

Institution: Loughborough University

Unit of Assessment: B9 Physics

1. Unit Context and Structure, Research and Impact Strategy

Physics has been a core discipline at Loughborough since 1966 and is best known for leading contributions to condensed matter and materials physics. In this assessment period, we have particularly grown our experimental capability, through staff recruitment and investment in experimental facilities as part of a £59M University investment in new state-of-the-art STEM laboratories and offices. Further enabled by a 64% increase in grant income compared to REF2014, our research has expanded to address the UK Grand Challenges declared in the Government Industrial Strategy. Our most significant contributions have been in “*AI & Data Economy*” and “*Clean Growth*” with particular highlights in spintronics, energy harvesting, novel computing and artificial intelligence, 2D and van der Waals materials, and medical technologies. At the same time, the Unit has doubled its proportion of female academics to 20%, including the Dean of the School of Science who is Professor of Theoretical Physics.

1.1 Research Structure

This Unit comprises all 18 academic staff from Physics and two physicists based in Mathematics, both Departments within the School of Science (SSci), which also includes Chemistry, Computer Science, and Mathematics Education. SSci is one of 9 autonomous Schools at Loughborough with its own Research, Enterprise and Senior Management Committees. Departments are represented on these committees through, respectively, their Research Coordinators, Impact Coordinators and Heads of Department (HoD). These key staff lead the effort within Departments and collaborate with their School-level leads (Associate Deans for Research and Enterprise, and Dean of Science). Both the Dean of Science and the Associate Dean (Research), who is also a member of the University Research Committee, are members of this Unit.

1.1.1 Research themes

Our four core research themes are:

- **Quantum and nano-engineering:** quantum metamaterials and quantum systems engineering,
- **Novel functional materials:** spintronics, caloritronics, as well as 2D and topological materials,
- **Physics of complex systems:** stochastic memristive artificial neurons and neuromorphic computing,
- **High-frequency solid state physics:** sub-THz/THz semiconducting and superconducting superlattices.

To promote **interdisciplinary research** in the School, six School Research Centres were established. The Physics Department is significantly engaged in three:

- Interdisciplinary Centre for Mathematical Modelling (ICMM)
- Centre for the Science of Materials (CSM)
- Interdisciplinary Science Centre from Laboratory to Fabrication (Lab2Fab)

ICMM fosters collaboration between Physics and Mathematics in quantum technology and soft-matter, while CSM and Lab2Fab promote collaboration with Chemistry in the field of 2D and smart materials, and the physics of live neurons, with the intention of capitalising on University investment in new shared laboratories and inspiring larger grant opportunities.

The institutional ‘CALIBRE’ strategic research framework drives interdisciplinary activity across all Schools. We engage with CALIBRE’s programmes, particularly the Global Challenges, Beacons, and Adventure programmes. For example, under the Health and Wellbeing Global Challenge we worked on superconducting medical brain sensors which resulted in one of our submitted Impact Case Studies. The CALIBRE framework also introduced the Institute of Advanced Studies (IAS)

to promote both interdisciplinarity and international collaboration. The Unit (Zagoskin) co-led the selected 20/21 theme “Time” (with colleagues from the Schools of Social Sciences and Humanities, and Business and Economics) which explored ‘time’ as a concept that underpins science and technology but also the development of societies and cultures.

1.2 Review of Objectives and Research Plans described in REF 2014

Achievement against the four strategic objectives from REF2014 is outlined below.

1.2.1 Concentration on research themes:

We prioritised research in our areas of strength, including novel functional and quantum materials and electronic components for medical, IT and AI technologies. For example, a collaboration with Chemistry and Computer Science investigated materials for memristive and spintronic devices and the architecture of memristor-based processors for Artificial Intelligence, respectively. We led pioneering research in quantum metamaterials after discovering a new class of distributed coherent structures, established the new research fields “spin-caloritronics” and “quantum system engineering”, and created the foundation for the application of stochastic memristive neurons to AI technologies.

1.2.2 Strengthening the experimental activities:

We radically upgraded and expanded Physics’ experimental facilities, accompanied by the addition of an enhanced experimental capability to complement what was previously a predominantly theoretical department. Within a total University investment of £59M and with the Department’s accumulated grant income, our experimental facilities have been greatly advanced (§3.3) to provide “full-cycle” capability for memristive, magnetic, and spintronic devices, where growth, fabrication, characterisation, measurement and theory are all located at Loughborough. Furthermore, SSci has co-located the Physics and Chemistry departments, enabling better sharing of equipment (e.g. X-ray diffractometers, Raman spectroscopy) and technical support.

1.2.3 Creating impact and reach far beyond the institutional boundaries:

We: (i) identified key stakeholders potentially interested in our research; (ii) informed them about our research achievements through publication in high-level outlets, patents and media releases, and dissemination via School/Department-based workshops, on-site visits and web-conferences; (iii) involved industry partners through KTP and joint PhD studentships; and (iv) informed the general public about Physics research and its impact. During this REF period new research networks have been established with world leading Universities and industry partners. The realisation of our strategy engaged new industrial partners, including global companies such as Hewlett Packard Enterprise (HPE), ARM, and Teledyne e2v, in our research in high-frequency electronics and neuromorphic computing. This also yielded several important grants (§3.1).

1.2.4 Encouraging a dynamic, effective and inclusive research environment:

We have significantly increased the diversity of our staff and broadened the Unit’s demographic profile. Revitalised plans made Physics at Loughborough a more attractive prospect to talented new staff and, by actively engaging with the University’s “Excellence100” campaign, we recruited a female professor in theoretical physics (currently Dean of School) and five lecturers (one female), from diverse ethnic backgrounds. Our engagement with and promotion of Equality, Diversity and Inclusion (EDI) principles were recognised by a bronze Athena Swan Award (2019) to SSci and the IoP Juno Practitioner award (2020) to Physics.

