Institution: University of Sheffield
Unit of Assessment: B-09 Physics
1. Unit context and structure, research and impact strategy

1.1 Overview

Our collective mission is to carry out world-class research at the forefront of knowledge in the discipline, from the fundamental building blocks of matter to supernovae and massive stars, across photonic nanostructures to the physics of living systems.

We aim to build strong partnerships at the interface between physics and other disciplines, locally, nationally, and internationally, leading to new understanding of the universe and translation to help address societal challenges and goals from sustainable energy to next-generation computing.

Our strategy has been to assemble a critical mass of excellent researchers, capable of working across boundaries, forming international collaborations, and creating real-world impact.

Our aim in this assessment period has been to build upon existing strengths in condensed matter physics, particle physics and astrophysics. Highlights include:

- A total research income in excess of £47M, with a 54% growth between 2013/14 and 2019/20, with an income of £223k/FTE in 2019/20.
- Contributions to significant international, national, and local interdisciplinary partnerships including the EPSRC Hub in Quantum Communications, the £3.4M GOTO observatory, the £1.6M Wellcome Trust support for physics at the interface with biology and the £10M STFC-funded WATCHMAN project.
- A 25% increase in PhD enrolment.
- The appointment of Tovey, Costanzo, Vickey and Malek to significant international leadership roles in particle physics.
- Major awards recognising colleagues for their contribution to science (Skolnick), the scientific community (Hobbs), and, through their impact activities, for innovation and for international trade (Buckley and Lidzey).
- Significant and continued investment in impactful research most notably from National Grid and Big Solar.

Our research is structured around four research groups, each supported by substantial grant income, providing a dynamic and supportive environment for our growing base of early career researchers (ECRs). The groups are underpinned by our investment in supporting infrastructure through access to international facilities, and our commitment to embracing diversity.

Our investment in people and our successful capture of research income have provided the unit with an excellent foundation for sustainable growth and further improving our impact activities, whilst continuing to enable high-quality outputs.

1.2 Unit structure, research strategy and progress towards REF2014 objectives

Our research spans the range of modern physics and astronomy from neutrinos and the Higgs Boson through to active galaxies, via photonic nanostructures, 2D-materials, hybrid organic/inorganic semiconductors, photovoltaics, and the physics of bacteria. We carried out a strategic review of our research in 2017 allowing us to build on clear synergies between areas, and subsequently structure our work in four groups: 'Inorganic Semiconductors', 'Materials and Biological Physics', 'Particle Physics and Particle Astrophysics', and 'Astronomy and Astrophysics' (see Figure 1).

Figure 1. Group membership

1.2.1 Unit structure

Specific achievements in this assessment period and aims for the next five years are described below for each research group:

Inorganic Semiconductors (IS): This group, comprising seven professors and one research fellow, is active in both experimental and theoretical research into nanophotonic semiconductor systems, 2D materials and quantum information theory. Our leading facilities in semiconductor physics have been supported by £3.5M of University and EPSRC investment in equipment and laboratory space. In January 2020 we opened the University's new Quantum Centre, consolidating research in this area. The group has benefited from awards in excess of £20M over the assessment period, including two EPSRC Programme Grants. These investments have been key in enabling notable discoveries including very high coherence on-chip single photons (Fox, *Nature Nanotechnology* 2018) which has led to the formation of a spinout company, elucidation of the nature of exciton states in moiré superlattices of 2D materials (Tartakovskii, *Nature* 2019), and discovery of a system that opens the way to a high-speed, low-power, integrated platform based on strong interactions between photons (Krizhanovskii, *Nature Communications* 2017).

Over the next five years the group will build on recent achievements in quantum science and technology in both III-V systems and in atomically thin 2D materials. Particular areas of focus will include on-chip entanglement of arrays of quantum dot spins, creation of new lattice potentials in 2D heterostructures enabling new many-body phenomena, Rydberg exciton polaritons as highly

non-linear mesoscopic systems, and topological photonics as a new route to on-chip chirality and single-photon non-linearities.

Materials and Biological Physics (MBP): This group, comprising three professors, one senior lecturer, and one research fellow, uses experimental approaches to investigate the physics and technological applications of solution-processable semiconductors, living systems, polymers, photonics and imaging instrumentation. The group is highly interdisciplinary and works closely with chemists, biologists, medics, biochemists and electronic engineers. The University, supported by UKRI and charitable funding, has invested substantially (£14.5M) in multiple cross-department and cross-faculty facilities and initiatives co-led from the group. These investments have been rewarded by a range of high-quality outputs, including new insights into the photophysical properties of entangled triplet-pairs in organic semiconductors (Clark, *Nature Comms*, 2017) and new atomic force microscopy approaches revealing the molecular architecture of the bacterial cell wall, (Hobbs, *Nature*, 2020).

Looking forward we will build on recent investments to grow our activities in biological physics, expanding existing strong cross-disciplinary interactions with Biological Sciences and Medicine, particularly in bacterial biophysics and cancer and utilise the unique capabilities available through new developments in atomic force and optical microscopies. We will also further develop our activities in energy materials, drawing on recent successes in collaboration with Chemistry and expand interactions with energy providers such as National Grid.

Particle Physics and Particle Astrophysics (PPPA): The group, comprising six professors, four senior lecturers, and two research fellows, focuses on four core STFC areas: particle physics (ATLAS), long-baseline neutrino physics (DUNE), dark matter searches including LZ and gravitational waves. The appointment of Vickey and Lohwasser has greatly enhanced the strength and depth of our ATLAS activity. The appointment of Malek has strengthened our neutrino physics activity and allowed us to lead the UK part of a major translation drive developing approaches for monitoring nuclear proliferation through WATCHMAN (£2M awarded to Sheffield since 2018). Members of the group have contributed to notable breakthroughs, including ionization cooling in muon beams, a critical step towards achieving the muon-beam quality required to search for phenomena at energy scales beyond the reach of the LHC (Booth, *Nature*, 2020), and the detection of merging compact objects with LIGO and VIRGO collaborations (Daw, *PRL* 2016).

Over the next five years, following a strong influx of new talent through recent years, we are well-positioned to capitalise on upcoming discovery phases in our major collaborations. We will also further engage with next-generation projects such as Hyper-Kamiokande and DUNE, and are expanding our dark matter interests with the strategic addition of axion searches.

Astronomy and Astrophysics (AA)*:* This group, comprising four professors, three senior lecturers and two research fellows, focuses on the building blocks of galaxy evolution, and high time-resolution astrophysics, underpinned by theoretical work on simulations of star formation and star cluster evolution. The recruitment of Maund strengthens our astrophysical transients activities, and adds synergy with Crowther on massive star and core-collapse supernovae research; Parker strengthens our theoretical capability in star and planet formation, complementing Goodwin; Parsons enhances high time-resolution activities of Dhillon and Littlefair. Our support for these ECRs has been rewarded by several notable outputs, including the discovery of a pulsating white dwarf in an eclipsing binary system, enabling empirical constraints on the core composition of low-mass stellar remnants (Parsons, *Nature Astronomy*, 2020) and the detection of a tidal disruption event associated with a Kerr black hole (Maund, *Nature Astronomy*, 2016).

