**Institution: The University of Manchester**

**Unit of assessment: 10 (Mathematical Sciences)**

## 1: Context, structure, research and impact strategy

### 1(i) Context and structure

Mathematical Sciences research at Manchester is diverse and impactful. With contributions to topics ranging from Lie algebras to landmines, ergodic theory to epidemiology and machine learning to metamaterials, the Unit impacts on fundamental aspects of the discipline and its applications. Mechanisms to support research ensure that the Unit provides an intellectually stimulating environment for all.

The Unit comprises the **Department of Mathematics** (DoM) and the affiliated **Manchester Centre for Nonlinear Dynamics** (MCND) at the University of Manchester (UoM). It provides an outstanding environment in which to carry out world-class research and to attract exceptional researchers across all career stages. The Unit is strongly research intensive with 92 category A submitted staff (89.95FTE), including 17 ECRs. 90 Unit staff reside in the DoM and 2 in the Department of Physics & Astronomy (DP&A). The Unit hosts over 120 PGR students and 150 postgraduate taught students. The DoM and DP&A reside within the School of Natural Sciences together with the Departments of Chemistry, Earth and Environmental Science and Materials. The School sits alongside the School of Engineering, comprising the Faculty of Science and Engineering (FSE).

Since REF2014, the Unit has enabled increases in key measures of success (figure 1). The 22 major staff prizes and awards included a Royal Society Professorship (**Higham** FRS) and Foreign Membership of the Royal Society (**Dongarra** ForMemRS). Additionally, research income more than doubled to GBP26M from GBP11.4M at REF2014.

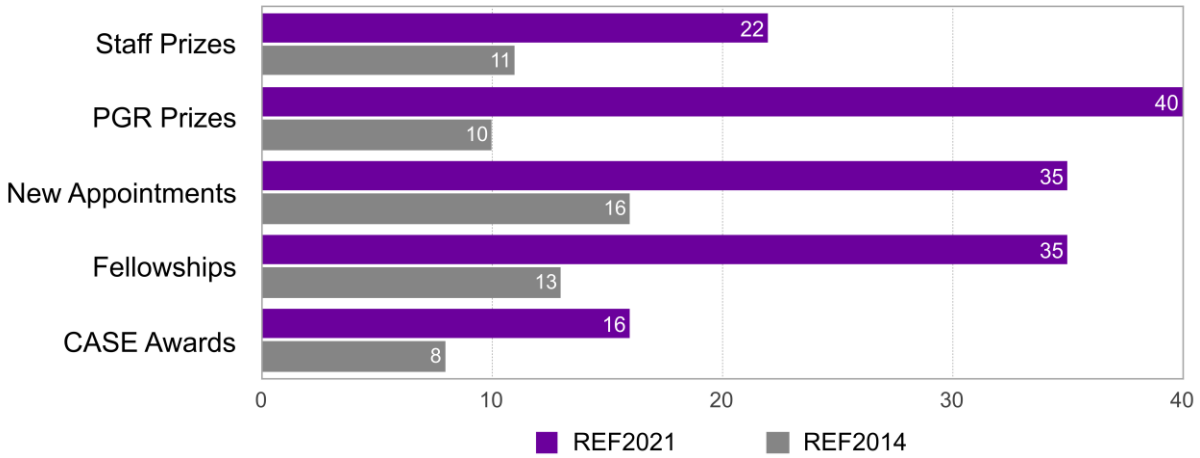
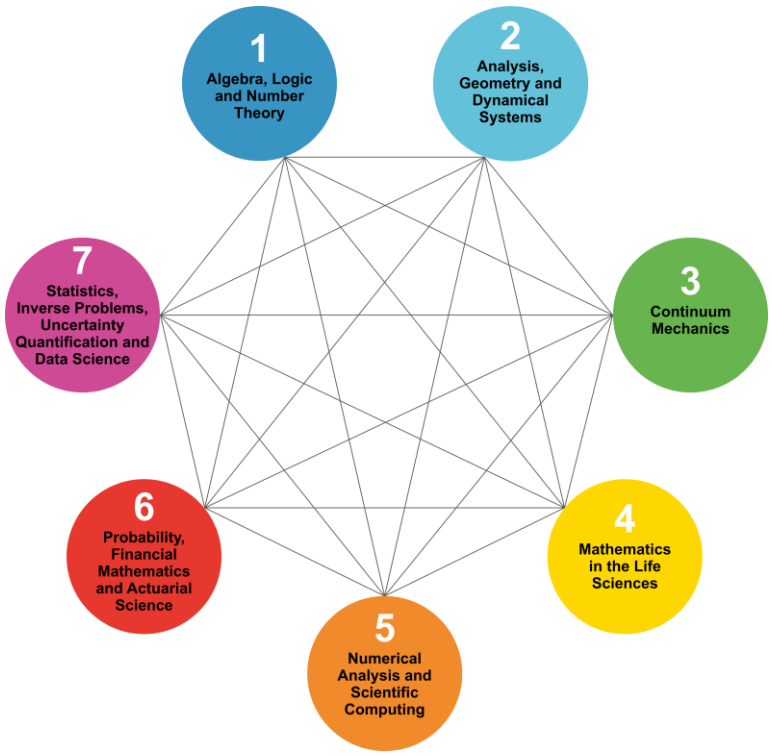



***Figure 1. Illustrating increases in key measures of success***

Over the period, the Unit has strategically strengthened its world-leading expertise in algebra, continuum mechanics, inverse problems, numerical analysis and probability whilst growing activity in applied statistics, number theory, mathematics in the life sciences, uncertainty quantification (UQ) and data science. The Unit's interdisciplinary activity has flourished with staff conducting research in advanced materials, data science, digital trust and security, energy, geophysics and planetary science, and the life sciences and public health. The Unit's impactful research has broadened, involving engagement with over 100 non-academic external partners.




The Unit is located primarily within the Alan Turing Building (ATB) at the heart of the University. MCND's experimental facilities are housed in the adjacent Schuster Building, home of the DP&A. Since REF2014 the Unit has restructured its research into seven interconnecting themes (figure 2). Informal links between all themes are an important facet of the Unit's culture, driving an array of intradisciplinary research.

***Figure 2. The Unit's interconnected research themes***

## 1(ii) Research objectives and achievement

The Unit identified broad strategic objectives in its REF2014 submission, addressing intellectual environment, recruitment, interdisciplinarity and impact, and income. It refined and adopted these as the blueprint for its development over the assessment period, via four strategic objectives:

**O1: Intellectual environment.** *Provide an outstanding environment in which to carry out world-leading research across the mathematical sciences.*

**O2: Recruitment.** *Appoint exceptional researchers to grow core strengths and to move into emerging areas of research.*

**O3: Intradisciplinarity and interdisciplinarity.** *Establish a unique identity associated with mathematical sciences research spanning internal and external boundaries and have transformational impact beyond academia.*

**O4: Income.** *Grow and diversify research funding to support high quality research.*

These objectives were defined by the Departmental Leadership Team, informed by the Departmental Research Committee, comprising the Head of Research (HoR, **Parnell**), Head of Business Engagement (**Hewitt**), Head of PGR (**Heil**), Outputs Lead (**Tisseur**), Impact Lead (**Hewitt**), and Research Leads (**House**, **GO Jones** and **Powell**), who assist with area-specific research strategy.

Following REF2014, the Unit recognised that restructuring its research could have a major impact on achieving **O1-O4**. The subsequent move from 12 narrowly defined sub-discipline areas to 7 broadly defined and overlapping themes created a more open environment, encouraged new interactions, and contributed significantly to the Unit's achievements over the period. The restructure also provided a strategic framework for recruitment, which has underpinned a planned reshaping of the Unit, with 35 new permanent appointments (see figure 3 below, illustrating the distribution of these across themes). The Unit invested strategically in ECRs, joint appointments and researchers with interdisciplinary interests, including experimental programmes. One key aim of the restructure was to increase

opportunities for interdisciplinary research, with explicit alignment of themes to opportunities in the physical sciences, engineering and the health and life sciences. The success of this approach is evidenced by e.g. **Chernyavsky**'s MRC- and EPSRC-funded research coupling modelling and experimental research on placental transport and **Evatt**'s Leverhulme Trust-funded project (with the British Antarctic Survey), the first UK-led expedition to the Antarctic to find meteorites. This growth in interdisciplinary research, described further in Section 1(iv), has driven significant diversification of funding beyond EPSRC (Section 3(i)).

Alongside this radical theme restructure, the Unit continued to exploit successfully the strengths and space of the ATB, ensuring a physical environment that is highly conducive for producing world-class research in mathematics. Coupled with a healthy sabbatical programme (Section 2(iv)), funding (Section 3) and wide-ranging research support mechanisms (Sections 3 and 4), the Unit aided staff in solving numerous open problems, as discussed in theme descriptions below. Over the period, staff published over 1300 research papers and attended over 1000 seminars in the Unit. As planned, the international standing of the Unit strengthened significantly: **Higham** was SIAM President (2017-18) and over the period, staff in the Unit have (numbers in parentheses indicate comparative data from REF2014)

- published with researchers in over 450 (100) international academic institutions in over 60 countries on six continents;
- published 60% (40%) of all outputs in the period with overseas collaborators;
- acted as senior editors for 14 (6) international journals.

Impact-enabling strategies described in Section 1(iii) cemented the Unit as a major force in UK industrial mathematics, including collaborations with over 100 external organisations (figure 4). Engagement broadened to non-profit sectors, 29 staff co-authored papers with non-academic partners and via research in big data and advanced materials (Section 1(iv)), the Unit contributed to national priorities. Noteworthy examples of impact-driven research include: **Pellis**' critical calculation of the UK's doubling rate of COVID-19 infections in March 2020, which, through SPI-M and SAGE, contributed to rapid UK lockdown; and **Lionheart** stepping into the minefield to detect landmines, and into the hospital to develop novel EIT methods for respiratory monitoring.

The headline examples above were underpinned by achievements in the Unit's seven overlapping themes, which are now described.

**(1)** ***Algebra, Logic and Number Theory:*** **(9 appointments)**
Strength in algebra was recognised by partnership with the Heilbronn Institute for Mathematical Research (HIMR) North in Manchester (GBP1.01M). Major results in algebra were proved by **Premet** (with Stewart), on the classification of the maximal subalgebras of exceptional simple Lie algebras and by **Eaton** (with Livesey) on Donovan's conjecture for abelian p-groups (supported by GBP687K EPSRC funding). In tropical algebra, **M Johnson** and **Kambites** established a deep correspondence between the geometric property of pure dimension for tropical polytopes, and the algebraic property of projectivity for modules over the max-plus semifield. The theme saw sustained growth in number theory having sought and secured philanthropic funding (GBP1.04M). The resulting appointments reinforced overlaps with theme 2. Future goals are to appoint to develop strengths in algebra and logic alongside HIMR North (see UoM Institutional Environment Statement, Section 2(iv) (REF5a 2(iv)) and to continue to attract funding from diverse sources.