1.3 Enabling and Facilitating the Achievement of Impact

In the REF2014 exercise, we identified three enablers of more efficient translation of research to impact. The first was to introduce a reward mechanism for impact-active staff. During the assessment period, our impact leaders received KTP funding for Research Associates as well as University-funded PhD studentships, and we actively supported staff to apply for University and

School funding to support their impact. The second enabler was a new SSci seedcorn funding scheme. The third action was establishing an advisory board for our spin-out company “Sonobex”.

These interventions were facilitated by a School five-point impact strategy:

- IS1 Investing in Staff Training
- IS2 Establishing & Nurturing Partnerships
- IS3 Maximising Organisational Support
- IS4 Resourcing Impact Generation
- IS5 Recognition & Reward of Impact.

A comprehensive programme of Staff Training Workshops is held annually for SSci which staff are encouraged to attend (IS1). The Research and Enterprise Office assisted us with specialist support in partnership development (contract research, consultancy, CPD, recruitment), contracts, intellectual property, commercialisation and marketing (IS2). We also appointed a Physics Impact Champion (senior female academic) to coordinate activities and develop action plans for each Impact Case Study (ICS) based on IS3-IS5.

IS2, IS3 and IS4 underpinned development of the ICS in applications to brain imaging and MRI of high-temperature SQUID magnetometer technology (Chesca). This development secured several KTP awards (2-year Research Associate) working on superconducting sensors complemented by university-funded studentships working on sensors. The underpinning research of this impact case, which appeared in *Nature* (2015), demonstrated a highly sensitive high- T_c superconducting SQUID array for weak field magnetometers. To promote impact from this research, we established collaboration with Star Cryoelectronics (USA) and CTF MEG (Canada).

IS2, IS3 and IS5 supported the continuation ICS with spin-out company Sonobex, recipient of a Loughborough Enterprise Award 2014. The co-founders, Chief Technology Officer, Elford, and Engineering Director, Chalmers, graduated from the Physics Department having worked under the supervision of Kusmartsev (co-founder, Company Director 2013-2014, Chair of Scientific Advisory Board 2012-2017) and Swallowe (co-founder, Scientific Advisory Board 2012-2017). Continued collaboration helped Sonobex to advance their award-winning noise control technologies and develop the first commercially available acoustic metamaterial-based technology. The Department supported Sonobex to develop their business and later join the Merford group of companies.

1.4 Research and Impact Objectives and Plans for the Next Five Years

Our objectives for the next REF period will be delivered, through the first half of the cycle, by our portfolio of active grants in the field of neuromorphic devices, energy harvesting, spintronics, and quantum materials including the following EU and EPSRC grants (total value of over £2.3M) awarded very recently to senior staff, Betouras, Zagoskin and Saveliev, and ECRs, Borisov and Greenaway:

- Space resolved detection of single microwave photons with superconducting quantum coherent arrays (part of the Supergalax consortium led by SIN-CNR, Italy), PI Zagoskin, EU, 2020-22.
- Designing and exploring new quantum materials based on Fermi surface topological transitions, PI Betouras, EPSRC, 2020-24.
- Neuromorphic memristive circuits to simulate inhibitory and excitatory dynamics of neuron networks: from physiological similarities to deep learning, PI Saveliev, EPSRC, 2020-23.
- Oxide Recurrent Neural Networks, PI Borisov, 2020-23.
- Quantum dynamics of electrons in emerging van der Waals devices, PI Greenaway, EPSRC, 2021-23.

The grants demonstrate we have both leadership and, in our talented ECRs, vitality in the 5-year plan. Our ambition is to establish ourselves as a **world-leading centre in physics of AI and smart devices for future technologies**, becoming the distinctive brand for the Physics at Loughborough. To do so, we set the following specific objectives:

O1 – Further development of experimental facilities for smart devices and functional material nanofabrication and sensitive transport/magnetic measurements, significantly enhancing our experimental research in areas of current strength, including novel quantum and neuromorphic IT/AI devices, and magnetic, topological, and van der Waals materials. This will involve consolidation of resources and joint funding applications planned with the Engineering Schools for development of our experimental base related to synthesis, growth, fabrication and characterisation of materials and devices.

O2 – Convert international recognition of individual staff members in quantum, nano-, and complexity physics into international reputation of the Unit. To provide broader opportunities for internal and external collaborations, we will further invest in developing novel interdisciplinary research, such as devices for artificial intelligence, physics of the brain and medical physics, building strategic collaborations with regional partners, nationwide and internationally, see §4.1.

O3 - Transform our interaction with industry to boost the impact of our research by prioritising conversion of our scientific findings into IP attractive for business and industry, maintaining and expanding our strategic partnerships with HPE, Teledyne-e2v, Sonobex, DSTL, ARM holdings, Star Cryoelectronics, CTF MEG and Serac Imaging Systems Ltd, which are flagships of the IT/AI, environment protection, defence and medical devices industries. We will proactively approach business for part-funded PhD studentships, as well as KTP, Innovate UK and other industry-driven research and enterprise funding.

O4 - Increase our diversity by encouraging applications from underrepresented groups (e.g. female and BAME applicants), inviting more researchers from underrepresented groups to the Physics seminars and conferences, improving PGR diversity by attracting the best national and international students through offering contemporary projects related to UK Global Challenge topics, and continuing to actively participate in the Juno project.

O5 – Expand the research capacity of the Unit by (i) attracting highly competent national and international researchers in the field of smart devices and materials able to secure early career funding, such as UKRI Fellowships and others (see 2.1); (ii) supporting staff in their applications for established career fellowships and pursuit of platform-type awards; and (iii) exploiting our academic and industrial partnerships and working with international PhD funding bodies to further increase the population of PGR students.

1.5 Open Research Environment

Loughborough is a pioneer of the 'Open Agenda', actively supporting Repositories for text-based outputs (since 2005) and data (since 2015), working beyond funder (including REF2021) open access requirements. Our landmark Open Research Position Statement committed to depositing the full-text of 100% of our primary research outputs in our now unified (2019) Research Repository (including on closed access where unavoidable) from 2020 and Physics has met this target.