A major focus of the group going forward will be scientifically exploiting its unrivalled access to world-leading facilities for high time-resolution astrophysics through guaranteed time on the Sheffield-led HiPERCAM (GTC, La Palma), ULTRACAM (ESO-NTT, Chile) and ULTRASPEC (TNT, Thailand) instruments, and also the detection and follow-up of variable sources discovered through its core involvement in the GOTO (£3.4M STFC 2020 investment) transient-hunting telescopes. Through recent appointments, the group is also well positioned to exploit the new generation of major telescope facilities.

1.2.2 Research strategy

Our overarching research strategy, consistent with our stated aims in REF2014, has been to build upon existing strengths, enhance cross-disciplinary research activities and expand our engagement with knowledge transfer and impact.

Our appointments since 2014 have cemented existing areas of excellence (e.g. Lohwasser, ATLAS), and established connections between areas of strength (e.g. Maund, astrophysical transients with evolution of massive stars). Our core research portfolio is underpinned by a healthy balance between EPSRC and STFC funding, but we have worked to broaden our range of funders, diversifying our income streams and adding to our resilience. Examples include the European Research Council, The Wellcome Trust, BBSRC, Cancer Research UK, the Royal Society as well as UKRI SPF.

Many of the techniques developed in the Department are widely used across science, medicine, engineering and more broadly, providing the opportunity both for translational applications and for developing new approaches to tackling unresolved questions in science, medicine and engineering. We aim to exploit these opportunities, where we already have existing interdisciplinary activity (through *Imagine:Imaging Life*) and where there are clear opportunities through a large number of currently isolated activities (machine learning/big data), growing new cross-cutting themes across the Department and more widely.

1.3 Approach to supporting interdisciplinary research

Since 2014 we have **enhanced our interdisciplinary research activities**, utilising a strong University commitment to underpinning infrastructure, and competitively obtained external funding in world-class instrumentation on campus to provide a unifying focus. We play a central role in a variety of interdisciplinary projects, linking with Biological Sciences, Chemistry and Electronic and Electrical Engineering.

New ventures established over the assessment period include the following:

- The Sheffield Quantum Centre joint with Electronic & Electrical Engineering and Computer Science. The Centre, which supports the activities of 70 academics across these three departments, including our inorganic semiconductor group, focuses on semiconductor nanotechnology covering both III-V semiconductors and atomically thin 2D materials.
- The *Imagine:Imaging Life* Initiative joint with Biological Sciences (£10M), co-lead by Cadby and Hobbs with Foster and Bullough (Biological Sciences), which included the establishment of the Biophysical Imaging Centre (£1.8M) in the Department and the formation of a cohort of cross-department and cross-faculty (Science, Medicine, Dentistry and Health) students focused on the development and use of imaging to understand living systems.

- The Lord Porter Laser Laboratory, joint with Chemistry, for which Clark is one the three academic leads, has received investments of ~£2M, and houses many advanced laser methods, allowing the study of light-induced reactions from tens of femtoseconds to milliseconds.

University investment in state-of-the-art laboratory infrastructure enables the full performance of equipment, while University investment in cross-department and cross-faculty PhD studentships (e.g. six between Physics and Biological Sciences/Medicine associated with *Imagine*) provide research and training opportunities. Support for interdisciplinary research has helped diversify our research income streams (see above), for example through joint funding of a studentship with Medicine that underpinned a CRUK/EPSRC Multidisciplinary Project Award. The strong departmental research theme in solar energy has also been supported through the University's Grantham Centre for Sustainable Futures (e.g. PhD studentship with Buckley).

Our strategy for interdisciplinary activities over the next five years is to further support the inherently interdisciplinary subject themed research (such as biological physics, energy materials, quantum technologies) while also growing and developing our activities in technique oriented interdisciplinary research (e.g. in imaging, data science/machine learning).

1.4 Impact strategy, support mechanisms and outcomes

In line with our REF2014 objectives, we have further enhanced our engagement with knowledge transfer and impact activities. We have used a range of mechanisms to grow this activity, including University Knowledge Exchange (KE) Funds, provision of dedicated laboratory space, staff sabbaticals, allowance for impact-related activities in our Workload Allocation Model (WAM), and support for collaborative grant writing. Although our current case studies come from the MBP group, our pipeline (see below) includes strong potential across all our groups.

Provision of staff time to grow impact activities is critical for their fruition. For example, two sabbaticals for Lidzey (one funded by the EPSRC SuperSolar Hub) enabled him to work on translating concepts developed in his research group into further product development at Ossila (a spinout in materials science of which he is a Director, *Growth of Ossila* case study). These products have contributed to the further growth of the business, which is receiving recognition for its strong export record (IoP Queen's Award for Enterprise, 2018). Provision of financial support through the University KE funds has helped Hobbs to further support the activities of Infinitesima Ltd. in their development of tools for the inspection and quality control of silicon devices for next-generation computing, building on the research that underpins the *Direct Height Infinitesima* case study. In the previous REF period we made an appointment with an industrial background, with the aim of seeding new and impactful activities in the Department. This has borne fruit in two of our case studies, with Buckley being a co-founder of Ossila and also the lead on our *Solar Photovoltaic* case study. Buckley's work on solar energy has been supported through University KE funds, and critically he has benefited from extensive mentoring in impact activities, leading to him taking a role on the University's KE committee as part of HEIF governance, and helping him to create the focus required to carry this work through to fruition.

We have utilised significant investment from University KE funds, totalling nearly £3M in over 80 projects aimed at facilitating the transfer of fundamental science breakthroughs to economic impact. This strategy of supporting colleagues with funds enabling a range of activities from proof of concept through to collaborations with industry has provided us with an excellent foundation for future impact.

