicine.

The JUNE model is currently the most sophisticated model of Covid-19 in the UK. It is extremely computationally demanding, requiring substantial supercomputer time, and possesses many uncertain parameters. This would normally pose insuperable obstacles both to the calibration of the model, and to its use to produce trustworthy forward predictions with realistic uncertainties. Dr Vernon contributed crucially to the project through a suite of Uncertainty Quantification (UQ) techniques, developed by the Durham statistics group, designed to deal with precisely such computationally demanding stochastic agent-based disease models. These techniques involve fast Bayesian emulation methodologies that provide speed increases of several orders of magnitude for the JUNE model, and an overarching UQ framework to represent all major sources of uncertainty, many of which are missed in standard epidemiological modelling approaches. This made possible the calibration of JUNE, and the subsequent predictions that were used by NHS England. The model helped NHS England's Emergency Preparedness Resilience and Response (EPRR) team understand the timing and nature of surges in infection, the spread of the disease through different age strata and the impact of social restrictions and other non-pharmaceutical interventions. The outputs from this model continue to provide unique insight and have helped to inform the national strategy and response to the COVID-19 incident.

Dr Kevin Fong, National Clinical Advisor in EPRR for the Covid-19 Incident, joined the JUNE team in May 2020, bringing further clinical expertise, access to up-to-date national data sets, and facilitating direct and efficient communication of modelling predictions to NHS England. He wrote "There is currently no other model in hand that is able to usefully explore inter-regional dependencies of the pandemic or the asymmetries produced by socioeconomic differences in the general population. Your work so far has provided unique and valuable insight and has helped us to close the gap between the modelling needs of the strategic planners and those of our frontline operational teams."

<sup>&</sup>lt;sup>1</sup> JUNE: open-source individual-based epidemiology simulation https://www.medrxiv.org/content/10.1101/2020.12.15.20248246v2.full.pdf submitted 16/12/2020