We strongly encourage staff to upload their outputs to arXiv to enhance their visibility. The University's research information system – LUPIN – automatically monitors published outputs databases such as arXiv, Scopus, Web of Science. The Physics Research Coordinator and HoD promote proactive usage of LUPIN by providing inductions for new staff and monitoring compliance with University's Open Access policy. Between 2014 and 2020, the Department of Physics' repository content accumulated more than 473,000 views and 373,000 downloads.

The Department's active support of the Open Research agenda is further evident in provision of computer code and algorithms. For example, original computer code supporting our research on quantum engineering, spintronics, semiconductor and superconductor devices was made publicly available via GitHub [<https://github.com/shalaka-kulkarni/Lboro/tree/master/lc-modelling>, <https://github.com/priimak/super-lattice-boltzmann-2d>, <https://github.com/debipattnaik>] and we contributed to the development of the open software QuTiP (Quantum Toolbox in Python) by providing new functions. QuTiP has approximately 50,000 unique annual downloads.

1.6 A Culture of Research Integrity

Loughborough University Ethics Committee is a joint sub-committee of Senate and Council, and considers all ethical matters arising in the conduct of the University's business. Ethics Committee has specific processes in place for areas such as experiments with human participants, work falling under the Human Tissues Act, and research with military applications. To support the University Ethical Policy, all Unit research proposals undergo ethical approval. We promote a culture of research integrity by creating equal conditions and opportunity for development and progression for academic, research, and technical staff and PhD students and by maintaining rigour, trust and confidence in the research methods and obtained results. All new Unit staff undergo compulsory training on avoiding academic misconduct. Training relates to work in physics research and teaching laboratories and the corresponding health, safety and behaviour issues. In addition, the Unit's internal review of papers pre-submission incorporates a check on potential research misconduct.

2. People

2.1 Staffing and Recruitment Policy

All academic staff contribute to teaching, research and enterprise activities. We expect and incentivise collegiality from the earliest career stages and, as careers develop, we expect broader leadership contributions in the Departments and School and at institutional level. Since 2014, three Unit staff served on the University Council and three on the Senate. Academic staff have open-ended contracts, while research staff are on fixed-term contracts related to projects in line with sector norms.

We monitor staff satisfaction via regular surveys. The last full University survey was in 2017 and SSci ran surveys in 2018 and 2020. In Physics, the Juno Committee runs surveys every three years (the last in 2018). These identified areas for improvement, such as workload and transparency, allowing the Juno, School Equality and Diversity and Athena SWAN Committees to develop an action plan for approval by the Senior Management Team.

The Department regularly assesses its succession needs and uses new appointments strategically to ensure critical mass and leadership in the research themes. All appointments, including replacements, need to be justified by strategic planning. Since REF2014, the University approach to recruiting excellent staff at all career stages, from postdoctoral and early career researchers (ECRs) through mid-career and senior roles, has radically changed, driven by the University Strategy. The University's 'Excellence100' campaign was based on pilot campaigns to recruit outstanding ECRs which were managed centrally and focussed unequivocally on excellence. In physics, three outstanding staff were recruited in these campaigns: Banerjee and Rousochatzakis (Lecturers) and Greenaway (Vice-Chancellor's Research Fellow). Building on this, recruitment to established posts is now conducted through biannual recruitment rounds, managed centrally but with significant School input, rather than piecemeal replacement hires. With excellence as the primary criterion, these rounds deliver better international recruitment and improved diversity.

In the Departments, all recruitment activity is checked and approved by the Department Equality and Diversity Coordinator as well as by the School's EDI Director. The selection committee and

Head of Physics will proactively approach potential candidates from underrepresented groups. As a result, we have doubled the proportion of female academic staff to 20%, at levels from Lecturer to Professor, and recruited additional BAME colleagues.

Since 2014, our main recruitment requirement has been to build experimental capacity to complement our theoretical capability. Of seven new academic appointments, from lecturer to professorial levels, four were ECR experimental staff with backgrounds in novel quantum and IT/AI devices, magnetic, topological, and van der Waals materials. The high calibre of these staff is evidenced by three having secured EPSRC New Investigators Awards (NIA) and two having already been promoted to Senior Lecturer. We targeted ECRs in order to develop new capabilities in spintronics, smart devices and medical imaging, and senior staff members to strengthen the leadership within the Department.

The Departments welcome part-time working and look to offer flexibility according to need such as to reduce hours for flexible/phased retirement or to increase hours as circumstances change e.g., Everitt transferred to a permanent full-time position from a part-time contract and is now leading our Quantum Systems Engineering work. Fixed-term contracts have been used effectively to attract promising new staff who can then be appointed to permanent posts e.g., Morrison was originally employed on a fixed-term contract and she has since secured EPSRC NIA and Early Career Fellowship awards, and is a member of the Physics REF team and senior management team.

2.2 Staff Development

All Unit staff are supported through Loughborough's Organisational Development, which provides a variety of training targeted at staff at all career levels. Courses range from earliest stages (Welcome to Loughborough) through essential training (Information security training, Unconscious Bias) to training for staff becoming senior managers (Coaching conversations for managers, Recruitment and selection).

All colleagues are expected to obtain Fellowship of the Higher Education Academy (HEA). For new lecturers, this is integral to their dedicated development programme. More experienced colleagues are supported through our 'Recognition of Experienced Practitioners' scheme which requires preparation of a dossier of evidence to support their application.

The School allocates funding for staff to attend major scientific conferences (£2000 within every two-year period) including staff currently without external research funding to support dissemination of their research.

2.2.1 Supporting postdoctoral researchers

Following the principles of the *Concordat to Support the Career Development of Researchers*, the University provides structured support to research staff for career progression and development, including preparation of applications for funding. The School arranges regular career development events for research staff such as the "Research Lunch", where successful academics and Careers Network staff provide individual guidance on future career strategies and share good practice.