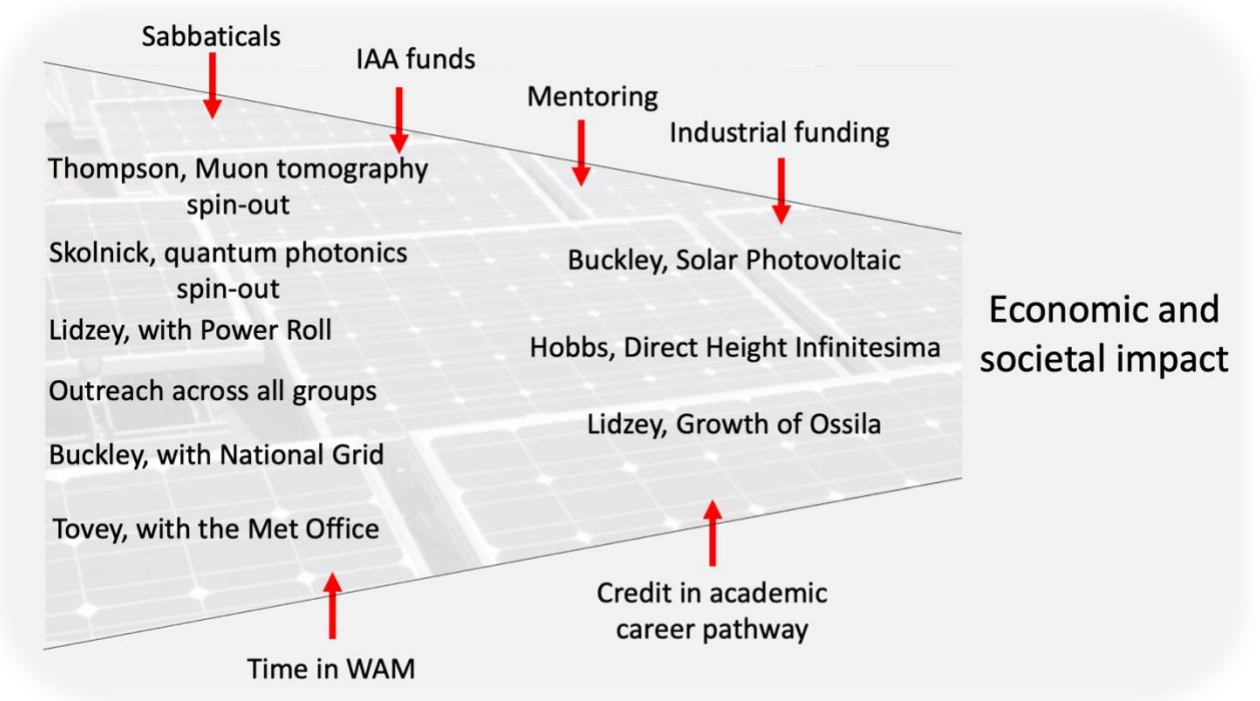

Figure 2: Impact pipeline, showing mechanisms to encourage and support impact

We will ensure that our impact pipeline is continually refreshed, identifying the most promising internal investment opportunities, such as the University's Impact Acceleration Account. Recent PPPA group appointments permit an increase to our STFC-commended industrial engagement and impact work. The appointment of an Ogden Outreach Officer has allowed us to build a hub for outreach opportunities beyond our local community, enabling us to develop activities with greater reach.

1.5 Open research

Open science approaches to research have a long history in physics, are deeply embedded in the culture of most of our research areas and have seen strong growth into the areas where they have been less prevalent. To ensure maximum discoverability of our research, we aim to put all outputs in White Rose Research Online, our shared repository with Leeds and York (green route). The 1,657 outputs deposited over this assessment period were downloaded 51,000 times. This is our preferred route, ensuring equity in publishing opportunities regardless of available funding; we also publish outputs in fully OA journals, or hybrid where required for funder compliance. 95% of staff have put some of their work on preprint servers such as arXiv (or bioRxiv where more appropriate), while two thirds always put submitted work onto arXiv, providing a rapid and open route for research dissemination, accessible to all.

All high energy particle physics data is stored in the STFC-funded Durham HEP data repository, our AA group makes extensive use of publicly accessible data repositories, and in our condensed matter research areas metadata is published as extensive supporting information files associated with publications and shared through the University's data repository (ORDA, hosted by figshare). Our staff have contributed significantly to the growth of open data. For example, Dhillon is responsible for the 20 TB ULTRACAM/HiPERCAM data archive, containing nearly 20-years of high-speed optical images of the night sky. By far the most extensive such database in the world, the data are available for use by anyone in the astronomical community following the one-year proprietary period. Costanzo, while ATLAS Computing Co-ordinator (2017-2019) oversaw the

release of tabular data from the ATLAS experiment in CERN for use in educational activities, the start of a shift towards more openly accessible data.

Often the code that is used to mine and manipulate experimental data is a critical aspect of both open access and ensuring the integrity of the analysis. Over two-thirds of staff make the code they develop and use OA or ensure that the analysis can similarly be performed with OA code. Littlefair is a core team member of the open-source Astropy project, providing library packages for astronomical software in Python, which is used around the world, including at NASA, LIGO and IBM (for space-junk collision avoidance). In recognition of the importance of this work, the Astropy team was awarded the Group Achievement Award by the Royal Astronomical Society (2020).

Over the next five years, we anticipate open data playing a critical role in the Department, while recognising that such decisions are beyond the reach of researchers involved in large collaborations. Costanzo has now taken on a leadership role within the Faculty as IT Champion, helping to spread best practice developed in physics and ensuring that the resources are available and appropriate for our data.

1.6 Research integrity

The University's Good Research and Innovation Practices (GRIP) policy governs research in the department, with adherence being overseen by the research committee and, at a local level, by Group Heads and individual PIs.

Training in all aspects relating to research integrity starts at PGR level, with all our students undertaking three mandatory research professionalism and integrity training modules, inducting students in the principles of open research and research integrity. They review recent case studies of professional malpractice and hear from senior academics, providing guidance on the different aspects of the difficult decisions involved. The procedure of whistleblowing is outlined, and the modules emphasise the importance of honesty and creating an environment where, if a mistake is made, researchers can come forward without fear of reprisal.

Clear expectations are set for research staff through the induction process, with support given by line managers and through the assignment of independent mentors. This is supported by online resources covering our expectations and support for research integrity, best practice and professional conduct. Our annual EDI away day provides a forum where all staff come together to share best practice and receive additional training on aspects such as unconscious bias which can unknowingly distort research integrity.

Following high profile international/UK bullying and harassment cases elsewhere in physics, we have developed a new Code of Conduct for staff and students, which was co-created by ECRs/students, and has involved consultation with academic staff/PGR students and our UG student representatives. This has been widely publicised and is re-visited at staff meetings to ensure it is deeply embedded into our departmental culture.

2. People

We pride ourselves on our collegiate community, with a research environment that aims to stimulate, support and nurture all our researchers. We uphold the principles and implement the responsibilities of the 2019 Concordat to Support the Career Development of Researchers. As a signatory (2019) to the Civic University Agreement, our strategic priorities align closely to those of the City of Sheffield and the local region.

2.1 Staffing and recruitment policy

New appointments over this assessment period have followed our research strategy of building upon excellence where we have an internationally recognized reputation. Specifically, we have strengthened our activities in ATLAS physics (Vickey 2015, Lohwasser 2017), neutrino physics (Malek 2015) and astrophysics (Maund 2014, Parker 2017, Parsons 2019), while an appointment to MBP (2016) left to return to CNRS, Paris (2017).

Following the success of our recruitment of independent research fellows (IRFs) in REF20214 (Anastopoulos, Chekhovich, Clark, Mullaney) we have continued to focus on attracting IRFs as future leaders to our research groups (Lohwasser, Maund, Parker, Parsons). We provide a fully-funded PhD studentship for each IRF to help develop their independent research programme. Also, since 2018, we have guaranteed progression to an open-ended contract for all IRFs with fellowships longer than three-years to ensure the stability they require to reach their full potential. Figure 3 summarises our IRF support strategy.