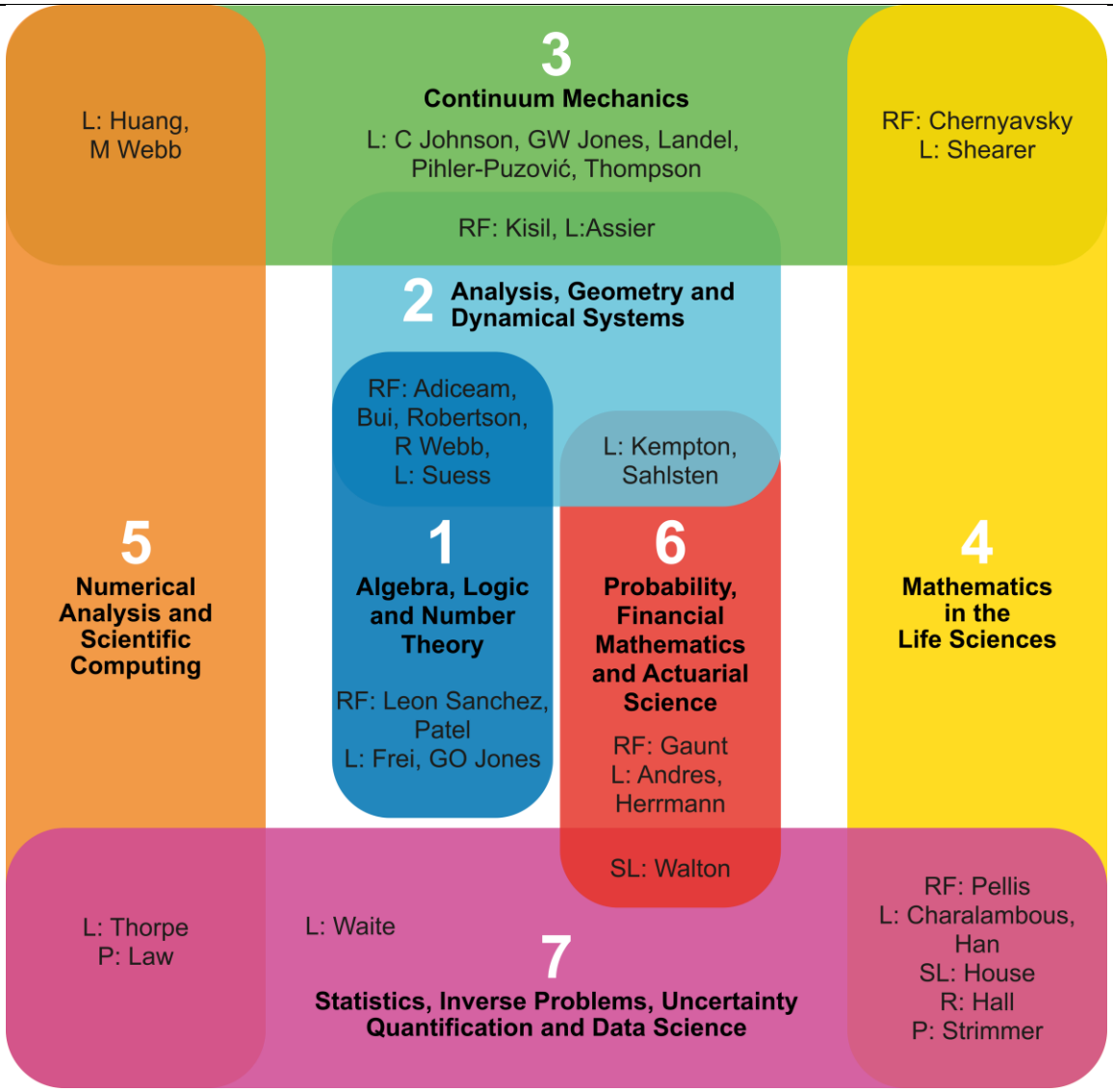



***Figure 3. Illustrating new permanent appointments in themes and their overlaps, together with their role at appointment (RF: Research Fellow, L: Lecturer, SL: Senior Lecturer, R: Reader, P: Professor).***

**(2)** ***Analysis, Geometry and Dynamical Systems:*** **(2 appointments)**
This theme saw intradisciplinary research conducted at intersections with theme 1. In algebraic geometry, **Suess** (with Ilten) gave the first effective application of Chen-Donaldson-Sun's resolution of the Yau-Tian-Donaldson conjecture. Connecting number theory with analysis and dynamical systems, **Sahlsten** (with Le Masson) proved a quantum ergodicity theorem for fixed spectral window and sequences of compact hyperbolic surfaces converging to the hyperbolic plane. The legacy of the inspirational Broomhead, who passed away in 2014, lives on in the interdisciplinary approach of the Unit, e.g. **Muldoon**'s work on the ecological dynamics of the upper respiratory tract microbiome on the Horizon 2020 grant CURE (GBP891K UoM share), associated with asthma treatments. Future aims are to build on recent appointments to establish critical mass at the intersection of dynamical systems and number theory and seek new application areas.

**(3)** ***Continuum Mechanics*****: (7 appointments)**
This theme has seen further growth in MCND, led by **Juel** (American Physical Society Fellow, 2019, Co-I UK Fluids Network 2016-19), combining cutting-edge mathematical and computational modelling with quantitative experimental investigations in fluids, soft matter and granular materials. MCND research featured on journal front covers on 14 occasions. **Gray** (GBP1.38M EPSRC Fellowship) showed that the μ(I)-rheology for

granular flow was ill-posed at high and low inertial numbers. Connections to advanced materials were provided by e.g. **Hewitt** (GBP1M funding) in materials modelling and **Parnell** (LMS Whitehead prize 2019, GBP2.7M funding) in metamaterials. Continued excellence across fluid dynamics, solids and wave mechanics saw the broadening of external connections, including two industry-funded research hubs (Section 1(iii)). Expertise in biomechanics ensured strong connectivity to theme 4. The Unit intends to grow its strength in MCND, and ensure broader connections to industrial partners and to advanced materials (one of UoM's research beacons) via the Henry Royce Institute.

**(4)** ***Mathematics in the Life Sciences:*** **(2 appointments)**
The emergence and extensive growth in this richly interdisciplinary theme is consistent with the REF2014 aim to increase engagement across biomedical research, from fundamental biology to healthcare applications. It builds on the strategic appointment of **Jensen**, who co-leads a Wellcome Trust PGR Programme in Quantitative and Biophysical Biology (GBP2.56M, 4 cohorts, 2016-23, involving 10 Unit staff) and is Co-I on a GBP3.78M BBSRC sLoLa project on extracellular matrix modulation. Significant funding secured by **Chernyavsky** and **Fedotov** (see Section 3(i), leveraging UoM's excellence in obstetrics and radiation therapy), supported the theme's expansion together with the joint appointment of **Shearer** with Materials. Strong overlaps with theme 7, and epidemiology in particular, added further strength. Looking ahead, the Unit will broaden collaboration with life scientists at UoM (e.g. via the Christabel Pankhurst Institute and the Digital Futures digital health theme) and beyond, bringing further diverse opportunities for large-scale partnership and impact.

**(5)** ***Numerical Analysis and Scientific Computing:*** **(2 appointments)**
Strength and broad expertise in numerical linear algebra is provided by **Dongarra** (SIAM/ACM prize in Computational Science and Engineering 2019), **Güttel** (2 KTPs), **Higham** (LMS Naylor prize and Lectureship 2019) and **Tisseur** (LMS Fröhlich prize 2020). **Dongarra** and **Higham** are at the forefront of HPC research exploiting mixed precision algorithms, and **Higham**'s probabilistic analysis provided new insights into rounding error propagation. The theme also provides wide-ranging expertise in finite element (FE) approximation. **Silvester** and **Powell** (GBP381K EPSRC funding) developed adaptive FE-based algorithms for PDEs with uncertain inputs. Alongside **Cotter** (1 KTP, with **Waite**), they provide Numerical-Analysis-focused UQ expertise and pivotal links to theme 7. Theme members have a strong track record in developing open source software (Section 1(v)) and impactful research with partners (Argent & Waugh, Arrow, Arup, IBM, NAG, NPL). Future goals include developing software to address challenges in machine learning and exascale computing, and to incorporate UQ into engineering applications, thereby strengthening links to theme 7.

**(6)** ***Probability, Financial Mathematics and Actuarial Science:*** **(4 appointments)**
**Peskir** and **Zhang** maintain a leading position in probability theory and its applications. **Peskir** solved open problems on the Markowitz mean-variance portfolio optimisation in continuous time, and the quickest detection problem for Bessel processes (open since the 1950s). **Zhang** derived discrete/lattice approximations to stochastic PDEs and reflected stochastic PDEs for the first time. **Walton** (Erlang prize 2018) resolved a conjecture by Shah et al on optimal queue-size scaling in switched networks. **Denisov** developed a general approach to renewal theory of Markov chains. As planned the theme grew links with external partners (e.g. Autotrader, NASA, Royal London, Toyota Mobility Foundation, TfGM). Future goals are to reinforce links to theme 7, further broaden collaboration with external partners and grow research in financial mathematics.

**(7)** ***Statistics, Inverse Problems, UQ and Data Science:*** **(9 appointments)**
Building on existing activity in statistics, inverse problems and numerical algorithms, a large strategic investment strengthened and broadened research across this theme. New expertise in statistical and machine learning algorithms for Bayesian inverse problems

ensured strong connections to themes 4 and 5. **Hall** (joint with the Faculty of Biology, Medicine and Health (FBMH)), **House** and **Pellis** established the Unit's epidemiology expertise (GBP1.7M funding), overlapping with theme 4. Their expertise played a critical role in aspects of the UK's COVID-19 response, with **Hall** a member (since 2006) of SPI-M. In inverse problems **Lionheart**'s leadership enabled engagement on major interdisciplinary projects (GBP7.5M) with 12 external partners. **Dorn** (3 CASE PhDs) is at the forefront of level set methods for inverse scattering. **Cotter** developed novel computational methods for inverse and multi-scale problems associated with biochemical networks. **Powell** led international UQ initiatives including a six-month Isaac Newton Institute (INI) programme (2018) and as Program Director of the SIAM UQ activity group (2018-20). Unit staff engaged strongly with UoM and national Data Science institutes, with 11 securing Alan Turing Institute fellowships. The Unit will drive continued growth in this theme, overlapping with themes 4, 5 and 6, whilst ensuring alignment with UoM's digital futures theme (REF5a 2(iv)) and national priorities.

**O1-O4** provide firm foundations for progress beyond REF2021. Growth in themes as described above will drive fundamental, applied and interdisciplinary research with impact. The Unit will further diversify income; specifically, it will identify larger-scale funding opportunities, e.g. via further philanthropic funding, the additional GBP300M EPSRC Mathematical Sciences programme, and collaborative international funding mechanisms, for both single and multiple-site projects. It will do this by

- exploiting its theme structure and existing expertise, and by appointing in new areas, to align with national priorities and outcomes of the UK Research and Development Roadmap;
- increasing engagement with external partners;
- further aligning locally with UoM research beacons (REF5a 2(iii)) and other centres of excellence.

The Unit will invest in its people across all levels from PGR (including the Heilbronn Doctoral Programme), through ECRs to its most experienced professorial staff, with Equality, Diversity and Inclusion (EDI) embedded at the heart of all processes. This will secure a diverse people pipeline and leadership in the mathematical sciences in the coming period.

**1(iii) Enabling impact**

Aligned with UoM's impact agenda (REF5a 2), the Unit continued its drive from REF2014 to broaden its impactful research. Its overarching strategy has been to adopt a flexible and responsive approach to growing relationships with external partners via multiple engagement mechanisms. This enabled the Unit to build a broad, sustainable base of research, supported by over 100 non-academic external partners (figure 4). Mechanisms facilitated the continuation of established relationships with key collaborators (Section 4(ii)) whilst enabling new collaborations to develop. 40 Unit staff engaged with partners during the period, including co-authorship of over 100 papers with 39 external organisations.

The following mechanisms enabled and facilitated impact.

**Recruitment and staff exchange**
The Unit appointed **Assier**, **GW Jones** and Knowledge Transfer Fellow **Evatt** to Industrial Mathematics lectureships, working with **Hewitt** to develop new external collaborations. The Unit gave key partner staff honorary/visiting status, e.g. Hammarling (NAG), Nigro (Thales), Monks (AWE), Zimon (IBM), and 6 KTP Associates facilitated knowledge exchange. Staff also provided consultancy (Section 3(v)).