The Unit also supports applications for external (e.g. Royal Society, Newton international & EPSRC) postdoctoral fellowships, including arranging mock interviews for shortlisted candidates to maximise their chances of success. Internally, the Doctoral Prize Fellowship scheme funds to two-years research immediately post-PhD with a package of support including a mentor, dedicated training, and specialist Fellowship advice.

The success of the support provided is evidenced by all our post-doctoral research staff successfully continuing their careers either in research or industry (e.g. academic posts at Nottingham, Sheffield, and Manchester Universities, Swinburne University (Australia), Qatar Environment and Energy Research Institute, Sonobex, ISIS beamline).

2.2.2 New Lecturers' Programme (NLP)

All new lecturers are guided by an experienced and trained academic colleague from their Department who acts as Adviser. NLP (formerly academic probation) was substantially revised in 2017 and includes the full spectrum of research and impact activity (publication, funding applications, collaboration, public engagement, non-academic partnerships). New lecturers have a reduced workload in teaching (33, 50 and 67% of departmental norms in consecutive years), and administration which enables the establishment of a full academic profile in research, teaching and impact at a manageable pace. In addition to an extensive training programme leading to FHEA, the New Lecturer formally meets four times annually with their Adviser. Minutes of these meetings, as well as overall progress, are monitored in the School and by the University. SSci commits to providing a Ph.D. studentship, co-supervised by an experienced colleague. Supervision is a requirement to pass the programme, alongside a minimum expectation on research output production, and the submission of at least one substantial grant application. Eight Unit staff benefitted from NLP, which helped them to secure funding (see §3.1).

2.2.3 Support and integration of early career researchers into the Unit's research culture

Each newly appointed academic receives a modest start-up package, including a PhD studentship, at least £2k/annum funding and priority in funding allocated by the School's strategic calls. Newly appointed experimentalists can negotiate a significantly larger budget with the Dean. For example, Dejene received an additional £8k for purchasing a 2D transfer microscope stage and probe station and Bugby received £20k for nuclear imaging. Such measures have helped new academics establish their own research labs in spin caloritronics, superconducting spintronics and memristive technologies.

2.2.4 Developing mid-career staff and academic leaders

Two senior Unit staff achieved qualifications from the Institute of Leadership and Management (ILM), going on to become Head of Physics and Associate Dean (Research). One academic completed the University's Future Leaders Programme and female academics receive funding from the School to participate in the Aurora Leadership programme.

2.2.5 Respecting technical staff contributions

To promote contributions from technical staff, the University championed the establishment of the "Technicians Forum", which is now nationally recognised. Physics has dedicated technical staff to support research and teaching and they are actively involved in research projects. For example, Sutton co-authored three research papers, which helped him to secure a lecturer position at the University of Lincoln. Technical staff are represented on the School EDI and Juno Committees, enabling direct influence on the strategy and policies of the School and the Department.

2.2.6 Appraisal, promotion and reward

All members of post-probationary staff in the Unit have an annual PDR. This University scheme was totally updated in 2017, with a much stronger focus on development centred on a one-to-one discussion between the reviewee and a trained reviewer. The discussion focuses on strengths and areas for development across the full range of activities including CALIBRE-aligned goals for research and impact activity. New PDR is a transparent way to recognise performance exceeding expectations with additional financial reward and allows much fairer identification of candidates for promotion. The new scheme has particularly benefitted Unit research staff for whom a rigorous developmental discussion was previously sporadic and consideration for reward a rarity.

The University has also revised the criteria for academic promotion (Senior Lecturer, Reader, Professor), to ensure that the research components align with the University Strategy and CALIBRE. Evidence for cases can be based on research, teaching, enterprise (impact) or any combination to encourage balanced portfolios of work. We judge 'Excellence and International Reputation' and 'Academic Leadership and Influence' rather than traditional metrics based on quantity and not quality. This focus allows panels to take into account statements from promotion applicants describing how personal circumstances, such as caring responsibilities, may have

affected their profile. The School's "Promotion Demystification" workshop has supported four promotions to Senior Lecturer, and one case of successive promotion to Reader then Professor.

2.2.7 Research and impact leave

Unit staff can apply for either University or School fellowship schemes, which allow focus on exceptional activities for up to 12 months. The School's Maria Agnesi Fellowship Scheme enabled Zagoskin to accept a prestigious Residential Fellowship at Notre-Dame Institute of Advanced Study (2018), which established a new international collaborative project in quantum physics.

2.3 Postgraduate Research (PGR) students

We treat PhD students as partners in our research and their research contributes to our collective output in an essential way. The number of PhDs awarded has increased by more than 40% in this REF period.

2.3.1 How we fund our research students

The Unit maintains its PGR population (c.20 students) via University scholarships, industry funding, international scholarships, UKRI funding including Centres for Doctoral Training (CDTs) and DSTL, and high-quality self-funded students. The funding mix is approximately half internal funding, and a quarter each from UKRI and industry / self-funders. University scholarships are also available to cover international tuition fees. Unit staff are encouraged to bring third-party partial funding for match with internal funding or in a CDT. During the REF period, the Unit participated in two EPSRC-funded CDTs, in *Embedded Intelligence* and *Additive Manufacturing*. We were also awarded a University-funded mini-CDT in Quantum Systems Engineering under CALIBRE's Adventure Programme.

2.3.2 Recruiting doctoral research students

We require all potential supervisors to have undertaken training on Bullying and Harassment, Recruitment and Selection, Respecting Diversity, and Mental Health Awareness. Supervisors are then required to develop PhD recruitment plans that include approaching underrepresented groups (special mailing lists, diversity-related web-resources, conferences). All funded and non-funded projects are posted on the School website and the highly visible FindAPhD website. We arrange remote or in-person interviews of shortlisted candidates to ensure high quality students are recruited. Decisions on offers are taken by two members of staff.