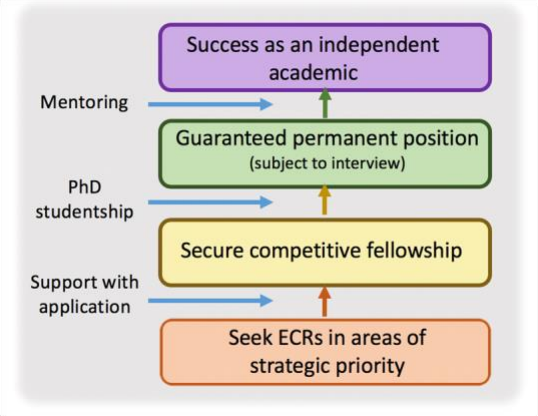

Figure 3: Independent research fellow support strategy

The result is an energetic cohort of outward-facing future leaders whose influence across the Department, wider University and scientific community is already evident. For example, Clark has developed strong links with biosciences on the photophysics of protein-organic semiconductor complexes (*JACS*, 2020), while Anastopoulos is now at the forefront in the search at the ATLAS experiment for new physics beyond the Higgs Boson, as well as having played a critical role in the consolidation of that discovery (e.g. *PRL*, 2015).

Following our independent review of our research we have introduced a system of regular refresh of group heads, enabled by a spread of senior staff across all research groups. This allows us to plan for the future based on maximising the development of our research strength, without having to immediately place large administrative loads on new staff.

2.2 Staff development, and support for ECRs

New staff receive a tailored induction and are mentored by a senior member of their research group as well as having access to additional independent mentoring from a senior colleague in another group. For new T&R staff a tapered approach is taken to introducing non-research load, with 60% in year one, 80% in year two, 100% in year three, providing time to develop a firm foundation for their research career. We provide a fully-funded PhD studentship on arrival and tailored financial support to set up their research activity. Our three-year probationary process is supportive, with regular mentor meetings to provide guidance and support. All our probationary staff have subsequently been highly successful. For example Malek (recruited 2015) is the UK academic lead for WATCHMAN, having been promoted to senior lecturer.

All staff receive formal support through an annual appraisal known as the Staff Review and Development Scheme (SRDS) with their line manager. This is an opportunity to reflect on work from the previous year and consider their career aspirations. Additionally, a mid-year review for all non-professorial staff with the Head of Department ensures that issues are dealt with rapidly. Time is set aside in the annual review to discuss training and career development needs. Where

appropriate, our mid-career and professorial level staff are put forward for the Sheffield Leader staff training programme, jointly run by HR and Research Services, which provides training in all aspects of leadership, including research.

We are committed to supporting and developing our **ECRs**. Development needs are considered during annual appraisal discussions, or at mid-year reviews, with dedicated departmental sessions offered to provide specific training (e.g. grant preparation, academic writing). Bespoke workshops highlighting fellowship opportunities regularly take place in the Department, with mentoring and peer review of applications for those deciding to follow this route. Think Ahead, a specific ECR staff development programme coordinated by our professional services team, highlights employment opportunities and a professional and career development programme, involving training workshops and career mentoring. Opportunities include ECRs acting as primary supervisors to funded summer student projects through the Sheffield University Research Experience scheme, supported by a senior academic. Our TRAM (The Researcher As Manager) programme is aimed at developing the skills needed to successfully manage a research team.

Other mechanisms within the Department run by ECRs for their benefit also contribute to their development, such as regular coding sessions and informal research talks. ECRs are encouraged to engage in wider activities, for example, the leadership of postdoctoral workers from the IS Group was instrumental in developing and running public engagement activities including stands at the Royal Society Summer Exhibition (2015) and the Cheltenham Science Festival (2017).

ECRs are vital to our research health, and in recognition of this during the present assessment period we have appointed a fellow as a full member of the departmental executive committee, providing critical feedback on the short-term impacts of decision making, for example playing a vital role in our successful return to on-site working following the COVID-19 lockdown. A PDRA also has an *ex officio* role on the departmental research committee, in addition to two early career academic staff, ensuring our research strategy has input at all levels.

2.3 Support and reward for research and impact

Our appraisal process is integral to preparing staff for promotion, working with a designated mentor. Staff are able to build a portfolio of achievements that align with organisational and personal goals, enabling them to maximise opportunities for reward and recognition, including promotion following the Academic Career Pathway (ACP) Framework. **ACP aims to clearly define expectations, importantly providing a clear route to recognising impact related activities**. In line with the principles of DORA, journal impact factors are not used in considering promotion cases.

Our promotions panel includes research group heads, our Director for Learning & Teaching, our EDI lead and has been expanded to include the EDI lead from a cognate department within the Faculty for external input. In this assessment period, three academic staff have been promoted twice and eight have been promoted to personal chairs, spanning all four of our research groups. Promotion is available to staff at all levels regardless of the nature of their contracts, including promotion across grade boundaries (e.g. Dawson was promoted as a PDRA, and has since secured a Senior Research Fellow position at QMUL).

We operate a fully transparent WAM, in which recognition is given for external research funding, PGR/PDRA supervision, major grant preparation plus a 20% allowance for scholarship for all academics. Impact-related activities receive additional recognition in the model once at a level to be part of the pathway on the ACP. Following our REF2014 aims, we have appointed six teaching specialists, enabling us to continue to deliver a high-quality undergraduate experience whilst

ensuring that academics with both research and teaching responsibilities are able to develop world-leading research programmes.

Individuals who step down from major administrative responsibilities are entitled to a period of study leave. Flexibility is given to permit research secondments, such as senior ATLAS management roles, and short-term sabbaticals, including Maund's three-month Royal Society policy secondment in the UK Department for International Development in 2019. Sabbaticals are made available to support impactful collaborations with industry (section 1.4), for example for Cadby to locate with Andor (Belfast) for six-months (2014) to work on new camera developments for super-resolution microscopy, and for Daw to explore the application of his wave detection algorithm for motor controllers and medical applications (with Creavo Medical Technologies, 2018). Impact-specific mentoring (e.g. for Buckley from Jones, supporting our *Solar Photovoltaic* case study, Sich from Skolnick) has helped staff balance and prioritise different aspects of their roles.

2.4 Research students

We have a vibrant research student community, with nearly 100 PGR students working across our research portfolio, a 25% increase in enrolment since 2014. A notable success of an increased focus on supporting our PGR students, both professionally and pastorally, has been an increase in four-year submission rates from just under 80% at the start of the assessment period to 96% towards the end of it.

The Graduate Student Committee, comprising academics representing the four research groups and PGR student representatives, is responsible for managing recruitment, allocation of students to academic staff, mentoring, pastoral care, training, oversight of the University Doctoral Development Programme (DDP), and monitoring progress. The three students on the committee are elected by their peers through an anonymised selection process to reduce unconscious bias. Their presence on the committee, introduced in 2015, has led to the introduction of a number of cross-department student-led activities, including coffee mornings and social events, financially supported by the department.