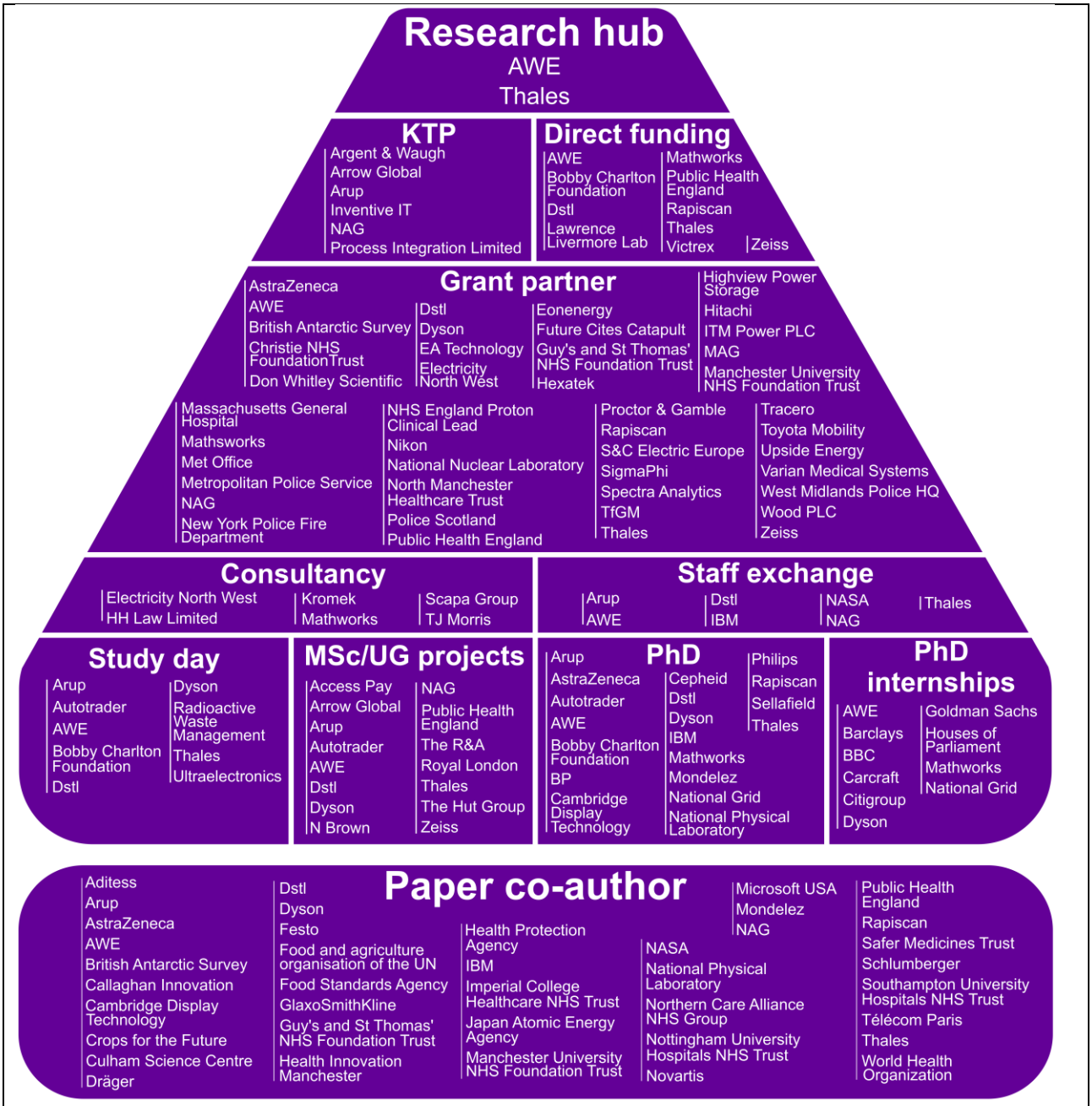



***Figure 4. The Unit employs various engagement mechanisms to collaborate with over 100 external partners.***

**Seed-corn funding**

The Unit's Applied Mathematics MSc provides an effective mechanism of external engagement. MSc (and Undergraduate (UG)) projects often stem from study days: intensive workshops with partners, who contribute GBP4K per event. During the period MSc/UG students completed over 45 projects, offered by 15 organisations. New partnerships with Autotrader and Dstl were established by this mechanism. External links yielded 16 new CASE studentships during the period (8 at REF2014), and 6 other industry-funded PhDs. The Unit encouraged PGR students to engage with internships, enabling new collaborations, e.g. with Dyson.

**Larger-scale funding**

Awards from all industry-related sources, including direct funding, CASE-award contributions, government funding supporting industry (GCHQ for HIMR, KTPs) and consultancy has grown to over GBP4.2M, increasing from GBP2M at REF2014. The Unit's six KTP awards (GBP1.56M) and six Impact Acceleration Account (IAA) awards (GBP125K) have been particularly impactful and fruitful mechanisms of external engagement. 44 external organisations partnered on research grants with the Unit.

**Research hubs**
The Unit's development of research hubs**,** which are large-scale formal strategic collaborations, exemplifies the growth model. They facilitate responsive engagement with a focus on long-term partner goals. Hubs were developed with AWE and Thales during the period, including over GBP1.43M direct funding and GBP1.3M leveraged funding (Section 4(ii)).

**Relation to Impact Case Studies**
The Unit's expertise across themes 3-7 underpins its seven Impact Case Studies (ICSs), which emerged from the nurturing mechanisms described above. ICSs associated with Thales (**Assier, Cotterill, Heil, Parnell**, theme 3), NAG (**Higham**, theme 5) and Rapiscan (**Lionheart**, theme 7) have emanated from long-term relationships. The ICSs benefitting Argent & Waugh (**Güttel, Higham,** theme 5) and Arup (**Higham, Tisseur**, theme 5), arose from study days. The COVID-19 ICS (**Hall, House, Güttel, Pellis,** themes 4, 5 and 7) illustrates the Unit's agile response to national priorities and delivery of rapid impact.

Beyond REF2021, the Unit will continue to adapt its enabling mechanisms to broaden and expand its hubs, consolidate other relationships and develop new collaborations in alignment with national priorities.

**1(iv) Interdisciplinary research**

Staff carried out a broad range of interdisciplinary research during the period, driving **O3**. Frequently, individual interactions are initiated by staff elsewhere seeking specific mathematical expertise, and by Unit staff seeking applications of mathematics. The following, more formal, mechanisms also enabled interdisciplinary research.

**Good practice and recruitment**
Leadership in interdisciplinary research from existing Unit staff (Section 4(v)) inspires PGR students and new recruits. The Unit's recruitment assisted in nurturing its interdisciplinary identity, including joint appointments **Shearer** and **Hall** (Section 2(i)) and shared fellowships (**Chernyavsky** and Pearce) with FBMH.

**Workshops**
The Unit funded workshops, e.g. with DP&A, Computer Science, Materials and the Life Sciences, on broad exploratory topics and focused areas including data-centric engineering, materials modelling and machine learning. Workshops facilitated **Jensen**'s Wellcome Trust PGR Programme. **Parnell** led on establishing the Manchester Materials Modelling Centre in 2019, initiated by a FSE-funded workshop. **Law**'s ATI-funded workshop on data-centric engineering led to an 18-month ATI-funded project on digital fingerprinting with Withers (Regius Professor, Materials).

**Interdisciplinary institute engagement**
A thriving array of interdisciplinary University Research Institutes provides avenues to grow interdisciplinary research. The Unit played an active role in, and used facilities in, various institutes during the period, e.g.
*UoM institutes*
- Institute for Data Science and Artificial Intelligence (IDSAI) (**Higham**'s advisory board membership, **Law**'s IBM CASE studentship facilitated by a 2020 IDSAI workshop);
- Manchester Urban Institute (**Walton** and Pinto (Planning and Environmental Management) PhD co-supervision).

*National institutes*
- Alan Turing Institute (11 Fellows);
- Henry Royce Institute, e.g. UoM Henry Moseley X-ray Imaging Facility (HMXIF) (6 staff);
- Diamond Light Source (3 staff);
- National Graphene Institute (NGI) (**Heil, Hazel** and Vijayaraghavan (Materials), PhD co-supervision).

The mechanisms above led to positive outcomes in the following areas.

*Advanced Materials*
**Pihler-Puzović**, **Hazel** and **C Johnson** worked on novel auxetic metamaterials, e.g. Soft Matter (2016). **GW Jones** published in Nano Letters (2017). **Parnell**'s Dyson collaboration led to the fabrication of novel acoustic metamaterials: Applied Physics Letters (2018). **Parnell** and Potluri (Materials) published in Composites B (2019).

*Data Science*
11 Fellows of the ATI and **Higham**'s Programme Grant (Section 3(i)) ensure national interconnectivity in this area. **Walton**'s ATI/Toyota Mobility Foundation project was the British Chamber of Commerce in Japan's Best UK-Japan Partnership (2020). **Holman** organised a Dstl-sponsored microlocal analysis workshop (ATI, 2018). **Law**'s Oak Ridge collaboration led to a 2018 Nature Communications paper. Six Unit staff are Editors of the new journal *Foundations of Data Science,* including **Law** (Editor-in-Chief).

*Digital Trust and Security*
HIMR partnership ensured connections with UoM's cross-cutting Digital Futures theme, encompassing cyber-security, data protection and privacy (**Kambites**). **Lionheart**'s security screening research involves collaborations with Peyton (Electrical and Electronic Engineering, 2 patents), Morton (Rapiscan, 2 patents) and Withers.

*Energy*
Collaborations between **P Johnson** and **Duck** with Howell (Business School) on optimal renewable energy storage resulted in four papers, e.g in Applied Energy, 2018. **Law** collaborated with Oak Ridge in a fusion project with General Atomics (GBP450K).

*Geophysics and Planetary Science*
Successful collaborations with earth scientists include: **Evatt**'s paper in Nature Communications (2016); **C Johnson**'s collaboration on precious metal-mineralised layers, leading to a Nature Geoscience paper (2020); **Gray**'s collaborative work on avalanches, e.g. on the moon (JGR Planets, 2017).

*Life Sciences and Public Health*
High-impact publications include those by **Jensen** and **Shearer** (Nature Cell Biology, 2020), **Chernyavsky** (European Respiratory Journal, 2018), **Cotter** (Developmental Cell, 2018) and **Muldoon** (Science Signaling, 2018). **Hall**, **House** and **Pellis**' epidemiology research included papers in Nature Communications and Infectious Disease Modelling.

**1(v) Open research**

UoM commits to an open and responsible research environment via its position statement (REF5a 2(v)).

The Unit trailblazed Open Access (OA) research with the Manchester Institute for Mathematical Sciences (MIMS) EPrints server (established 2005). UoM's library processes OA outputs and manages embargoes and requests for gold-OA funding. During 2016-20, the Unit published 144 gold-OA publications via the UKRI block grant (GBP282K) and 25 via UoM institutional funding (GBP13K). 97% of the Unit's outputs submission is OA compliant.

The UoM New Academics Programme (NAP) (Section 2(ii)) includes training in Open research principles. All research proposals have data management plans and UoM provides 8Tb storage for projects on Mendeley data. UoM has institutional arrangements for publishing data, allocating DOIs, importing information on published datasets into PURE (UoM's research repository) and linking to publications. PGR training in OA is mandatory.

Unit staff contribute to Open Source software including R packages on CRAN (**Boshnakov**, **Nadarajah**, **Pan**, **Strimmer**) and freely available MATLAB toolboxes (**Güttel**, **Higham**, **Silvester**, **Tisseur**). **Silvester** continued to develop IFISS and s-IFISS, and **Hazel**, **Heil** and **Pihler-Puzović** further developed oomph-lib. Ten Unit staff maintain Github (open) software repositories.

**1(vi) Research integrity**

UoM is strongly committed to the highest standards of research integrity (REF5a 2(v)). Robust organisational structures promote a culture of integrity and ethics at Unit level. Unit leadership is provided by ethics coordinator **Lionheart**, dealing with approvals via an online system. UoM handles legal obligations centrally, e.g. export control, employment law and data regulations. Staff receive advice on adherence procedures via FSE Research Support and HoR.

In accordance with UUK Concordat requirements, UoM has implemented mandatory data protection and research integrity training for all staff who undertake research (repeated every 2 and 3 years respectively) and for all PGR students. The NAP includes research ethics training. Concordat compliance is a requirement of receipt of HEFCE, UKRI and Wellcome Trust funding. Unit induction events reinforce research integrity awareness. Research Leads manage peer review of papers and proposals prior to submission, encouraging and embedding good practice (Section 3(i)).

The Unit engages with, and influences policies of, the professional learned societies via membership and leadership (Section 4), noting that their codes of conduct uphold professional standards.