2.3.3 Monitoring and support mechanisms

The Doctoral College runs an induction event for new starters, complemented by a School induction. All students have at least two supervisors with a recommended split of around 70:30 to ensure productive involvement of the second supervisor. All full-time students must have at least monthly recorded meetings via the University's dedicated online Co-Tutor tool. During the first year of PhD studies, there is an initial 6-month review followed by annual reviews based on a report and viva with an independent examiner, from which student progression is decided.

The School's Director of Doctoral Programmes (DDP) is supported by Deputy Directors in the Departments, who also monitor progression and arrange subject specific training and events such as regular student research presentations. Further specialist support is available from the Mathematics Learning Support Centre, the English Language Support Unit, the Student Advice Centre, the Careers Network, and the Student Wellbeing and Inclusivity Service. In the Unit, each PhD student is provided with travel and consumables funds (£1500 / £3000 for theoretical / experimental students, respectively).

SSci Departments have elected PGR student representatives, who are important points of contact when issues need to be resolved. PGR representatives participate in the School's Staff-Student Liaison Committee.

2.3.4 Skills development

The Doctoral College offers over 200 events annually, from induction and international orientations for new students to transferable skills and employability training. The Doctoral College also runs the Annual Conference, Summer Showcase, Three Minute Thesis competition and the 'Diversity in Research' workshops. SSci holds the annual "Science Matters" conference, organised by PhD students, as a professional development opportunity with popular lectures from prominent external speakers, student talks and poster presentations, and awards for outstanding doctoral student contributions.

Subject-specific training and seminars for Physics PGRs includes: prestige events (Sir Nevill Mott lecture (Physics), Sir David Wallace lecture (Mathematics)), weekly Landau seminars (mandatory for Physics PGRs), Mathematical Reviews, journal clubs and research talks, and monthly Health and Safety seminars. All students have the opportunity to gain experience in teaching by assisting in labs and tutorials (with approval of their supervisors) after completing the University's Teaching Skills course designed for PhD students.

2.4 Equality, Diversity and Inclusion

There is a strong leadership for EDI within SSci. The Associate Dean (Research) and the Dean, both Unit staff, have an extensive engagement with Project Juno working closely with the IoP EDI team. Physics actively participates in a range of School-level EDI activities, including Women in Science lecture series, Pride in STEM research showcase (talks by LGBT+ scientists), Black Excellence in STEM events, panel discussions about experiences of Black students and staff in STEM, and the Diversity Allies Campaign (encouraging staff and students to be better allies to underrepresented groups). There is an additional annual budget of £4,500 for School EDI activities. The gender balance of research seminars, invited lectures, and other research events is closely monitored across the School to ensure at least 25% female participation.

The Juno and the School EDI committees monitor EDI data and the impact of EDI activities. Monitoring by gender is undertaken annually for application rates, shortlisting, offers and hires to staff positions, PhD numbers and completion times, UG intake, seminar speakers, school roles, promotions, internal School funding and studentships.

The Physics Juno Champion (also a member of the University BAME network) sits on both the university level Athena SWAN SAT and the School EDI committee and develops EDI policy for the Department.

2.4.1 Arrangements for supporting flexible and/or remote working

Formal flexible working requests may be submitted for approval by HR. Academic staff within SSci may request up to one hour each day guaranteed to be free from teaching. This allows staff additional flexibility to accommodate e.g., school runs. Academic staff also have the ability to work flexibly or remotely on an informal basis so long as their responsibilities are fulfilled. For other circumstances, such as caring for a family member in poor health, staff can request compassionate leave for immediate issues or longer term flexible working for ongoing responsibilities.

Remote working is facilitated through the remote working portal, which permits staff to access all online resources remotely while protecting sensitive information from unauthorised access, as well as through the choice that academic staff have between a desktop computer or a laptop. These policies and supporting infrastructure have eased the transition to effective home working during the COVID-19 pandemic from March 2020.

2.4.2 Support for submission of funding applications

The Juno and EDI committees collect information about grant success rates and studentship applications by gender and seek support from the research committees (both at the School and the University levels) to promote a culture of equality and diversity in the research resource

distribution. The Physics Research Coordinator actively encourages Unit staff from underrepresented groups to access expert support available. These measures resulted in significant current (2020) EPSRC funds with 27% contribution from female staff and 65% from ethnic minority staff.

2.4.3 Support for staff and research students returning from periods of leave

In addition to University-level support, the Departments support staff returning from parental, maternity, adoption, caring responsibility, sick or other long-term leave by giving them phased workload reintroduction and release from substantial administrative activity. This has helped 5 Unit staff re-establish their research (Borisov and Greenaway subsequently obtained EPSRC NIAs, Morrison obtained a New Horizons grant).

2.4.4 Supporting the wellbeing of staff and research students

The University has a counselling service and also subscribes to an external service (for staff and PGRs) that provides 24-hour telephone counselling and sessions for more complex issues. SSci has a well-being advisor who supports staff and students with any well-being issues. Physics also has two mental health first aiders (trained academics with workload allocation) who provide support for staff.

2.5 Equality and Diversity in the Construction of our REF Submission

This REF submission was constructed by a mixed-gender team (20% female in line with the Unit ratio) and following the University's Code of Practice. All colleagues were asked to nominate and self-assess potential outputs for inclusion. In line with our Responsible Metrics Policy, these were peer assessed for originality, significance and rigour by a team of reviewers representing all research themes and covering different career stages, age, gender, race, and ethnicity. The submission team completed EDI and unconscious bias training and two members were also members of the University BAME network. Throughout our REF preparations, equality impact assessments (EIAs) were carried out to assess both institutional processes and our draft return, included outputs selected, against protected characteristics, and to monitor whether further action was required. EIAs confirmed no issues required attention.