The DDP commences with the student and supervisor carrying out an individually tailored training needs analysis (TNA), from which a training programme is designed, tailored to individual needs. The aim is to provide PGR students with a range of skills and competency-based training opportunities focused on enhancing their study and equipping them with transferable skills that extend their employability. Since 2018, every PGR student has been allocated a mentor from a small pool of experienced academic colleagues who, in addition to monitoring progress against the TNA, has a pastoral role, providing advice throughout the period of the PhD. Progress is formally monitored every six-months. Initially, all students start with a probationary PhD status, with a decision on progression to the full PhD made at the end of the first year of full-time study, on the basis of an assessment of their report, literature review and a *viva* with two academic colleagues not involved in direct supervision.

The Department also provides financial support to a PGR-led initiative, CREATE, involving creative workshops open to PGR students and staff, to enhance social interactions between researchers and improve their wellbeing. Other initiatives include the PRES student satisfaction survey, for which we receive positive to very positive feedback, and PGR students who have taken up UKRI-funded internships (e.g. policy internship at National Assembly for Wales).

Our PGRs have led impactful science across all groups, with ~60% of our outputs being co-authored by PGR students. Examples of their contributions include:

- The fabrication of back-contact perovskite solar micro-modules using a directional deposition technique leading to efficient back-contact perovskite photovoltaic devices. (Stringer, Routledge et al, *Energy and Environmental Science*, 2019).
- New insights into the evolution of Cataclysmic Variables from eclipse modelling (McAllister et al. *MNRAS* 2019).

Martin Dyer was awarded the 2019 Royal Astronomical Society Patricia Tomkins prize for the best PhD thesis in astrophysics.

2.5 Equality, diversity and inclusion

The University is a sector leader in driving excellence through inclusion, and we seek to create an environment in which all researchers can flourish. We are the only University listed in the Sunday Times list of 100 'Best Not For Profit Organisations To Work For' for the last three years. The Faculty and Department EDI committees meet bi-monthly and monthly, respectively, ensuring University EDI strategy is implemented. The Chair of our EDI committee is a member of our Executive Committee and Promotions Committee.

The University holds an Athena SWAN Silver Award, and our Institute of Physics Juno Practitioner status was renewed in 2018. Project Juno and Athena SWAN are reciprocal awards, so we are able to focus more of our efforts on reviewing and refreshing our approach.

We are underrepresented in women (9%) and BAME (6%) in our staffing profile. To address this, we have set ambitious targets in our EDI vision statement, namely:

"*Our goal is that our department attracts an above average proportion of excellent applicants from groups who are under-represented in physics, including women and BAME. This should lead to an increase in the representation of such groups at all levels, including the most senior, with an expectation of 25% women professors in 10 years, and a longer-term aspiration to fully reflect the diversity of wider UK society*."

An associated action plan includes:

1. A requirement that recruitment materials are screened for language and implicit assumptions which might deter applications from under-represented groups;
2. A requirement for selection panels to involve a senior female academic from the Department or a cognate discipline;
3. Unconscious bias training for all panel members and chairs;
4. Independent scoring of candidates against the essential criteria of the job.

We continue to have a male bias in our applicant pool for academic and research positions, although four of the 12 academic (including teaching specialist) appointments over the assessment period were to women (33%). We have also been proactive in ensuring a greater representation of women as invited seminar speakers, which is crucial to represent the diversity in physics and provide inspirational role models. For 2016-2020 this was 26% (71 of 272) across all research groups.

A number of academic staff are employed part-time to accommodate caring responsibilities or reduce hours prior to retirement. For example, Parker has received a fellowship which explicitly supports flexible working (Royal Society Dorothy Hodgkin). Research time of part-time staff is

protected in our WAM. A dedicated room for infant feeding has been recently refurbished in the Faculty, within easy access to laboratories and offices.

Sheffield's commitment to eliminating discrimination and promoting diversity includes strong and active support for our LGBT+ staff and students, as evidenced by our ranking of 11th in the Stonewall Top 100 Employers 2020 survey. One of our teaching-specialist academics who serves as an LGBTQ+ role model and has been on the University EDI Committee since 2017 has played a central role at an institutional-level, and is now further developing best practice within the Department as chair of the EDI Committee. This includes an annual refresh of our Code of Conduct for staff and students (see section 1.6).

The University has a Code of Practice that stipulates processes to ensure equality and diversity in preparation of our REF submission. All members of REF Committees undertook REF-specific EDI training including material on recognising and countering implicit bias. Peer review of outputs was undertaken by staff with a breadth of expertise. Following our Code of Practice, outputs were selected on the basis of ranked quality. When the cut-off was reached for the number to be submitted, we considered the protected characteristics of the attributed authors for all outputs at that particular star rating. The University has undertaken an equality impact assessment of our output scoring and attribution, and on our independent researcher decision-making, and found no evidence of bias. The institutional process for disclosing equality-related circumstances was highlighted to staff to ensure awareness of the support available. The University has clear policies that there will be no detriment to staff either in their classification as an independent researcher or in the number of outputs submitted, and REF submission data is not used during recruitment, review or promotion.

3. Income, infrastructure and facilities

3.1 Research funding

Our annual research income has steadily grown over the assessment period, increasing by 54% from £5.1M in 2013/14 to £7.8M in 2019/20 (£225k/FTE). The £47.0M total income comprises £34.0M from UKRI/Royal Society, £8.6M from the EU, £1.9M from industry, £1M from Innovate UK, £0.7M from other UK charities, and £1M from other sources. Notable individual successes include Tovey and Dhillon, who were both awarded ERC Advanced Investigator Grants, and Hobbs, who was awarded a joint Investigator Award from the Wellcome Trust, one of only a small number of physicists to receive such a grant.

All research groups have healthy research grant capture, as evidenced by selected large individual grant successes as follows:

- The IS group (plus colleagues in Electronic and Electrical Engineering) is supported by a £5.6M EPSRC programme grant (2016-2022, PI Skolnick), a £1.4M EPSRC Centre to Centre award with TU Dortmund (2020-2024, PI Tartakovskii), a £2.2M quantum technology capital award, and a very recent £1.6M strategic equipment award (2020-2023, PI Tartakovskii). Skolnick also received an ERC Advanced Investigator award (€2.1M, 2013 – 2018). Chekhovich is supported by a Royal Society URF (2015-2023).
- The MBP group has benefited from the UKRI Strategic Priority Fund "Physics of Life" programme grant, (PI Hobbs: £2.1M), and a joint Wellcome Investigator grant (PIs

Hobbs/Foster, £1.6M). An EPSRC award supports research on perovskite solar cells (PI Lidzey, £0.9M, 2019-2022). Clark is supported by an institutional Advanced VC Fellowship and an EPSRC Programme Grant (PI Leggett, Chemistry, 2020-2025).

- The PPPA group is supported by a £2.4M STFC consolidated grant (2019-2022, PI Thompson), and a £1.3M STFC DUNE construction grant (2019-2023, PI Spooner). Tovey received an ERC Advanced Investigator award (€1.6M, 2016-2020) while Lohwasser has an ERC Starting grant (€1.5M, 2017-2022). Anastopoulos is supported by a Royal Society URF (2015-2023).