## 2. People

**2(i) Recruitment and staffing strategies**

The Unit invested strategically across the early career stage during the period, with the appointment of 20 Lecturers, and 10 Research Fellows (RFs) whose roles continue to permanent appointments (Table 1). This investment enhanced, reignited and initiated areas of research. The Unit also made 5 strategic senior appointments in applied statistics and data science.

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|---|
| **Research Fellow** | | | 1 | 2 | 1 | 1 | 3 | 2 | **10** |
| **Lecturer** | 1 | 3 | 5 | 2 | 5 | | 2 | 2 | **20** |
| **Senior Lecturer** | | | 1 | 1 | | | | | **2** |
| **Reader** | | | | | | 1 | | | **1** |
| **Professor** | | | | | 1 | 1 | | | **2** |

***Table 1. Recruitment distribution of permanent Unit staff.***

New recruits span the Unit's themes (figure 3), with expertise ranging from fundamental mathematics to interdisciplinary activity. Supporting **O2-O3**, the 35 appointments grew the Unit significantly (23FTE net growth in permanent staff), with nine retirements and only Abrahams, Lotz and Moriarty from the REF2014 census departing. Seven additional staff arrived and left during the period. The Unit proactively appointed ECRs when staff retired/departed and adopted the strategy to create RF roles (via philanthropic funds) that continue to permanent appointments. This enhanced the attractiveness of the positions to potential applicants and also aligned with FSE's Dame Kathleen Ollerenshaw (DKO) and UoM's Presidential fellowship schemes (REF5a 3.3.2). This overarching strategy led to an improved demographic balance across career stage since REF2014 (Table 2). An EDI analysis of staff, including Postdoctoral Research Associates (PDRAs) in the Unit indicated a steady increase in BAME staff (29% in 2013 to 36% in 2019) and a relatively steady level of 10% female staff.

| | Research Fellow | Lecturer | Senior Lecturer | Reader | Professor |
|---|---|---|---|---|---|
| **REF2021** | 16.3% | 25.0% | 17.4% | 10.9% | 30.4% |
| **REF2014** | 0% | 28.6% | 14.3% | 10.7% | 46.4% |

***Table 2. The Unit's demographic balance.***

Beyond REF2021 the Unit will ensure continued balance across the career spectrum, seeking to appoint high-quality ECRs, whilst providing leadership across all themes, consistent with future plans (Section 1(ii)). Increasing the proportion of female and BAME staff remains high priority.

**Influence of staffing strategy on theme development**
Taking into consideration the need for recruitment in areas driven by departures/retirements, and supporting the general strategies described above, the Unit recruited into themes in the following manner (figure 3).

In **theme 1**, GBP1.04M philanthropic funding for Turing/Neumann Fellows brought a vibrant group of young researchers (**Bui**, **Leon-Sanchez, Patel, Robertson**) to the Unit. Coupled with the lectureship appointments of **Frei** and **GO Jones** and DKO Fellow **Adiceam**, this revitalised logic, and launched a strong presence in number theory and research across interfaces. These appointments were augmented by five HIMR Fellows (**Barber**, **Calvert, Peacock, Smith, Sutton**) and EPSRC Postdoctoral Fellow (now lecturer) **R Webb**. **Suess**' appointment in algebraic geometry overlaps with **theme 2**, whilst **Kempton** and **Sahlsten**'s appointments in ergodic theory drive connections with **theme 6**.

In **theme 3**, **Assier** and (Dorothy Hodgkin Fellow) **Kisil** strengthened expertise in wave mechanics, overlapping with analysis (**theme 2**). The appointments of **GW Jones**, Thales RF **Cotterill** and EU Marie Curie Fellow **Meng** enhanced expertise in solid mechanics. The appointments of **C Johnson, Landel, Pihler-Puzović** (DP&A) and **Thompson** strengthened MCND. **Theme 4** benefitted from the joint appointment of **Shearer** with Materials and Presidential Fellow **Chernyavsky**, both having strong overlaps with the life sciences.

**Huang** and **M Webb** further strengthened **theme 5**. **Andres** and **Herrmann** reinforced financial mathematics and actuarial science in **theme 6**. DKO Fellow **Gaunt** enhanced expertise in applied probability alongside the appointment of **Walton**. In **theme 7**, professorial appointments **Law** and **Strimmer** and Lecturer **Thorpe** established a new presence in data science. **Charalambous, Han** and **Waite** enhanced applied statistics expertise whilst providing further overlaps with **theme 4**. **Hall** (joint with FBMH and Public Health England (PHE)), **House** and (Sir Henry Dale Fellow) **Pellis** established the Unit's epidemiology expertise, connecting to **theme 4**.

15 Unit staff were appointed on fixed-term contracts, with 8 leading to permanent contracts. Five HIMR Fellows hold contracts with renewal opportunities on application.

**Evidence of success**
Of the RFs eligible to apply for funding and newly appointed lecturers, 18 of the 19 in post for more than two years secured external funding, amounting to a credit share of GBP3.24M (34 awards, including 16 UKRI grants). New appointments published over 250 papers in leading international journals since joining and at census date they were involved in the supervision of over 60 PGR students. After joining the Unit, **Walton** won the Erlang prize, **Law** became Editor-in-Chief of *Foundations of Data Science* and **Hall, House** and **Pellis** had national impact with their COVID-19 research. During the period, 5 of the Unit's 9 newly appointed lecturers who have been in post more than four years (beyond probation) were promoted to Senior Lecturer and both newly appointed Senior Lecturers were promoted to Reader.

## 2(ii) Staff development

UoM's Concordat Implementation Plan ensures full support for *the Concordat* (REF5a 3.2).

**Support and training**
In 2018 the Unit increased its number of Line Managers (LMs) to 13, from 4 at REF2014, to ensure improved, regular support for academic staff. LMs carry out annual Performance and Development Reviews, assist with promotion/sabbatical applications, review and sign-off probation objectives, meet staff informally, and advise on workload allocation. LMs of PDRAs are their supervisors.

All academic staff undertake mandatory EDI, and Unconscious Bias (UB) training, with refresher courses every three years.

Annual away days bring staff together to discuss Unit strategies and informal support is provided by HoR and Research Leads. FSE and the UoM Staff Training & Development Unit offer a wide-ranging career development programme. For staff in management positions, UoM runs the *Inspiring Leaders* programme.

**Induction and assimilation**
PDRA induction includes a tailored welcome meeting with supervisors, where training needs and other requirements are discussed. UoM provides a general induction for all new permanent staff, comprising a welcome event and contextual guide to the University, its policies, and the Concordat. The Unit complements this with its own induction programme. Strong assimilation of all appointments into the Unit is ensured by

- all staff, including PDRAs, joining at least one research theme;
- mentorship (see below) and HoR/Research Lead meetings when appointed, and regularly thereafter to discuss funding opportunities;
- the Early Career Forum (Section 2(iii));
- the Unit's varied programme of events and seminars;
- informal coffee mornings, continuing virtually after March 2020.

**Mentoring and probation**
The probationary period is 4 years for academic staff and 9 months for PDRAs. In addition to a LM, academic staff on probation are assigned a mentor who provides one-to-one support. Ambitious, achievable probation criteria are devised as a set of tailored, measurable objectives via discussions between the appointee, LM and Head of Department (HoD, **Jensen**). Passing probation includes the successful completion of the NAP, which involves attendance at two research-focused days and the writing of a teaching-focused portfolio. NAP completion is externally recognised by fellowship of the Higher Education Academy. The Unit's senior mentor coordinates the probation process and after liaising with LMs, reports to the Departmental Promotions Committee (DPC) where probation outcomes are decided.

**Promotions**
Driven by EDI, the DoM initiated a new promotions procedure in 2018. An annual email encourages all eligible staff (including PDRAs) to submit paperwork to DPC, comprising members of the Department Leadership Team, a member from another department, and an elected departmental representative, who serves as the DoM Athena SWAN (AS) representative, ensuring that the Committee adheres to AS/EDI principles. The DPC makes recommendations to the Faculty Promotions Committee (FPC), which makes final decisions. 52 promotion cases were made to FPC. The success rate was 94.2%: 6 to Professor, 8 to Reader, 17 to Senior Lecturer and 18 from Grade 6 to 7 (to Lecturer or Research Fellow).

**2(iii) Support for ECRs**

In addition to the support described in Section 2(ii), newly appointed RFs and Lecturers are supported during probation by

- **reduced teaching loads** and protection from significant administrative roles;
- **start-up packages of GBP2-5K** for travel and networking. Larger packages allow experimentalists (e.g. those interfacing with MCND), to initiate lab-based activity. After probation, further support is available (Section 4(i)).

To help ECRs integrate into local research culture, they are encouraged to

- **co-organise Research Seminars**, to broaden their networks and gain exposure nationally and internationally;
- **co-supervise PGR students.** Senior staff team up with new Lecturers on PhD projects. The former take the lead supervision role while the latter co-supervise, gaining valuable experience. After probation, new appointees transition to lead supervisors.

A key support mechanism for ECRs, and particularly PDRAs, is the DoM's **Early Career Forum (ECF).**

The ECF is led by ECRs (formerly **M Johnson**, now **Chernyavsky**), with oversight from senior staff. Set up in 2013, with support from the DoM's AS committee, today it is a thriving, highly active group, connecting to corresponding structures at FSE and University levels. Membership comprises late-stage PGR students, PDRAs, RFs and new Lecturers. The ECF provides the following support mechanisms.

- **Informal meetings.** These take place 4-5 times every year over refreshments in the ATB, helping ECRs to network with peers. These continued online after March 2020.
- **Training events**. The ECF regularly surveys participants to determine their most pressing training requirements. The ECF lead then liaises with senior staff to plan bespoke events. The Unit provides financial support as needed. Recent events included grant-writing club sessions, a fellowship-writing workshop and a collaborative research sandpit co-organised with other Departments in the School of Natural Sciences. Events are advertised to all Unit ECRs and frequently involve presentations from Professional Services (PS) staff, and successful grant holders. Senior academics assist with interactive activities, e.g. mock panels.
- **Web resources.** ECF representatives maintain a dedicated web-page, electronic newsletter, and since March 2020, an online repository of resources to support homeworking and well-being.

Support for PDRAs assists the sustainability of the discipline (Section 4(v)).

The ECF enjoys strong links with the DP&A ECF (Section 2(vi)).

**2(iv) Sabbatical leave**

All full and part-time academic staff who have taught for 6 consecutive semesters or more, and whose contract duration is longer than this period, are eligible to apply to DPC for sabbatical. The Unit's research sabbatical strategy, aligned with UoM's, is to ensure that staff engage in continued research and impact activity, with complete relief from teaching and administrative duties. In addition to carrying out high quality research, staff are encouraged to write a grant proposal. During the assessment period, 36 one-semester and 4 two-semester sabbaticals were awarded, facilitating staff to publish over 50 research papers, submit 16 successful grant applications, develop 23 new collaborations and undertake 34 research visits. Notable examples of successful outcomes are (a) **Eaton**'s EPSRC grant (2019-22, GBP369K), (b) **Powell** leading a six-month INI UQ programme (2018), (c) **Evatt**'s impactful trip to Antarctica (Sections 1(ii),(iv),4(v)), (d) **Suess**'s Leverhulme Trust grant (2020-24, GBP284K), (v) **Peskir**'s work noted in Section 1(ii), and (vi) **Silvester**'s Romberg Visiting Professorship (University of Heidelberg, 2019).

**2(v) Staff exchange programmes**

Partner staff spend time in the Unit, e.g. Arup (Kannan), AWE (Monks), Dstl (Desai, Watson), NAG (Hammarling), Thales (Cotterill, Nigro) and Zeiss (Thompson). Having held a Royal Society Industry Fellowship during the last period, Thales employee **Cotterill** continued to spend 0.5FTE on knowledge transfer activity in the Unit until retirement, when he joined the Unit at 0.2FTE via Thales funding. Davey joined Thales after an Impact Fellow position (Section 2(vi)). In 2020 the Unit appointed Zimon (IBM) to an Honorary Lectureship, recognising the emerging relationship with IBM. Unit staff engaged with hubs have funding to work in associated organisations. **House** spent time at IBM (Royal Society Industry Fellowship) prior to March 2020 and 6 KTP Associates distributed time between the Unit and partners. See also Section 3(v).