3. Income, Infrastructure and Facilities

3.1 Research Income

Our strategic aim since 2014 was to significantly increase the active grant portfolio. This was achieved by: analysing our past successes and failures, establishing research themes (objective 1.2.1), and strengthening our experimental activities (objective 1.2.2) through recruitment (Dejene, Borisov, Banerjee, Bugby) and by securing high value equipment. In addition, the School introduced grant-writing training and one-to-one sessions with Research Development Managers and an external adviser (GrantCraft), while Physics introduced internal peer-reviews for all applications and provided a repository of successful grants.

Our total grant income (excluding in-kind) reached £3.5M, an increase of 64% compared to REF2014. At the point of submission, our active research and enterprise grants totalled £3.7M. This includes **major and prestigious awards**: an EPSRC Early Career Fellowship (Morrison, £843k), and three New Investigator Awards (Banerjee, £186k; Borisov, £277k; Greenaway, £274k) reflecting our ECR support (see §2.2.2).

Our strategy for collaboration also resulted in research grants supporting **three major research consortia**:

- Brain Inspired Computing - Salk Institute for Biological studies (USA), Texas A&M University (USA), University of Massachusetts Amherst (USA), ARM Ltd. (UK). £966k to Loughborough.
- SUPERGALAX - Consiglio Nazionale Delle Ricerche (Italy), Istituto Nazionale Di Ricerca Metrologica (Italy), Istituto Nazionale Di Fisica Nucleare (Italy), Ruhr-Universitaet Bochum

(Germany), Karlsruher Institut für Technologie (Germany), Leibniz-Institut für Photonische Technologien E.V. (Germany). €2.5M total with €387k to Loughborough.

- New quantum materials - Boston University (USA), Max Plank Institutes (Germany), Universities of Nottingham and St. Andrews. £575k to Loughborough.

3.2 Organisational Infrastructure Supporting Research and Impact

3.2.1 Research development

We benefit from the continuous and proactive support provided by the Research Development Managers (RDMs). The RDMs arrange one-to-one sessions with staff developing applications, and general drop-in sessions for staff developing ideas. For large and strategically important applications, including prestigious fellowships, RDMs arrange mock panels (e.g. for Morrison's and Rouschatzakis' EPSRC Fellowship applications), contact industry partners, and share best practice.

3.2.2 Partnership development and commercialisation

Unit staff work closely with our Partnership Development Manager (PDM), who supports the development of links and networks with industry and provides specialist IP support. They also arrange drop-in sessions for staff seeking to generate impact from their work. Recent successful examples include development of strategic relationships with ARM, Hewlett Packard Enterprise, Merford, Dstl, Star Cryoelectronics and CTF MEG.

3.2.3 Research quality and visibility

The University Research Policy Team arranged mandatory workshops for Unit staff to promote open access repositories, Google Scholar, Researcher ID, ORCID, Scopus and other research networks/databases in order to increase awareness of ways to enhance research visibility. Unit staff were also trained to use the Vertigo Ventures Impact Tracker to collect evidence for impact case studies and demonstrate different pathways to impact, even from very fundamental research. Experienced Unit staff complement this support by offering extensive internal reviewing of preprints, which helped to secure publication of 51% of our current REF outputs in the top 1% of journals by SJR.

3.3 Operational and Scholarly Infrastructure and Facilities Supporting Research and Impact

University investment dramatically accelerated progress against objective 1.2.2 (*to improve experimental facilities for all our research themes*) and created the basis for much of the Unit's plans post 2021 (specifically objectives O1, O2 and O5 of section 1.4). Unit staff now have new offices and meeting spaces, more space for PhD students and academic visitors, a new clean room (ISO class 6/FED), and co-location of lab facilities with Chemistry. The immediate result of this investment was development of new thin film and photolithography facilities and shared X-ray characterisation and sample preparation facilities (e.g. 3D printing, furnaces), optimising technical support.

Additionally, School investment and EPSRC equipment funding over the last 5 years has yielded an upgrade of specialised electronics for high-precision low-noise measurements; development of ferromagnetic resonance (FMR) and a Magneto Optic Kerr Effect magnetometer (MOKE), an atomic force microscope (AFM), a 9 Tesla cryogen-free magnetometer with resistivity, thermal transport, and ³He options (CFMS) for ultra-low temperature measurements, and a maskless photolithography system accompanied by an ion miller for top down fabrication of devices. Unit staff also proactively collaborate across the University to access additional experimental facilities, such as a new confocal AFM in the Department of Materials, awarded under an EPSRC Strategic Equipment call.

The addition of a clean room and ancillary fabrication equipment, such as the maskless photolithography system to the various structural, surface, magnetic and electric characterisation techniques, has enabled a wider breadth of research. This includes advances in spintronics,

Unit-level environment template (REF5b)

memristors, 2D materials and novel magnetic and superconducting states, all of which have received funding during this REF period.

Unit research is also supported by access to state-of-the-art facilities in the Loughborough Materials Characterisation Centre (LMCC), which contains over £6M of equipment including:

- Surface analysis such as X-Ray Photoelectron Spectroscopy (XPS), Micro X-ray Fluorescence (μ XRF) and Scanning Electron and Transmission Electron Microscopy (SEM & TEM) with various secondary detectors.
- Optical Microscopy
- Thermal Analysis

Our research and impact activities are also advanced by support from the Loughborough-funded High Performance Computing (HPC) service, which comprises the Hydra cluster (a 2460-core 64-bit Intel Xeon cluster supplied by Bull) and the Tier-2 HPC Midlands Plus funded by EPSRC and hosted by Loughborough on behalf of the Midlands Innovation partnership of the 8 research-intensive universities in the Midlands.

In order to access **major large-scale facilities**, Unit staff secured beamtime and facility in-kind support exceeding £4.8M from ILL, ESRF Grenoble, the ISIS Neutron and Muon source, STFC and Lawrence Berkeley National Laboratory. These have enabled world class measurements on, for example, magnetic proximity effects in multilayer films (Morrison, Banerjee), magnetic excitations in bulk alloys (Morrison) and high-resolution powder diffraction of functional materials under strain (Kusmartseva).