- The AA group is supported by a £1.1M STFC consolidated grant (2018-2021, PI Tadhunter). Dhillon received an ERC Advanced Investigator award (€3.5M, 2014-2019). Maund was supported by a Royal Society URF (2011-2019), Parker is supported by a Royal Society DHF (2017-2021) and Parsons is supported by a STFC Ernest Rutherford Fellowship (2018-2023).

These large awards facilitated significant contributions across all of our areas, including large international collaborations (e.g. Lohwasser, *PRL*, 2019), developing new instrumentation for high time-resolution astronomy (Dhillon, Littlefair, *Nature*, 2016), and producing new types of nanostructured devices (Skolnick, Fox, *Nature Nanotechnology*, 2018). We have successfully broadened our range of funders by targeting different streams (e.g. EU) and by growing our strength in interdisciplinary areas, allowing access to a broader range of funders, with Wellcome, CRUK, BBSRC being notable areas of success. This diversification in funders has allowed us to broaden the reach of our outputs (Cadby, *eLife*, 2018). The strategy of pursuing large and flexible funding streams, particularly programme grants and fellowships, has provided the time and resource to move into exciting new fields. For example, Tartakovskii into 2D heterostructures (*Nature*, 2019), and a new method developed in an EPSRC programme grant (Hobbs, *ACS Nano* 2016) which enabled a study in a BBSRC grant (Hobbs, *Nature Comms*, 2018) which led to a Wellcome Investigator award (Hobbs, *Nature*, 2020).

Our strategy is to provide support for grant capture at all levels, delivered through our strong group structure. Internal peer review on draft applications is carried out for all UKRI grants with at least two independent reviewers providing feedback prior to submission. For fellowship and major grant applications, support is provided by Research Services who coordinate mock interviews with academics across the University who have served on relevant committees. This approach has helped us to obtain several prestigious fellowships and programme grants, ensuring that we present our case to its full potential.

Over this period we have further developed the impact of our research, targeting both direct industrial funding and joint ventures with industry. We have received £1.4M research awards from industry, most notably £837k from National Grid (PI: Buckley), feeding into the development of our *Solar Photovoltaic* case study, £274k from Power Roll Ltd. (PI: Lidzey) and income contributing towards PhD studentships (~£40k each) from AWE, Cytec-Solvay, Akzo Nobel, Ossila, Lonza, Biologics, Cairn Research, Solvay and VBC IE. Extensive joint projects with industry have been funded both by EPSRC (Prosperity Partnership with AkzoNobel/International Paint, joint with Manchester) and Innovate (e.g. £1.2M with VBC IE), helping VBC IE to move into the Asian aeroplane engine repair market.

Our future funding strategy is an enabler for our wider research strategy. We will expand our biological physics activity, cementing strong interdisciplinary interactions with biosciences and medicine, supported through access to the wide range of life sciences funders and through the growing realisation amongst funders of the important role that physics can play in meeting societal

challenges in this area. We will expand our activity in energy materials, focusing on interactions with industrial partners and feeding into our objective to expand our impact activity. Growing our IS group will help ensure continued access to large flexible funding streams following mid-term retirements.

3.2 Research infrastructure and dedicated research facilities

Our experimental research groups are housed in state-of-the-art laboratories which have undergone extensive renovation and re-tooling in this assessment period (investment of £3.7M), use and co-lead cross-faculty and cross-institutional facilities housed in other parts of the University (investment of £20M), and help develop, utilise and lead large national and international facilities.

The MBP group has benefited from significant investment in the Biophysical Imaging Centre (BICEN) laboratories (£1M for state-of-the-art air-conditioned low noise laboratory space and £800k of new microscopes co-funded by BBSRC and Wellcome, including a Bruker FastScan Bio AFM and a Cairnfocal adaptable optical microscope) permitting high resolution imaging and force measurement for category 2 biological pathogens. This investment has helped Cadby build new relationships with a number of optical microscope camera manufacturers (Andor, Hamamatsu, Photometrics) and with Cairn Research, an innovative UK microscope company, further developed through CASE studentships and a sabbatical. It has also played a critical role in the MBP group's funding, and enabled new cross-disciplinary science.

To support our IS research the University has provided a new, temperature-controlled low noise laboratory (£600k), giving dedicated space for the study of light-matter interactions in semiconductor nanostructures, focused on polariton physics (e.g. Krizhanovskii, *PRL*, 2017), as well as new fabrication facilities (£900k). This work is further supported by a recent successful bid by Tartakovskii (with colleagues from the MBP group, and from across science and engineering) for EPSRC funds to purchase and install a customised scanning near field optical microscope (£1.6M). The equipment provides a unique suite of novel optical techniques capable of 10nm spatial resolution, 50 to 1000 times below the optical diffraction limit.

We have also invested £200k in a laboratory containing welding facilities which supports ATLAS upgrade engineering, plus collaborative industrial R&D projects which have benefited from sustained Innovate UK investment linked to aerospace and robotics. A further £180k investment from the University allowed us to upgrade clean room facilities for solution-processable photovoltaic research and build on recent advances in spray-deposition of perovskite solar cells (Lidzey, *Energy & Environmental Science*, 2014).

Our research capabilities are further enhanced by a dedicated team of workshop technicians capable of carrying out entire instrument projects in-house, from mechanical design to final manufacture. The team also has access to general-purpose clean-room facilities. The research of the IS group is underpinned by a dedicated helium liquefier, staffed by two research technicians. All of these facilities were crucial enablers for the development of particle physics detection technologies across all our areas of interest (Spooner, Thompson, Vickey), while mechanical workshop technicians led the design and engineering work for Dhillon's ERC-funded HiPERCAM camera.

As noted above, our interdisciplinary research benefits from shared access to world-class instrumentation housed elsewhere on campus, including:

- National Epitaxy Facility in Electronic Engineering. Our IS research benefits from the close proximity to the National Epitaxy Centre which includes three molecular beam epitaxy and two metal-organic chemical vapour deposition reactors, with adjacent electron beam lithography and dry etching facilities all housed in 550m^2 clean rooms. This facility was enhanced by a £10M EPSRC contract awarded in 2016.

- The Soft Matter Analytical Laboratory and Lord Porter ultra-fast spectroscopy facilities in Chemistry (see section 1.3), £4.5M.

- Cryo-electron microscopy in Biological Sciences, which has benefited from ~£3.2M of University investment through the *Imagine:Imagine Life* initiative over this period, has been used for complementary cryo-EM AFM studies of the bacterial cell wall (Hobbs, *Nature*, 2020) and bacterial spores.

- The Light Microscopy Facility (LMF) provides an array of fluorescence microscopy instruments which complement the in-house research instruments in BICEN and are extensively used by our MBP group (Cadby, *eLife*, 2018). Cadby sits on the management board of the LMF, providing invaluable insight into technological aspects of the instrumentation, and recent investment in light-sheet and Airyscan systems (£640k) complement the super-resolution STORM and SIM systems obtained in the previous period.