**2(vi) Rewarding staff and impact support**

Research and knowledge transfer are two of four (equally weighted) categories of promotions criteria, thus rewarding success in both areas. The Unit's workload model accommodates significant grants and knowledge transfer activities with reduced workloads elsewhere. Staff with research fellowships are relieved from all other duties. Impact Fellows supported ICS development and UoM's business engagement team offer broad support for impact (Section 3(iii)). Unit/UoM social media and newsletters highlight key achievements. 15 staff had 15 papers highlighted on the FSE *In Abstract* webpage, highlighting outstanding research.

Staff were recognised at UoM awards, including
*Better World Awards*

- **Nadarajah** (2019, 2020) for his *Educating Africa* charity;
- **Güttel** (2017) for industrial installation alarms research (leading to an ICS).

*Research Staff Excellence Awards (initiated 2020)*

- **Pellis** (with 2 PDRAs), won *Best Contribution to Impact* (COVID-19 research);
- **Chernyavsky** (with Boya, DP&A), runners-up in *Best Contribution to Research Environment* (ECF work).

**2(vii) Postgraduate Research**

The Unit maintains a large and vibrant PGR community. 217 PGR students registered in the Unit during the period and there were 205 completions, compared with 201 and 125 at REF2014. Completion rates for students starting in 2014 and 2015 were 92% and 100%, respectively.

**Recruitment**
The Unit recruits outstanding PGR students from a wide range of institutions. 1FTE DoM PS staff provides administrative support for recruitment, while three PGR Admissions Officers connect applicants with supervisors. Two nationally-advertised Open Days are held annually in the ATB. Opportunities are disseminated via the Unit's varied networks and funded projects are advertised on UoM and DoM websites, and on FindaPhD.com. Recruitment is based on academic record and potential, judged by (i) taught course performance, (ii) research experience, (iii) interview performance, and (iv) references. Interviews are conducted with two academics (having taken the EDI/UB training noted in Section 2(ii)), including the intended supervisor. Following an academic offer, students without financial support are considered for funding.

**Support for PGR students with protected characteristics**
The Unit monitors PGR data and recruitment practices for potential biases. Its PGR recruitment strategy has been informed by the DoM's 2014 survey to determine PGR aspirations, especially amongst female and BAME students. Care is taken to ensure that staff and students involved in Open Days represent a gender and ethnicity balance, and that webpages and printed materials feature diverse representation. To encourage applications from under-represented groups, targeted events/schemes are

- *Meet a Researcher* (annually). Role models from under-represented groups talk about PGR experiences and career progression;
- *Women in Mathematics.* Organised in 2019 by Unit staff, supported by the Advanced Mathematics Support Programme;
- *Unit mentor scheme* (initiated in 2019) for female and non-binary students considering PGR study. To date 14 students have engaged with this scheme.

The annual proportion of newly registering female PGR students fluctuated between 19% and 41%, with the two-year rolling average increasing from 26% to 34% between 2014 and 2019.

**Funding**

Students are funded via diverse mechanisms, avoiding over-reliance on DTP funding (figure 5).

- **Unit funding.** A substantial DoM budget is administered by the DoM's PGR Committee, which makes decisions on a rolling basis.
- **UoM funding**. The President's Doctoral Scholar (PDS) Award scheme funds 100 outstanding PGR students annually across UoM. FSE provides Dean's Awards.
- **Case awards and other industry.** 17 Unit staff supervised PhD projects with external partners (figure 4) during the period.
- **Overseas Governments.** The Unit recruits international students with financial support from overseas government agencies, e.g. CSC (Chinese Scholarship Council) and CONACyT (Consejo Nacional de Ciencia y Tecnología).

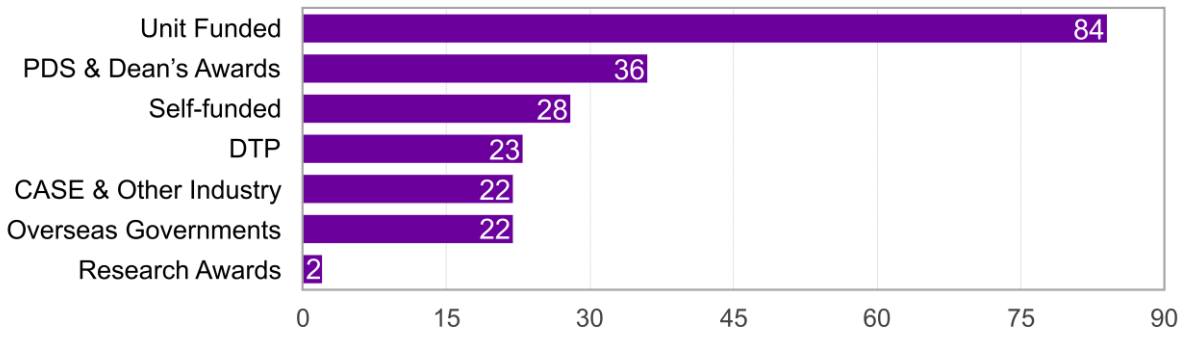



***Figure 5. Funding mechanisms for the Unit's 217 newly registered PGR students.***

The DoM PGR committee funded 210 students and the DP&A committee 7, with 5 DP&A students having co-supervisors in DoM. Over the period, Unit staff co-supervised students with collaborators in 10 other Units across UoM. The Wellcome Trust PGR Programme supported 20 PGR students; 19 were registered in FBMH but all had co-supervisors in the Unit and benefitted from Unit facilities.

**Progression**

1FTE PS staff provides DoM PGR administrative support. Every student has a main supervisor, at least one co-supervisor, and an advisor. Rigorous procedures monitor students via the UoM online system eProg. Students complete quarterly progress reports and receive written feedback. They also submit annual reports including future plans, assessed by the supervisory team and an independent assessor. Following an oral exam, feedback is recorded and progression depends on a satisfactory report and viva. In 2019, the Unit established the Derek Matthews prize (via philanthropic funding) for the best first-year PGR student progress report. Over the period, over 90% of students were awarded PhDs without or with minor corrections. Almost all interruptions/extensions granted were due to health issues or maternity leave.

**Development**

Students undergo regular skills audits and have access to a broad range of FSE training. Students are required to pass 100 hours of Taught Course Centre (TCC) material, chosen from the MAGIC TCC, the Academy for PhD Training in Statistics TCC, and/or the Unit's MSc courses (including rigorous summative assessment).

PGR students have access to regular Unit and FSE employability events and UoM's award-winning Careers Service. Frequent opportunities exist in teaching and outreach (Section 4(iv)). Annually, one student acts as a UoM-funded Widening Participation Fellow, engaging in community outreach. PGR students take an active role in organising events, e.g.

- the annual **Mathematics Research Students Conference (MRSC),** featuring presentations and posters from current students (supported by the Unit, IBM and NAG);
- the Unit's active **SIAM-IMA Student Chapter** runs an annual one-day meeting and organises an annual Industry Challenge (supported by N Brown);
- two weekly **PGR seminar series**, where students present work to peers;
- in 2015 a Unit PGR student initiated the **PGR Showcase**, where students present posters (now a successful annual UoM event).

The cohort experience on the Wellcome Trust PGR programme enabled training of students in the major questions and experimental techniques in biology and in the application of mathematical modelling and statistical analysis.

**Conferences and internships**

The Unit supports PGR students' attendance at national and international conferences with a simple internal funding application. The majority of students speak at 2-3 events (often more) during their programme. All CASE-funded students undertake placements of 3 months and the Unit actively encourages other students to undertake internships (figure 4).

**Prizes**

The Unit's PGR students won over 40 awards and prizes over the period, including ABTA Doctoral Researcher Awards, David Crighton Fellowships, and

- **UoM Awards**: DTA Doctoral Prizes, President's Distinguished Achievement Awards;
- **Travel Awards**: IMS, SIAM;
- **Best Talks/Posters/Papers**: American Statistical Society, BAMC, SIAM, Biennial Numerical Analysis Conference, British Society of Rheology, Designed Experiments, UK Fluids Conference, and Young Researchers in Mathematics conference;
- **Other Competitions**: Take Aim, UK Fluids Network Photo Competition.

One former PGR student appeared in the Sunday Telegraph's 2018 "*Top 50 Women in Engineering*". In 2020, a Unit PGR student was recognised at the UoM *Making a Difference Awards* for their *WellSpring Mental Health app* (outstanding contribution to social innovation).

**2(viii) Equality and diversity**

The DoM supports the LMS Good Practice Scheme and has held an AS Bronze award since 2008. The DoM AS committee initially focused on issues affecting women's careers, but later broadened its remit to include all EDI matters. Committee members included academic staff and PGR representatives. The Unit embeds institution-level EDI policies in its procedures and supplements these with its own strategies to support staff and PGR students.

**Flexible and remote working, and sabbaticals**

In 2016, DoM introduced a core-hours policy, stipulating that meetings and seminars should be held 10am-4pm. All staff can apply for flexible working, with many having unofficial arrangements such as shifted days to accommodate childcare. In the last AS survey (December 2018), 98% of academic staff said they had the opportunity to work flexibly. The Unit adapted swiftly to remote working in March 2020, supported by UoM's institutional Zoom licence. Staff continue to accrue sabbatical credit during maternity, paternity and adoption leave. During the period, the Unit modified job advertisement language to encourage applications from qualified candidates seeking flexible and/or part-time appointments. Staff involved in recruitment undertake enhanced EDI training.

**Career pathways for fixed-term staff**
UoM places all staff coming to the end of fixed-term contracts onto their redeployment register. The ECF provides support for the careers of fixed-term staff. HIMR Fellows benefit from the wider HIMR network, and associated diversity schemes.

**Enabling research**
The AS committee regularly monitored DoM procedures for bias during the period, to ensure equitable access to resources to support research. An annual Unit budget of GBP3-5K was used to fund additional female seminar speakers and to fund events aimed at encouraging PhD applications from under-represented groups (Section 2(vii)).

**Career progression and leadership**
EDI considerations drove changes to promotions procedures (Section 2(ii)). During the period, two Unit staff benefited from the externally-run Aurora and Stellar HE leadership programmes, which are tailored for female and BAME staff, respectively. HoD liaises with LMs regularly in efforts to maintain balanced representation on decision-making committees and at leadership level. The 13 LMs are distributed across career stage from Senior Lecturer to Professor and 3 are female.

**Periods of leave**
LMs offer tailored support for academic staff returning from periods of leave due to illness, maternity, paternity or adoption leave, or caring responsibilities. This includes a review, and where possible a reduction, of workload upon return to work. UoM launched its flagship *Returners Scheme* in 2018. Academic staff returning can apply for a teaching replacement for one semester (pro-rata for part time staff), and up to GBP3K to support research. In the Unit, returning staff can also access GBP1K research funds, increased from the annual funding pot (Section 4(i)). Staff who would incur extra costs by attending conferences, e.g. due to childcare or immobility, are encouraged to apply to the AS committee for funding. During the period the Unit liaised with DASS twice to ensure supply of specialist software and equipment for staff following return from illness. PGR students can request interruptions where their programme clock is paused. Return to study is managed by their supervisor who makes arrangements for assimilation back into the Unit and signposts students to support (see **Wellbeing** below). From students registering during 2013-15, seven interrupted; six returned, with five completing, and one to submit in 2021.

**Protected characteristics**
Support for research staff with protected characteristics is strongly embedded in UoM and Unit policies, through for example, the Disability Confident scheme used for job advertising, overseas travel guidance, promotion workshops targeted at under-represented groups, staff Networks (including Black Minority Ethnic, LGBT, and Disabled groups), same-sex partner leave for new parents, Occupational Health involvement in work conditions, and zero-tolerance “Report & Support” procedures on harassment.