4. Collaboration and Contribution to the Research Base, Economy and Society

4.1 Research Collaborations, Networks and Partnerships

To fulfil our strategic objectives to extend reach beyond our institutional boundaries and encourage a dynamic, effective, and inclusive research environment, we prioritised development of collaborations with world-leading groups, some new and some an expansion of existing collaborations. This was aided by travel grants, development of the School's Interdisciplinary Research Centres, which brought international conferences/workshops to Loughborough, the IAS visitor programmes, and the School's Maria Agnesi Fellowships, which supported study leave of Zagoskin (University of Notre Dame, USA, and MISIS, Moscow), and Betouras (Crete, TU Munich, Toulouse, and the Max Planck Institute of Physics of Complex Systems, Dresden). Our Landau Seminars, which attract world-leading researchers to give talks across broad areas of physics, also played an important role in establishing new collaborations. For the REF period, we invited on average 25 scholars per year to give Landau seminars on topics from as diverse as conversation analysis to antimatter imbalance in the universe.

In total, Unit staff enjoyed collaborations with 87 international groups across 22 countries. The world-leading institutions with whom we continue to have ongoing projects include: MIT, University of Massachusetts Amherst, Boston University, Lawrence Berkeley National Labs, Harvard University, Salk Institute for Biological Studies, Texas A&M University, University of Cambridge, Oxford University, University of Manchester (Nobel Laureates Geim's and Novoselov's groups), University of Nottingham, Tokyo Institute of Technology, National Institute of Advanced Industrial Science and Technology (Japan), École polytechnique fédérale de Lausanne (Switzerland), TU Munich (Germany) and MPI-CPFS, Dresden (Germany). For example, Banerjee is collaborating with Prof. Jagadeesh Moodera's group at MIT's Francis Bitter Magnet Lab on designing experiments to directly detect the unconventional mechanism of superconductivity; Saveliev worked closely with Prof Yang's group from University of Massachusetts Amherst and Prof. Albright from Salk on pioneering research in volatile diffusive memristors to emulate brain activities. Greenaway collaborates with Profs Geim and Novoselov on describing electrical and transport properties of graphene and van der Waals materials. Everitt works with Dr. Tilma from Tokyo Institute of Technology on Wigner function tomography for quantum nano and smart

devices. These collaborations resulted in joint publications, including 19 articles in Science, Nature, Nature Communications and Nature Research journals.

Our extensive visiting programme has supported visits of world-leading scholars including Prof. Mele (University of Pennsylvania, Leverhulme Professorship), Prof. Chubukov (University of Minnesota, Leverhulme Professorship), Prof. Anlage (University of Maryland, IAS Fellow), Prof. J.S. Moodera (MIT, IAS Fellow), Prof. Khramov (Innopolis University, Russia, School-funded), Prof. Marchesoni (Universita' di Camerino, School-funded). This programme not only added to the Physics' international visibility and reputation, but also allowed us to strengthen our research portfolio and seeded research funding. Our approach to establish collaborations through participation in conferences and seminars and then advancement of them through mutual visits yielded several successful joint research grants.

The above collaborations contributed significantly to the enrichment of our research environment. For example, our long-term research collaboration with HP Labs/Texas A&M University on polarons (Profs Alexandrov and Williams who delivered the Mott lecture 2018) seeded extremely successful joint research in memristive devices, with excellent publications (e.g., "Memristors with diffusive dynamics as synaptic emulators for neuromorphic computing" in *Nature Materials*, "Fully memristive neural networks for pattern classification with unsupervised learning" in *Nature Electronics*, "A novel true random number generator based on a stochastic diffusive memristor" in *Nature Communications*) and contributions to the EPSRC Awards on Neuromorphic memristive circuits and Oxide Recurrent Neural Networks that underpin future plans (§1.4).

4.1.1 Key research users, beneficiaries or audiences

The Unit's 5-point Impact Strategy (§1.3) has helped to develop strong collaborative links with industrial users. With the support of PDMs, Unit staff proactively develop contacts with industry at conferences, policy-making events, industrial exhibitions (such as The AI Summit London), and via personal contacts. The main industrial partners were invited to the School Industrial Advisory Board established by SSci in 2019.

Prominent collaborations include: research on neuromorphic memristive circuits to simulate inhibitory and excitatory dynamics of neuron networks with Hewlett-Packard (USA) and Arm Holdings (UK); synthetic materials using metallic and non-metallic nanoparticles at microwave frequencies with European Space Agency (International) and IMST GmbH (Germany); acoustoelectric methods for the generation, manipulation and detection of THz Radiation with Teledyne e2v (USA/UK); quantum system engineering with DSTL (UK); testing and optimising a measurement technique geared towards studying magnetism at high pressure with Almax-easylab (Belgium); designing novel algorithms to simulate large quantum coherent systems using GPU processors supported by NVIDIA Corporation (USA); synthesis optimisation of transition metal dichalcogenides films with QinetiQ (UK); and novel sensors and imaging systems for nuclear medicine with Serac Imaging Systems Ltd (UK).

We also focussed our efforts on other promising impacts, (i) related to magnetic energy harvesting (supported by an EPSRC Fellowship), (ii) sensors and imaging for nuclear medicine in collaboration with clinical partners (Sheffield University Hospitals) and with Serac Imaging Systems Ltd, and (iii) neuromorphic AI technologies (supported by several current EPSRC grants).