The University has invested over £2M over the assessment period in a shared high performance computing facility (Bessemer), allowing access to high-speed parallel filestore and providing cloud computing capabilities within the campus. The University is a partner in the N8 Tier 2 HPC facility, a joint venture between the eight research-intensive universities in the north of England to provide UK-leading computational capacity, leading to sharing of resource and expertise in this key technology for a number of our activities in IS and MBP groups.

Dhillon led the team that designed, built, and commissioned HiPERCAM, a revolutionary high-speed, five-colour CCD camera mounted on the 10.4m Gran Telescopio Canarias on La Palma. Thanks to seed funding from the University, the AA group are one of the founding members of the Gravitational-wave Optical Transient Observer (GOTO), an array of wide-field optical telescopes to search for the electromagnetic counterparts to gravitational wave sources discovered by LIGO/VIRGO/KAGRA. GOTO recently received £3.4M from STFC to complete the deployment of the array in Australia and La Palma.

We make extensive use of general user international research infrastructure, including Diamond, ILL, ISIS for X-ray and neutron scattering (Jones, Lidzey), plus the European Southern Observatory and Hubble Space Telescope (AA group). By way of example, Parsons was recently awarded 36 orbits with the Hubble Space Telescope (the second largest allocation to the UK for Cycle 28) to unravel the origins of thermonuclear supernovae.

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

Over this assessment period, individual staff members have continued to make substantial and varied contributions to the broader research base at both national and international levels, helped to drive growth and economic prosperity both locally and nationally, and played influential roles in areas that are critical challenges for modern society.

4.1 Research collaborations and partnerships

Research collaboration is at the heart of our success across all of our research groups and we have a range of procedures to support and ensure that staff are able to benefit from, contribute to and, where appropriate, lead, these activities.

International research leadership. During this assessment period three members of our PPPA group have made significant contributions to the scientific leadership of the ATLAS collaboration:

- Tovey was elected ATLAS Physics Coordinator for 2015-17,
- Costanzo was elected ATLAS Computing Coordinator for 2017-19,
- Vickey has been elected as ATLAS Run Coordinator for 2020-22.

These leadership roles were enabled through substantial sabbaticals and are part of our strategy to further strengthen our ATLAS activities, including the appointment of two new staff in this area (Vickey and Lohwasser). **Holding all three of these positions over just seven years mean we have made a uniquely high contribution to the leadership of ATLAS over this period.** Also from our PPPA group, Malek is the UK academic lead and joint spokesperson for the joint US-UK nuclear non-proliferation project WATCHMAN, led by Lawrence Livermore National Laboratory, with key UK partners STFC's Boulby Underground Laboratory, AWE and Sheffield. This activity is part of our aim to diversify our STFC activities towards research with societal impact.

Skolnick in our IS group has collaborated with a group of Russian labs for nearly 20 years, which has led to the recruitment of excellent academic staff and extended visits from two Russian academic staff to the Department as well as much new science. He is Director of a Russian Megagrant (2017-20, £1.5m) which supports a team of approximately 10 researchers in Russia and has already produced significant outputs (Krizhanovskii, *Nature Photonics*, 2020).

International research collaborations

All of our staff are involved in active international research collaborations, and 87% of our submitted outputs include co-authors from non-UK institutions. Here we discuss just the most significant examples.

Our PPPA and AA groups carry out almost all their research with international partners because of the multinational nature of particle physics, and because observational astronomy cannot productively occur in the UK. Particle physics collaborations vary in scale, from more than 3,000 researchers for ATLAS, 1,200 for LIGO, to 500 for T2K, 300 for DUNE, 250 at LZ, and 350 at Hyper-Kamiokande – these are truly international endeavours. The extended time commitments that these activities require are enabled by a high-level of flexibility in teaching and administrative roles, part of our overall strategy. In our AA group, Dhillon's activities are particularly noteworthy, with extensive international collaborations, including with the IAC in Spain where he is an affiliated researcher, the European Southern Observatory and Thailand's NARIT, at whose facilities the HiPERCAM, ULTRACAM and ULTRASPEC instruments he developed are deployed.

As well as the above-mentioned collaboration with Russian institutes, our IS group has a strong collaboration with TU Dortmund, supported by an EPSRC centre-to-centre grant to Tartakovskii. He has also been co-ordinator for two EU ITNs during this period, bringing together ten member consortia across Europe.

National research collaborations play a critical role in many of our research activities. As well as the use of formal networks, such as the White Rose University Consortium (which funds cross-institutional studentships), we encourage the development and widening of national collaborations

through funding a seminar programme for each of our research groups, with weekly seminars that are open to all during term-time. Highlights of our national collaborations include:

- Skolnick, Fox, Wilson and Kok are involved in Phase 2 of the Quantum Communication Hub led by York.
- Tartakovskii collaborates with Manchester on a range of projects related to 2D materials.
- Lidzey collaborates with Southampton on polaritronics (EPSRC Programme Grant £5.1m) and is a member of the CDT in New and Emerging Photovoltaics, a consortium of seven universities.
- Dhillon is Executive Board and Steering Committee Member of GOTO, the Gravitational-Wave Optical Transient Observatory, which has the aim of detecting electromagnetic radiation from gravitational wave compact mergers.
- Hobbs leads a cross-disciplinary £2.1m UKRI strategic priorities grant on “The Physics of AMR” with colleagues from Cambridge, Newcastle, and Edinburgh.

4.2 Contributions to the sustainability of the discipline

All research staff contribute widely to the discipline, through journal editorships, membership of committees, invited talks at conferences or conference organisation, and refereeing for publications and research proposals. We encourage these activities and our WAM provides time so they can be given the necessary priority.

Awards

Skolnick’s continued contributions have been recognised by the Quantum Devices Award in 2015 and the IoP Optics and Photonics Prize in 2018 and he is a Foreign Member of the Russian Academy of Sciences. Hobbs was awarded the 2019 IoP Phillips prize for his “significant contributions to the IoP Biological Physics Group through organising major conferences and inputting into policy” and he was amongst the recipients of the 2020 IoP Rosalind Franklin Prize awarded to the Physics of Life UK Network (PoLNET) steering group for its support of the community and influence on UKRI strategy. Buckley and Lidzey are co-directors of Ossila, our *Growth of Ossila* case study, which was awarded the 2018 IoP Queen's Awards for Enterprise and International Trade. Geoptic, a spinout company of which Thompson is Director, was awarded the 2020 IoP Business Start-Up award for the innovative contribution it has made to the rail industry via the development of non-invasive imaging instrumentation and techniques.

Grant panel membership

All staff contribute to the grant process, through refereeing, panel membership etc. Where the contribution is substantial, additional allowance is made in our WAM, in recognition of the importance to the wider discipline. Examples include Fox, who was Chair of EPSRC Physical Sciences Prioritization Panels in 2019 and 2020, Skolnick who was a member of the Royal Society URF Appointment Panel A(i) (2011-2015, Deputy Chair 2014-15), and the 1951 Royal Exhibition panel 2019/20, Crowther who was a Member of the URF Appointment Panel A(i) (2014-2019, deputy chair for 2017-2019), and Tovey who is a Member of URF Appointment Panel A(i) from 2019-2021.