**Wellbeing**
In addition to arranging regular check-in meetings with staff, where appropriate, LMs signpost staff to UoM counselling and wellbeing services, and e-resources to support mental health. A dedicated Student Support Officer provides PGR students with wellbeing guidance and direction to UoM services, including counselling and DASS (4 PGR students were registered with DASS at census).

**REF return**
The Unit’s outputs return was selected in accordance with UoM’s annual Research Review Exercise, led in the Unit by **Tisseur**, with oversight from FSE. Papers selected by authors were distributed to at least two internal referees (Unit staff) who had undergone tailored REF assessment training and were supported by EDI/UB training (Section 2(ii)). Results were compiled and considered at a panel chaired by Tisseur. Broad consensus contributed to final grading. Authors fed their own feedback on scores into the process via an online system,

managed by **Tisseur**. An EDI analysis of the Unit's return showed an average of 2.3 outputs from both Male and Female authors and an average of 2.3, 2.1 and 2.7 outputs associated with White/BAME/Unknown or refused ethnicity, respectively.

**Hewitt** managed ICS selection, supported by HoR and the Unit's Impact Officer (Section 3(iii)). A broad range of potential ICSs were discussed at rolling panels with Unit and FSE staff. ICSs were ultimately selected on the basis of quality and evidence.

The Unit's environment statement was written by **Parnell**, with a core team of 8 staff (2 female). Input was sought and information returned from Unit staff on several occasions to provide illustrative examples and data.

## 3. Income, infrastructure and facilities

### 3(i) Research funding strategies

The Unit's strategic objective **O4** to grow and diversify research funding is bearing fruit, with GBP26M total income over the assessment period, up significantly from GBP11.4M at REF2014. Its appointment strategy drove a healthy balance between curiosity-driven research and responsiveness to specific funding calls. A key mechanism in achieving **O4** was improvement of support for grant proposal preparation via the appointment of Research Leads (RLs). As part of the Unit's new proposal submission approval process, RLs manage intensive internal peer review (two referees), involving multiple iterations of drafts to improve proposals and PI responses, and to ensure call alignment. Particular attention is provided to ECRs, mentoring them through the process and ensuring support post decisions. HoR/RLs discuss unsuccessful proposals with PIs to consider potential improvements and future funding options. Mock interviews are always arranged as appropriate. The Unit consistently grew its market share (HESA data) of research income (figure 6).

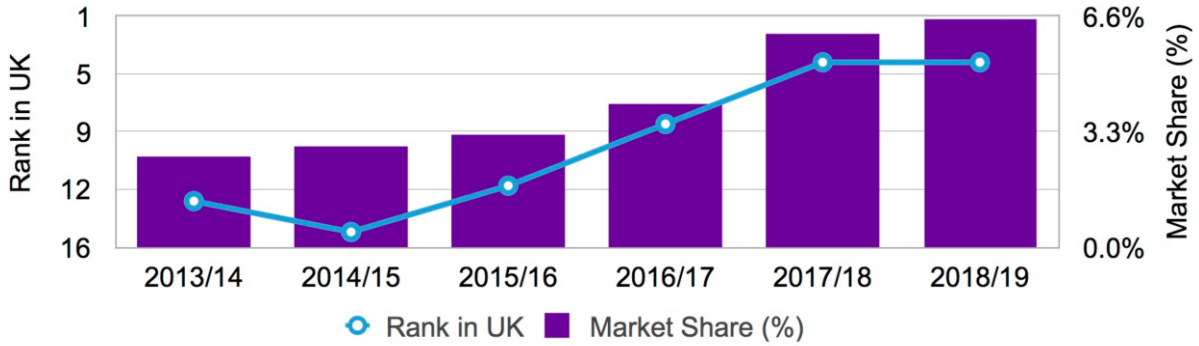



***Figure 6. Market share of research income***

Credit share of external research awards during the period totalled GBP25.2M (figure 7). The proportion of Research Council awards was 62%, compared to 72% and 90% in REF2014 and RAE2008, thus further reducing Unit reliance on this source. "Other" sources (philanthropy, overseas institutions, etc.) increased significantly to GBP1.97M from just GBP42K at REF2014, illustrating increased, diversified funding.

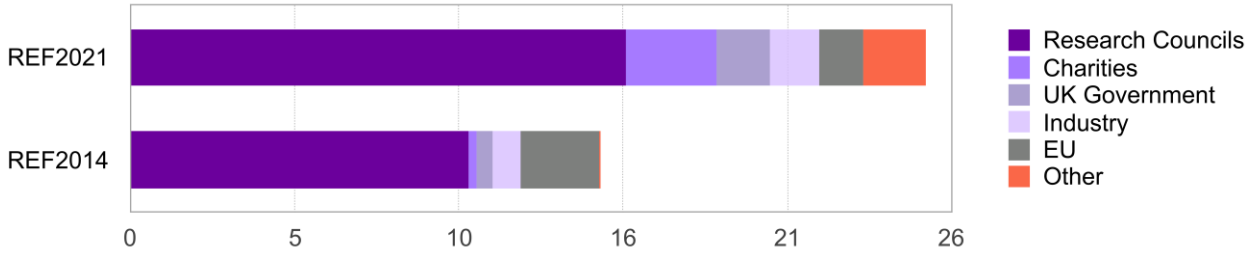



***Figure 7. Research awards (GBP M) comparing proportions at REF2014 and REF2021***

The Unit's diverse research enabled access to UKRI funding beyond the EPSRC mathematics panel, including BBSRC (**Jensen**), ESRC (**Fedotov**), MRC (**Hall, Han, Chernyavsky**) and NERC (**Gray, C Johnson**). Notable sources outside UKRI include:

- **HIMR Partnership** (5 fellows, GBP1.01M) with further appointments and Heilbronn Doctoral Partnership PGR funding to follow after the period;
- **Research hubs** with AWE and Thales (GBP1.43M);
- Six **KTP projects** (GBP1.56M including government and industry contributions);
- **European Commission** funding for five projects (GBP1.38M);
- **Philanthropic** funding for Turing/Neumann Fellowships (GBP1.04M, 2015-20) and follow-on funding (GBP0.8M, 2020-25) after the period.

The Unit placed strategic emphasis on encouraging and supporting applications for research fellowships. 35 were hosted during the period (compared to 13 at REF2014), including 31 new fellowships. Sixteen arose from applications to external bodies:

- **Chernyavsky** (MRC, 2016-19, GBP444K);
- **Gray** (EPSRC Established Career, 2015-20, GBP1.38M);
- **Hewitt** (William Penney Fellowship Extension, 2016-2019, GBP150K);
- **Higham** (Royal Society Professorship, 2018-23, GBP1.39M);
- **House** (EPSRC Healthcare Technologies Impact, 2016-19, GBP320K and Royal Society Industry, with IBM, 2019-22, GBP140K);
- **Kisil** (Royal Society Dorothy Hodgkin, 2019-24, GBP643K);
- **Meng** (EU Marie-Curie Individual, 2019-21, GBP149K);
- **Parnell** (EPSRC Early Career, 2014-19, GBP1.1M, and Extension, 2019-2022, GBP897K);
- **Pearce** (Leverhulme Trust Early Career, 2015-18, GBP70K);
- **Pellis** (Wellcome Trust Sir Henry Dale, 2017-21, GBP640K);
- **Shearer** (EPSRC Postdoctoral, 2014-17, GBP220K);
- **Stafford** (Leverhulme Emeritus, 2019-21, GBP16K);
- **Symonds** (Leverhulme International Academic, 2018, GBP25K);
- **R Webb** (EPSRC Postdoctoral, 2019-20, GBP38K).

Thales provided GBP45K explicit funding for RF **Cotterill** (2018-21, Section 2(v)). The remaining 14 independent fellowships were supported by UoM, and were awarded in open competitions administered by the Unit/UoM. Direct funding to the Unit supported five HIMR Fellows (**Barber, Calvert, Peacock, Smith, Sutton**, GBP843K, 2019-22) and philanthropy funded six Turing/Neumann Fellows (**Bui, Leon-Sanchez, Loughran, Patel, Prendiville, Robertson**, GBP1.04M). **Loughran** and **Prendiville** arrived and departed during the period. Philanthropic funding to UoM accounted for two DKO Fellowships (**Adiceam,** 2018-23, GBP215K; **Gaunt,** 2016-21, GBP218K) and UoM supported one Presidential Fellow (**Chernyavsky**, 2019-23, GBP193K) (REF5a 3.3.2).

Additionally, four fellowships awarded during the REF2014 period overlapped with the REF2021 period: **Hewitt** (William Penney Fellowship, 2013-16), **Higham** (ERC Advanced, 2011-16), **Moriarty** (EPSRC Early Career, 2012-17), and **Tisseur** (EPSRC Leadership, 2011-16).

The Unit's seven ICSs were supported by 29 grants, totalling GBP11.4M.

Table 3 evidences links between key outputs and grants.

| Output | Author | Funding Awards |
|---|---|---|
| Diffraction by a quarter-plane. Analytical continuation of special functions. *Q. J. Mech. Appl. Math. (2019)* | Assier | EPSRC (EP/N013719/1) |
| Donovan's conjecture and blocks with abelian defect groups. *Proc. Am. Math. Soc. (2018)* | Eaton | EPSRC (EP/M015548/1) |
| Well-posed and ill-posed behaviour of the μ(I)-rheology for granular flow *J. Fluid Mech. (2015)* | Gray | NERC (NE/E003206/1, NE/K003011/1), EPSRC (EP/I019189/1, EP/K00428X/1, EP/M022447/1) |
| A new analysis of iterative refinement and its application to accurate solution of ill-conditioned sparse linear systems. *SIAM J. Sci. Comput. (2017)* | Higham | ERC (267526), EPSRC (EP/I01912X/1, EP/P020720/1) |
| Pfaffian definitions of Weierstrass elliptic functions. *Math. Ann. (2020)* | GO Jones | EPSRC (EP/N007956/1) |
| Soft phononic crystals with deformation-independent band gaps. *Proc. R. Soc. Lond. A (2017)* | Parnell | EPSRC (EP/L018039/1) |
| Systematic selection between age and household structure for models aimed at emerging epidemic predictions. *Nat. Commun. (2020)* | Pellis | Wellcome Trust and Royal Society (202562/Z/16/Z) |
| Displacement flows under elastic membranes. Part 2: Analysis of interfacial effects. *J. Fluid Mech. (2015)* | Pihler-Puzović, Juel, Heil | EPSRC (EP/J007927/1) |
| The Ziegler spectrum for derived-discrete algebras. *Adv. Math. (2017)* | Prest | EPSRC (EP/K022490/1) |

***Table 3. Examples of links between key outputs and funding.***

**O3** is underpinned by Unit staff playing integral roles in large intra- and inter-disciplinary research projects, including

- **Fedotov:** EPSRC, *Bioproton* (GBP1.4M, 2019-24) with FBMH, Massachusetts General Hospital and NHS-England;
- **Higham:** EPSRC Programme Grant, *Inference, computation and numerics for insights into cities*, (GBP5.3M, 2017-22) with Imperial, Oxford and Edinburgh, and national and international police forces;

- **Landel:** Dstl**,** *Modelling chemical decontamination of porous surfaces*, (GBP1.3M, 2019-22) with Cambridge;
- **Lionheart:** EPSRC Platform Grant, *Next Generation Multi-Dimensional X-ray Imaging*, (GBP1.2M, 2015-20) with Materials; EPSRC, *Robust Repeatable Respiratory Monitoring with EIT* (GBP890K, 2014-18) with Guy's and St Thomas' NHS Foundation Trust; Sir Bobby Charlton Foundation (two grants: GBP2.2M and GBP1.5M) with Electrical and Electronic Engineering;
- **Jensen:** BBSRC, *Opportunities to Modulate Extracellular Matrix Secretion and Assembly for Long-Term Health (*GBP3.78M) with FBMH and Bristol;
- **Muldoon:** Horizon 2020, *Connecting Lung Structure and Function in Cystic Fibrosis Through Physiological Modelling, Image Analysis and UQ (EURO2.91M, 2017-21)* with 10 partners in 7 countries.