4.1.2 Wider contributions to the economy and society

Unit staff proactively promote science among diverse groups of the general public and in schools. Key activities included: developing a 'Thermal Measurement' Subject in a Box Activity for GCSE students, developing multiple outreach activities and workshops for the "Science in the Community day" at Loughborough (at least annually with more than 500 visitors), developing and running workshop on Wind Power for the annual Ford Fund Residential for Girls (annually, ~50 participants), coordinating observatory visits for local beavers/scouts/rainbows groups as part of their 'space' badge (around 100 visitors annually), and local school talks. Staff have also participated in Big Bang Fairs (London and Derby), the annual "Science in the Park" and "Light

Night" in Nottingham, and in development of a new Girlguiding badge "I'm a Physicist", which has distributed over 20,000 badges (>100,000 hours of physics at an average of 5 hours per badge), and is currently being rolled out to the rest of the UK.

4.1.3 Engaging with diverse communities and publics

We are committed to engaging with popular science and gave a number of interviews and presentations for the popular media. Recent examples include BBC's "The One Show" about our pioneering noise barrier technology (Sonobex) and three BBC Radio Leicester interviews about the neuromorphic artificial "brain", Weyl semimetals and future technologies, and energy harvesting and the spin Seebeck effect. Recent popular articles have included "Thermal imaging of the Thomson effect" for Physics World (02/04/2019) and APS Physics Viewpoint (02/09/2020), and an interview to RIA Novosti -- Russian News Agency – on the perspectives of quantum computers.

Since 1995, the Department of Physics has run the prestigious Sir Nevill Mott Lecture series, an annual lecture for the general public with which Nobel Prize winner Sir Nevill permitted his name to be associated in recognition of his collaborations with the Department. Invited speakers include eight Nobel Prize Laureates. For this assessment period, we invited world leading scholars: Professors Stanley Williams, Michael Kosterlitz (2016 Nobel Prize winner), Zahid Hasan, Yuri Pashkin, Sir David Wallace, and Sir John Pendry.

4.2 Contribution to the Sustainability of the Discipline

Unit staff have served as members of STFC Public Engagement Early-Career (PEER) Forum, East Midlands IoP Committee (Morrison), and delivered keynote talks at the IoP supported National Student conference (Chesca, Saveliev, 2018). In 2016-19, a team headed by Everitt delivered training in the emerging field of quantum system engineering for over 50 DSTL and EPSRC-funded PhD students from the Bristol *CDT* and various quantum technology hubs.

The Unit also runs workshops and events that attract a mixture of academics, industrial partners and private investors including: School supported workshops (Magnetic and topological materials, spintronics, and neuromorphic devices); EPSRC network plus meetings on classical and quantum emergence and physics far from equilibrium; a Dstl meeting on Defence & Security Quantum Community; and the Innovative Energy Harvesting Special Interest KTN Group launch in 2016.

The discipline leadership of Unit staff has also been recognised by 3 APS Fellowships and 5 IoP Fellowships.

4.3 Indicators of Wider Influence

As active contributors to the Physics community, Unit staff **participate on grant committees** for various national and international funding bodies including ERC, EPSRC (3 staff are members of the EPSRC Peer Review College), STFC, Royal Society, the Leverhulme Trust, H2020 (including Evaluation Panels), Israel Science Foundation, US-Israel Binational Foundation, WM Keck foundation (US), National Science Foundation (USA), Russian Science Foundation, Research Foundation – Flanders, Netherlands Organisation for Scientific Research, National Natural Science Foundation of China, German Research Council, Human Frontier Science Program, Irish Research Council, CINT Los Alamos, South Africa's National Research Foundation (NRF), and Carnegie Trust.

Unit staff have increased their influence on **advisory boards and in policy making**. Eberlein contributes to Institute of Physics (IoP) policy as a member of IoP Council (2020-present), while Everitt serves on IoP's Accreditation Review Group (2017-present), having also served on the 2016 QAA Subject Benchmark Statement Review group which revised of the nationwide university curriculum in Physics. Zagorski is a member (2017-present) of the international advisory board for the NEDO project dedicated to the development of Japanese quantum computer at the National

Institute of Advanced Industrial Science and Technology (AIST). Morrison is a member (2020-present) of EPSRC Physical Sciences Strategic Advisory Team and the Reflectometry Scientific and Technical Advisory Panel for the European Spallation Source (2019-present).

Our increasing influence in our research theme areas has resulted in formal international recognition for a growing number of Unit staff, evidenced by **honorary and visiting positions** such as:

- Balanov (Visiting Scientist, Saratov State University);
- Bugby (Visiting Professor, Universidad de la República, Uruguay);
- Morrison (Visiting Scientist, Imperial College London);
- Zagoskin (Visiting Professor, MISIS Moscow and Visiting Researcher Fellow in RIKEN Japan);
- Kusmartsev (Visiting Professor at University Roma (TOV), Professor of Excellence at St Petersburg University (ITMO), and Professor of Excellence at Peking University, China, and Fellow of International Institute of Physics (FIIP) Brazil).
- Saveliev (Visiting Researcher, Augsburg, Salk Institute for Biological Studies); and

Saveliev was recognised by the prestigious Friedrich Wilhelm Bessel Research Award from the Alexander von Humboldt Foundation, for his outstanding contribution to Brownian and nanomotor research and THz superconducting electronics. This award supported Saveliev's honorary position at the University of Augsburg held until 2015.

The Unit contributed to setting quality targets for the international academic community by accepting invitations for **Journal Editorship**. Six staff have served as editors for the following journals: (Q1 by SJR ranking) Superconductor Science and Technology, Scientific Reports, and (Q2 by SJR) Europhysics Letters and Frontiers in Physics. Additionally, two Unit staff served as guest editors for New Journal of Physics Focus Issue on Time Crystals and a special issue of the Proceedings of the Royal Society (both Q1 by SJR).

Unit staff gave over 160 **invited talks** and 13 **plenary and keynote talks** at international conferences, and **chaired international conferences** on 10 occasions. Examples include Invited talks at: the APS March meeting (2016, 2017), MRS Spring Meeting, (2020-online), EPS Condensed Matter Division Conference and DPG Condensed Matter Division, Berlin, Germany (2018), SPIE Spintronics at San Diego (2020).