Committee membership

Again, staff are strongly encouraged to support their wider research community, and many have made significant contributions to their activities. Here we highlight examples where leadership roles were taken. Booth is Chair and Secretary of the Collaboration Board, and member of the Executive Board of the international Muon Ionisation Cooling Experiment (MICE), Crowther was sub-panel chair for the Hubble Space Telescope Time Allocation Committee in 2020. Dhillon is the UK representative on the international WEAVE board, which is the new £25M fibre-fed spectrograph for the William Herschel Telescope on La Palma, and Chair of the GOTO executive Board. Hobbs was Co-I of the first Understanding the Physics of Life EPSRC NetworkPlus (PoLNet) and co-authored the resultant “Roadmap” which was used by UKRI when it launched its Strategic Priority Fund in this area in 2018. He also chaired the IoP Biological Physics group from 2014-2018. Kudryavtsev was Chair of the Institute Board and a member of the Executive Board of the LZ Collaboration in 2018-2019; Tovey was STFC Science Board Chair-elect 2015, Deputy Chair 2014-15, member 2013-14, and Chair of the STFC Oversight Committee for the LUX-ZEPLIN experiment; Tadhunter was Chair of the STFC Liverpool Telescope Oversight Committee 2014-2016.

Conference invitations and organisation

95% of our staff have given invited talks at international conferences over this period, with a total of 298 over the period, and many have been involved in conference organisation, with staff involved in organising over 48 national and international meetings over the period. Here we highlight a few particular examples. Clark (ECR) was a Committee member for the International Conference on Optical Properties of Organic and Hybrid Optoelectronic Materials and Applications (every two years), the International Conference on Ultrafast Phenomena (every two years) and the Physical Chemistry of Semiconductor Materials and Interfaces Session at SPIE (yearly). Crowther and Maund (ECR) co-organized the Royal Society Theo Murphy international workshop "Bridging the Gap: from Massive Stars to Supernovae" (2016). Hobbs was an organiser of the EBSAIUPAB 2017 congress in Edinburgh (around 1300 participants), and he has also organised conferences including “Quantitative approaches to AMR” (Edinburgh 2017), “Understanding the Physics of Cancer” (Sheffield 2017), “Merging clinical, biological and physical sciences approaches to cancer research” (London 2018), Krizhanovskii co-organised the 2017 Optics of Excitons in Confined Structures meeting in Bath. Kudryatsev was co-organiser of the international conference Identification of Dark Matter in Sheffield in 2016. Lidzey co-organised the European Optical Society Annual Meeting and has been a session co-organiser for 'TOM 7' on organic and Hybrid Semiconductors for the last 10 years. Tovey was co-chair of the Programme Committee for the 6th Annual Conference on LHC Physics (Bologna 2018) and a member of the advisory committee for the international workshop “Dark Matter at the LHC” (2016-2019).

4.3 Contributions to society

One of our overarching aims over this period has been to further expand the wider impact of our research, providing strategic support, time and funding to do this. This has led to a wide range of activities beyond those covered by our impact case studies, from partnerships with national and international companies through spinouts to large public engagement events. Examples that show promise to provide substantial impact over the next 5-10 years include:

1. Sich and Dufferwiel, former researchers within the IS group, are now CEO and CTO of a spin-out company AegiQ, which received £207k from Sheffield’s IPDa|C fund to commercialise high-performance quantum photonic systems based on on-demand single photons, for applications in broadband quantum communication, imaging, microscopy and

scalable quantum computing, building directly upon outputs of recent ESPRC programme grant support.

2. Instrumentation that Thompson helped to develop whilst Sheffield PI on a DECC/Premier Oil funded project has resulted in him forming a spin-out company with colleagues from two other universities. They are working with Network Rail to provide the capability to find hidden voids in railway tunnels. The company recently completed delivery of its first external contract, are midway through their second, and have been commissioned for a third.

3. Lidzey has worked extensively with Power Roll Ltd. over the past five years, with experimental activity at Sheffield enabling the company to validate their research concept of a back-contact perovskite solar cell (*Energy and Environmental Science* 2019). This engagement has allowed the company to raise further venture capital to expand its activities.

4. Building further on the impact covered in our *Solar Photovoltaic* case study, Buckley has worked closely with National Grid and others to openly monitor GB photovoltaic energy generation and system deployment, including work with Open Climate Fix and the Alan Turing Institute in developing open data and machine learning for tracking PV deployment.

Wider outreach activities play an important role in widening participation in science and are strongly encouraged. Outreach activities span all research groups:

- AA group: Crowther co-curated ‘Sounds of the Cosmos’ at Festival of the Mind 2014, which involved a live orchestral performance of Holst’s Planets Suite interweaved with astronomy presentations. This coincided with visits targeted at WP schools to engage with the STFC ‘Seeing the universe in all its light’ interactive roadshow. ‘Sounds of the Cosmos’ was subsequently performed at the Crucible Theatre as part of Doc/Fest 2015, and Latitude Festival 2015. Crowther and Dhillon have also contributed to the YouTube astronomy Deep Sky Videos channel, highlighting research results on the Westerlund 1 star cluster (45k views) and runaway stars (38k views).

- Our IS group have produced YouTube videos attracting >150k views and been involved in three National Science Festivals. This included being visited, at Cheltenham in 2017, by the Prime Minister who discussed the exhibit and the importance of Quantum Technologies.

- MBP group: *KrebsFest*, a celebration of the interdisciplinary biosciences work inspired by the Sheffield Nobel Prize winner Hans Krebs, was co-organized by Cadby in 2015, and had over 100k visitors, and won Highly Commended status in 2016 in the Public Engagement and Advocacy category at the Association of Research Managers and Administrators awards.

- PPPA group: Cartwright was a guest on Melvyn Bragg's Radio 4 *In Our Time*, in 2015, and a guest at Cheltenham Science Festival 2019, for a panel discussion on James Clerk Maxwell.

To further expand this aspect of our research we recruited an Ogden Outreach Officer in 2019, who has facilitated staff and students to engage locally and more widely in outreach linked to their research, and helps to coordinate the annual ‘Discovery Night’, involving members of the public visiting the University to engage through demonstrations and talks with staff.

The analytical approaches that underpin physics can have significantly wider application and hence impact. Jones, now in Manchester developing further innovation policy, has contributed significantly to science policy over this period, including co-authorship of ‘The Metric Tide’, and of a Nesta report ‘Bursting the biomedical bubble’ (2018) which has been influential in shifting the funding policy of the Wellcome Trust. His blog post ‘Resurgence of the Regions’ (2019) was cited by the PM’s Chief Policy Advisor at the time, leading to Jones’ involvement in science policy discussions in Downing Street prior to the 2020 Spending Review.