**3(ii) Organisational infrastructure**

**MIMS**
The Manchester Institute for Mathematical Sciences is the organising centre for the Unit's research activities. It provides facilities and funding (GBP15K/year) to host visitors at all career stages, seminars, workshops and conferences (Section 3(iii)).

**MCND**
The Manchester Centre for Nonlinear Dynamics is the Unit's experimental arm, offering staff approximately 300m$^2$ of laboratory space, facilities and 1FTE technician support. MCND's facilities grew further via GBP100K investment in microfabrication facilities, key to experiments on biomimetic blood flows (**Chernyavsky, Jensen, Juel**), airway reopening and viscous fingering instabilities (**Pihler-Puzovic, Juel**) and surface microfabrication for wetting studies (**Juel**). The Centre also benefitted from the use of UoM facilities in Chemistry, Materials, NGI and FBMH and has developed strong collaborative links with Chemistry and Chemical Engineering.

UoM institutes and centres (Section 1(iv) and REF5a 2(iii)) provide focus for interdisciplinary research.

**3(iii) Support infrastructure**

UoM's Estates Department maintains the GBP40M ATB, housing 120 staff and PGR offices, large computing clusters, and dedicated MIMS space for research dissemination. MIMS facilities include two seminar rooms, a hot-desking area, Access Grid room (interactive videoconferencing facilities), meeting rooms, and 3 multi-occupancy visitor offices. A GBP20K annual budget allows for standard improvements to the building. In 2018, AV equipment in seminar and computer rooms was upgraded (GBP42K).

**Research and impact support**
Comprehensive institutional support is provided (REF5a 4.1). The Unit has two dedicated Research Support Officers (RSOs) and a Research Support Manager (RSM) for pre- and post-award support. Funding opportunities are distributed by HoR and RSM. RLs assist in identifying potential applicants and discuss opportunities with staff. To enable impact, UoM funds an Impact Officer, who assists in the development and maintenance of new and existing industrial contacts, facilitates pull-through of impact and assists in ICS development. The UoM Business Engagement team provides broader expertise and connectivity.

**Computational resource**
In addition to the Research IT Computational Shared Facility to which the Unit contributed seven compute nodes (GBP64k), the Unit has its own computational resources hosted in a dedicated fileserver room in the ATB. Compute nodes for specific projects run alongside servers available to all staff. Total Unit investment in this infrastructure over the period was GBP110K.

**Funding**
For non-CASE PhDs, the Unit provides funding when external organizations part-fund projects (six during the period). UoM/EPSRC provided assistance for impact development via *impact support funds*, with the Unit benefitting from two *impact fellow* awards (GBP92.5K). These projects are connected via the FSE impact support network managed by the Faculty Impact Team. UoM's dedicated KTP support team assisted in the award of six KTPs with Argent & Waugh (GBP245K), Arrow Global (GBP278K), Arup (GBP261K), Inventive IT (GBP194K), NAG (GBP302K) and Process Integration Ltd (GBP280K). Six IAA awards totalling GBP125K provided proof-of-concept and relationship-incubator funding for **Gray, Lionheart** and **Parnell**, together with external partners. The UoM Innovation Factory funded **Gray** (GBP60K, 12-month PDRA support, market assessment and patenting costs, 2016); **Law** (GBP5K to establish collaboration with Victrex, who contributed GBP5K); and **Parnell** (GBP25K, market assessment and patenting costs).

**Facilities**
Shared UoM infrastructure, including the library, Research IT and large equipment has benefitted from significant UoM investment (REF5a 4.2).

**3(iv) Equality, diversity and inclusion**

The Unit takes great care to treat all staff equally with regard to access to research facilities and support. The Unit's MIMS director **Tisseur** (female) makes recommendations on Unit OA funding based on research quality and career stage. The female to male ratio of RLs is 1:2; HoR and RLs ensure equal treatment in terms of associated support (Section 3(i)) and access to facilities. Recently, the Unit trialled double-blind research proposal peer review to remove any potential for unconscious bias and this approach will be adopted in the future for appropriate calls.

MCND has an intentionally horizontal structure; access to experimental infrastructure is therefore straightforward for all in the Unit, with experimental advice provided at weekly meetings. Led by **Juel**, it is an exemplar of support for female scientists with pro-active drawing in of new appointments (several female) into existing projects and new funding proposals.

All facilities within the ATB and Schuster (MCND) are fully accessible with no steps on entry, dedicated disabled toilets and lifts to all floors.

**3(v) Relation of infrastructure, facilities and expertise to impact**

The ATB permits flexible engagement with partners including dedicated office space for external partner staff. This has increased engagement with industry and improved the quality and sustainability of interactions (Sections 1(iii), 2(v)).

**Consultancies**
The Unit recognises the value of staff undertaking consultancy, provided that it forms part of a virtuous circle, whereby research is applied to novel applications, which in turn identify open questions that inform new fundamental research. Unit staff provided consultancy to a diverse range of organisations (figure 4), totalling GBP274K.

**Contracts and Intellectual Property**
All projects with external partners have contractual agreements drawn up by UoM's contracts office. The UoM Innovation Factory provides support to manage IP arising from impactful interactions, e.g. they assisted **Gray** in obtaining a US patent in 2020 (US 10,752,444 B2).

**3(vi) Specialist and shared research infrastructure**

**Institutes**
Unit staff benefitted from facilities at the INI and International Centre for Mathematical Sciences (ICMS) in Edinburgh, with staff having organised 8 meetings during the period and 17 attending meetings. The Unit's ATI Fellows benefit from its array of facilities in the British Library. Staff also enjoyed use of HMXIF and Diamond (Section 1(iv)).

**International**
Staff benefit from international computing infrastructure, e.g. **Law** and **Dongarra** (*Summit*, Oak Ridge, USA) and **Law (***Shaheen*, KAUST, Saudi Arabia).

**Healthcare**
During the COVID-19 pandemic, **Hall, House** and **Pellis** accessed confidential datasets in PHE and Hospital facilities that would otherwise have not been possible to share, e.g. the Office for National Statistics' Secure Research Server, a major national research investment.

**In-kind support**
The Unit received over GBP2M of in-kind support from partners during the period, including partner staff time on CASE PhDs, access to equipment and computational resource, and sample fabrication. Examples include

- **Assier**, EPSRC First Grant (2015-17), *Thales*, staff time (GBP44K);
- **Chernyavsky**, EPSRC (2020-22), *McMaster University* and *St Mary's hospital*, staff time and other resources (GBP70K);
- **Gray**, EPSRC Fellowship (2015-20), *EPFL* and *Procter and Gamble*, experimental facilities (GBP330K);
- **Lionheart**, EPSRC (2014-18), *Guy's & St Thomas' NHS Foundation Trust*, facilities and clinician time (GBP153K).

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

**4(i) Research collaborations, networks and partnerships**

**Support for collaboration**
The Unit supports and encourages collaborative research via

- MIMS (supported over 50 meetings during the period);
- 12 weekly seminar series, including 2 PGR series (GBP20K annual budget);
- sabbaticals (Section 2(iv));
- GBP0.5k annual travel stipend with supplementary GBP1K budget on application;
- strategic initiatives for collaborative PhD supervision.

Additionally, since 2017 the DKO Trust has provided GBP30-50K annual funding for activities including 4 distinguished Visiting Professors (Cherlin, Masser, Payne, Pillay), 4 research visitors, 5 public lectures, and outreach (Section 4(iv)).

After campus closure in March 2020, the Unit moved its collaborative activities online, including the majority of its seminar series. Staff also initiated new international online seminar series (Wavinar, E-NLA, eNBSAM, Mathematics of Machine Learning, Mathematical Biology and Data Science).

**Networks**
Additional support for collaborations was provided by externally funded national research networks, e.g. UK Fluids Network (EPSRC**, Juel**); From Models to Decisions (UKRI, **Powell**); North British Semigroups and Applications Network (LMS, **Kambites**); Tropical Mathematics and its Applications (LMS**, M Johnson**); Transpennine Topology Triangle (LMS**,** Ray) and LMS

Research in Pairs grants (**Leon Sanchez, Prest,** Stafford**, Voronov**). Manchester is a named node in three additional LMS Scheme 3 networks spanning combinatorics and number theory, ergodic theory and group theory.

The Unit's collaborative reach was described in Section 1(ii). Effectiveness of the collaborations is evidenced by outputs with over 500 UK and international academic institutions (increasing from 100 at REF2014) and over GBP8.5M in grants with research institutions in the **UK**, e.g. Birmingham (**Powell, Silvester**), Cambridge (**C Johnson, Landel**), City (**Eaton**); Edinburgh (**Chernyavsky**), Leeds and Loughborough (**Parnell**), Liverpool (**Hazel**), Nottingham (**Jensen**) and Oxford (**GO Jones**); **Europe**, e.g. EPFL (**Gray**), Marseille (**Assier**), INRIA, BSC and DLR (**Dongarra, Higham, Tisseur**), and **worldwide**, e.g. Lawrence Livermore (**Higham, Tisseur**), National University of Mexico (**Montaldi**), Oak Ridge (**Law**), Universidade de São Paulo (**Fedotov**), Virginia Tech (**House**).

**4(ii) Relationships with key beneficiaries to develop impact**

The Unit's numerous mechanisms for engagement (figure 4) have facilitated strong long-term relationships with key partners, including **Arup, AWE, NAG, Rapiscan** and **Thales**. Partner representatives participate strongly in PGR student and PDRA co-supervision, building close relationships with Unit staff. Visits, workshops, and staff exchange with key partners enrich the local research environment, providing a constant source of relevant research problems, ensuring broader engagement and the development of impact.

The relationship between **NAG** and the Unit dates back over three decades, whereas the relationship with **Arup** was initiated via a study day in the previous assessment period. Both collaborations provide vehicles for researchers' algorithms to be made widely available: new modified Cholesky and nearest correlation matrix codes based on Unit staff's work appeared in the **NAG** library in 2019. During the period, 6 Unit staff engaged with **NAG** via 1 KTP (1 PDRA) and 3 MScs. 4 Unit staff engaged with **Arup** via 1 KTP (1 PDRA), 2 PGR students and 2 MScs.

Significant impact has been delivered to **AWE** and **Thales** through the Unit's hub model. The relationship with **Thales**, beginning with **Parnell**'s CASE PhD (2001-04), is their **longest continuous UK academic collaboration** and during the period, engagement involved projects with 8 Unit staff, 5 PGR students and 4 PDRAs. The Unit's collaboration with **AWE**, established via **Hewitt**'s Penney Fellowship (2013-2019) is blooming, with projects during the period involving 9 Unit staff, 5 PGR students, 1 PDRA and 2 PhD internships.

The relationship with **Rapiscan** began with consultancy (**Lionheart**), developing via two CASE studentships (2007-2011), leading to ICSs at REF2014 and REF2021, and the formation of the **Bobby Charlton Foundation** charity, a partnership including UoM and **Rapiscan** that supported research in the Unit over the current REF period via GBP3.7M grants.

**4(iii) Contributions to economy and society**

Unit staff generate impact by applying and translating new and existing mathematical knowledge to address current societal challenges.

In addition to the Unit's seven ICSs, in **healthcare**, **Lionheart**'s research has been instrumental in developing a prototype 3D Electrical Impedence Tomography (EIT) system for **real-time monitoring** of mechanically ventilated patients in ICU. **Muldoon** developed statistical analysis to show that **mosaic vaccines for HIV** induce improved immune responses. This was instrumental in bringing the mosaic approach to the forefront of HIV vaccines, making it only the fifth vaccine to reach efficacy testing in the last 35 years.

**Landel** is leader of the EPSRC UK Fluids Network Special Interest Group in the fluid mechanics of **cleaning and decontamination**, involving academics and company representatives, and he works with Dstl to develop efficient decontamination strategies.

Members of theme 7 worked with e.g. Dstl, IBM and NPL to embed cutting-edge **UQ methodologies** in broader communities, having co-authored key monographs: *An Introduction to Computational Stochastic PDEs* (**Powell**, 2014), and *Data Assimilation* (**Law**, 2015). **P Johnson** and **Duck** worked with National Grid and UoM's Climate Crisis Centre on applying stochastic models to optimise **energy** usage.

**4(iv) Engagement with diverse communities and publics**

The Unit organises online and in-person engagement activities, catering for all ages and communities. **Public lectures and events** bring the public into the Unit's research environment (e.g. IMA Festival of Mathematics 2014, Women in Mathematics Research 2019, annual DKO lectures by: Marcus Du Sautoy 2015, Hannah Fry 2016, David Sumpter 2017, James Grime 2018, Vicky Neale 2019, Katie Steckles 2020). **Outreach events** take staff and PGR students into the community (e.g. regular popular talks in schools, pubs and cafes, and science fairs). Research is publicised via **social media**, YouTube videos (e.g. **Chernyavsky**, **Parnell**, **Sahlsten**) and blogs (e.g. **Borovik**, **Evatt**, **Higham**, **Khudaverdyan**, **Walton**), attracting tens of thousands of hits annually. **Mainstream media** regularly covers the Unit's research, including work on meteorites (Evatt) (BBC, New Scientist), ribbon curling (**Jensen**, **Juel**) (BBC), football match result prediction (**Boshnakov**) (BBC), and the COVID-19 pandemic (**Hall, House, Pellis**) (BBC, ITV). **Evatt, Hazel** and **Walkden** contributed puzzles for BBC R4 Today Programme's "Puzzle of the Day", published in the Today Programme Puzzle Book (2018).

Events for school children include the Alan Turing Cryptography Competition (ages 11-16, approximately **4000** participants/year), the DKO Mathsbombe (ages 16-18, approximately **1500** participants/year) and MakingMaths@Manchester, an annual two-day residential course for approximately 80 sixth-form students.

During the period, Unit staff presented their research at e.g. Big Bang Fair, New Scientist Live, Manchester Science Spectacular and at events designed to reach non-traditional audiences including ScienceX (Trafford Centre, 2016-2019) and the Manchester University Community Festival (2017-2020). PGR students and ECRs played an active role in all outreach, and the teams were representative in terms of gender and ethnicity.

**4(v) Discipline sustainability, interdisciplinary exemplars and responsiveness to national and international priorities and initiatives**

Staff played key roles in national and international institutes, e.g. SIAM President (**Higham**, 2017-18), ICMS Director (Abrahams, 2014-16, **Glendinning** 2016-present). **Glendinning** is president elect of the IMA (2022-23).

Additional examples of leadership are:
**Borovik** (LMS Council, 2014-20);
**Güttel** (Secretary and Treasurer, SIAM UKIE section, 2016-18; Vice-Chair, GAMM Activity group on Numerical and Applied Linear Algebra, 2015-present);
**Glendinning** (IMA Vice-President (Learned Society), 2010-2014; IMA Council, 2015-18; INI Scientific Steering Committee, 2016-present);
**Juel** (Euromech Council, 2018-2024);
**Powell** (Program Director, SIAM Activity group on UQ, 2018-20);
**Tisseur** (President, UKIE SIAM section, 2019-21; Program Director, SIAM Activity Group on Linear Algebra, 2013–15; Vice-President, SIAM UKIE section, 2013–15; Board of Directors of the International Linear Algebra Society, 2011-14).

Staff also sat on UKRI strategic advisory teams and boards (Section 4(vi)).

**Powell** was principal organiser of a six-month INI UQ research programme (2018, over 100 participants). **Dongarra** and **Higham** co-organized a Royal Society discussion meeting on *Numerical Algorithms for High-Performance Computational Science* (2019, 150 attendees). The Unit actively engages in training the next generation of researchers, employing 91 PDRAs during the period. Of the 67 whose contracts ended, 21 moved onto new PDRA positions, 25 into academic appointments, 17 into scientific careers in industry, and 4 destinations are unknown.

The Unit's active participation in interdisciplinary projects helps sustain the discipline; key exemplars addressing national and international priorities are:

**Environment**

- **Evatt**'s lost meteorites of Antarctica project (Leverhulme Trust, partnering with British Antarctic Survey), with earth sciences, and electrical and electronic engineering.
- **C Johnson**'s work on the V-PLUS project (NERC highlight grant) to improve predictions of volcanic ash dispersal in the atmosphere, with earth sciences.

**Healthcare**

- National and international epidemiological modelling (**Hall, House, Pellis**) connects public health, policy and mathematics.
- **Jensen**'s leadership in engagement with life sciences, leading to the Wellcome Trust PGR Programme, training 20 PGR students to work at the interface between mathematics and the life sciences.
- **Chernyavsky**'s work (EPSRC and MRC) on placental modelling, in collaboration with UoM's Maternal and Fetal Health Research Centre.
- **Shearer**'s (EPSRC, joint appointment with materials) work on tendon biomechanics, with the Division of Cell Matrix Biology and Regenerative Medicine, FBMH.

The Unit responds rapidly and proactively to research priorities, engaging with the UK Research and Development Roadmap, and applying to priority funding calls, e.g. 12 submissions to the EPSRC New Horizons Scheme. Staff played key roles in aspects of the national response to the COVID-19 pandemic. The Unit's 11 ATI Fellows address national priorities in Data Science. **Duck** and **P Johnson** address societal challenges in energy usage. **Lionheart**'s Royal Society Challenge Grant addressed the global problem of landmine detection and clearance.

**4(vi) Contributions to the discipline and leadership**

**Awards and Prizes**:
**Dongarra**
SIAM/ACM prize in Computational Science and Engineering, 2019;
Women of the ENIAC Computer Pioneer Award, 2020;
**Frei**
Prize of the Austrian Mathematical Society, 2019;
**Higham**
Royal Society Research Professor, 2018-23;
LMS Naylor Prize and Lectureship, 2019;
**Landel**
APS Gallery of Fluid Motion Award, 2017;
**Parnell**
LMS Whitehead Prize, 2019;
**Tisseur**
Olga Taussky-Todd Lecture prize, ICIAM 2019;
LMS Fröhlich Prize, 2020;
**Walton**
Erlang Prize, 2018.

Royal Society Wolfson Research Merit awards: **Gray** (2016-21), **Lionheart** (2015-20), **Tisseur** (2014-19) and Abrahams (whilst part of the Unit, 2013-16). Wilkie (FRS, Emeritus) was awarded the LMS Polya prize (2017).

**Fellowships**:
**Dongarra**
Foreign Member of the Russian Academy of Sciences, 2017;
Foreign Member of the Royal Society, 2019;
Fellow of the International Engineering and Technology Institute 2019;
**Higham**
Elected Member Academia Europaea, 2016;
Fellow of the Institution of Engineering and Technology, 2018;
**Juel**
Fellow of the American Physical Society, 2019;
**Tisseur**
SIAM Fellow, 2016.

**Service on advisory boards**
Unit staff served over 40 boards and committees including the EPSRC Mathematical Sciences SAT: Abrahams (2014-15) and **Juel** (2015-18). **Parnell** is an advisory group member of the EPSRC's additional funding programme for mathematical sciences. At REF2014, Abrahams was Deputy Chair and **Higham** was a member, of sub-panel 10.

Additional examples include:
**Donev** (Co-chair, design of experiments working group, European Research Consortium for Informatics and Mathematics, 2014-21);
**Dongarra** (Co-chair, International Exascale Software Program, 2008-present);
**Glendinning** (Nominating Committee, LMS, 2014-16);
**Hewitt** (Member, Nuclear Security Science Network Management Panel, 2015-present);
**Juel** (Chair, IUTAM UK panel, 2020-22; Member, IUTAM Congress Committee, 2018-22; Nominating Committee, Division of Fluid Dynamics, APS, 2018-20);
**Jensen** (Member, Research Policy Committee, LMS, 2016-2019; Member, World Council on Biomechanics, 2010-22);
**Heil** (Member, Co-chair and Designated Chair, Euromech Fluid Mechanics Conference Committee, 2014-present);
**Kambites** (Member, Society Lectures and Meetings Committee, LMS, 2017-present);
**Powell** (Steering committee, KTN Special Interest group on UQ in High Value Manufacturing, 2016-18);
**Prest** (Nominating Committee, LMS, 2013-14);
**Tisseur** (Member, SIAM Fellows Canvassing Committee, 2017-20);
**Walton** (Member, Council, Applied Probability Society, 2014-16; Member, Applied Probability Section, Royal Statistical Society, 2016-19).

**Journal editorships**
37 Unit staff served on over 80 journal editorial/advisory boards. Leadership was provided as senior editors for 14 journals:
**Dongarra** (*International Journal of High Performance Computing Applications*, *Supercomputing Frontiers and Innovations*, *Applied Numerical Mathematics* and *Journal of Computational Science)*;
***Duck*** *(Quarterly Journal of Mechanics and Applied Mathematics)*;
**Hazel** *(Computer Physics Communications)*;
**Higham** *(Linear Algebra and its Applications* and *SIAM Fundamentals of Algorithms book series);*
**Jensen** *(Mathematical Medicine & Biology: A Journal of the IMA)*;
**Law** *(Foundations of Data Science)*;
**Parnell** *(Wave Motion)*;
**Peskir** *(International Journal of Theoretical and Applied Finance)*;

**Premet** *(Transformation Groups)*;
Wilkie (Emeritus) *Annals of Pure and Applied Logic*.

Furthermore **Higham** edited the *Princeton Companion to Applied Mathematics (2015),* (Associate Editor: **Glendinning**).

**Grant/Prize committees**
Unit staff served on 47 grant-awarding committees, including as chair/deputy-chair (**Glendinning, Heil, Juel, Parnell, Silvester**) in nine different countries. Staff served on prize committees including the SIAM Moser Prize, 2015 (Chair) and 2017 (**Glendinning**); the IMU Rolf Nevanlinna Prize, 2018 (**Higham**); SIAM Ralph E. Kleinman Prize, 2019 (**Lionheart**), Householder Prize, 2014 and 2020 (Chair) (**Tisseur**).

**Keynote and plenary lectures**
Staff contributed to over 600 scientific meetings, and gave over 170 keynote/plenary lectures, including:
**Borovik** (Morning speaker, BMC, 2014); **Dongarra** (SIAM CSE19); **Eaton** (Morning speaker, BMC, 2018); **Frei** (BIRS-CMO, 2018); **Gajjar** (ISTAM, 2019); **Gray** (Debris-Flow Hazard Mitigation 2019); **Higham** (ICIAM, 2019); **Jensen** (SIAM Conference on the Life Sciences, 2014); **GO Jones** (Diophantine Geometry, 2018); **Juel** (APS Division of Fluid Mechanics, 2020); **Kambites** (Research Programme Invited Speaker, Mittag-Leffler, 2018); **Law** (USNCCM, 2017); **Parnell** (IMECE, 2019); **Pan** (Multivariate and Mixed Linear Models, 2019); **Peskir** (Symposium on Optimal Stopping, 2018); **Premet** (ESI, 2017); **Prest** (Auslander Conference, Woods Hole, 2017); **Tisseur** (ICIAM, 2019); **Walton** (Markov Lecture Discussant, 2020); Wilkie (Emeritus, 26th Annual Gödel lecture, 2015); **Zhang** (Stochastic PDEs and related fields, 2016).

**Workshop and conference organisation**
Staff organised over 130 workshops and conferences, over 50 of which were in Manchester, including:
European Study Group with Industry, Manchester, 2015 (**Assier** and **GW Jones**); 3rd IMA Conference on Dense Granular Flows, INI, 2019 (**Gray**); Workshop on thin liquid film modelling, Banff, 2019 (**Hazel**); UK Fluids Conference, Manchester, 2018 (**Jensen**); Fundamental Challenges in Inkjet Printing, Lorentz Center, 2019 (**Juel**); Fluid Mechanics of Cleaning and decontamination, INI, 2018 (**Landel**); Data-Centric Engineering, MIT, 2019 (**Law**); Symposium on Optimal Stopping, Houston, 2018 (**Peskir**); Statistical Methods for Postgenomic Data, Imperial College, 2017 (**Strimmer**); Developments in Commutative Algebra and applications to classical rings, Chennai Mathematical Institute, 2015 (**Symonds**); Model Theory of Modules, Algebras and Categories, Erice, 2017 (**Tressl**).