Institution: University of Bath

Unit of Assessment: UoA 9 Physics

1. Unit context and structure, research and impact strategy

The Department of Physics, which forms Bath's UoA 9 submission, has substantially grown its research scope and staff numbers during the assessment period. It has delivered on its primary strategic objective, stated in the REF 2014 submission, to establish a new research group in Astrophysics, to complement existing strengths in Nanoscience, Photonics and Theory. Fifteen new academic staff (an increase of 11.4 FTE of which 7 were women) have been appointed, including 7 in Astrophysics and 5 Royal Society Fellowship holders to increase research quality and impact. The scope of our research ranges from answering big questions in fundamental Physics to solving problems of global significance which are increasingly cross-disciplinary. Since 2014, 30 articles, representing 34% of our submitted outputs, were published in the *Nature* and *Science* family journals. 40 further articles appeared in specialist journals such as *Nano Letters*, *ACS Nano*, *Advanced Materials, Small and PNAS* (17 papers) and *Physical Review Letters* (23 papers). Physics staff have given over 250 invited talks at international conferences and workshops. Highlights of major discoveries made during the assessment period include: observation of the X-ray counterpart of the gravitational wave event GW 170817 (*Nature* **551**, 71 (2017); *309 citations*); odd elasticity (*Nature Physics* **16**, 476 (2020); *19 citations*); graphene sensor for non-invasive glucose monitoring (*Nature Nanotechnology* **13**, 504 (2018); *88 citations*). Physics staff are leading six international consortia totalling 21.8M€ and contribute to a further 32 research hubs on quantum technology, solar energy, extragalactic exploration and biomedical devices. Since 2014, staff have founded 1 spin-out (Ceryx Medical) and 2 start-ups (ORCA Computing, Veriqcloud). The department's research excellence has been recognised with Mundell's appointment as Chief Scientific Adviser to the Foreign & Commonwealth Office (2018) and Knight's election to FRS (2019).

Research groupings

Research activity is organised across four research groups in Astrophysics, Nanoscience, Photonics and Theoretical & Computational Physics. Within each group, members share common research interests, experimental facilities, materials and intellectual knowhow. The groups provide a collaborative environment for supporting the career development of postgraduate students and staff through group seminars, grant pipeline events and joint PhD supervision. Several academics are members of more than one group.

The Astrophysics group explores the dynamic Universe seeking a deeper understanding of pulsating, resonating and exploding stars, relativistic jets shaking up their surroundings, motions of gas in and out of galaxies, and the expanding fabric of space itself. Activities centre on accretion and black-hole driven phenomena (*Mundell, Schady, Tsang, van Eerten, Villforth*), the properties of gamma-ray burst host galaxies and afterglows (*Mundell, Schady, Wuyts*), and the structure and enrichment history of galaxies through statistical censuses from the Local Group to the distant Universe (*Scowcroft, Schady, Villforth, Wuyts*). The seven Astrophysicists are joined by two academics with expertise in remote sensing (*Blondel, Watson*), three postdoctoral researchers and 11 PGR students. In establishing the group, the strategic focus has been to pair observation and theory to enable mutual benefits from shared expertise in big data analytics, and target growth areas that are strongly aligned with UK priorities. Group members are users of existing and upcoming facilities that form the cornerstone of the UK strategy for astrophysics, including the Vera C. Rubin Observatory (four academics are LSST:UK Affiliate PIs), the Square Kilometre Array (SKA), and new ESO instrumentation (we have membership of the VLT/MOONS Science Team and will have group buy-in to the 4MOST consortium) culminating in the European Extremely Large Telescope (ELT). The group has made substantial contributions to

the detection of the first gravitational wave event with electromagnetic counterpart (*Nature* **547**, 425 (2017); *Nature Astronomy* **11**, 791 (2017); *Nature Communications* **9**, 4089 (2018)).

The Nanoscience group is active in the Physics of nano-objects where reduced dimensionality brings novel electrical, magnetic and superconducting properties with important applications to electronic devices, energy materials and healthcare. Since 2014, research in 2D-systems and dichalcogenides has become increasingly cohesive through the collaboration of scanning probe microscopists, theoreticians and experimentalists in quantum transport and optoelectronics (*Andrews, Bending, Crampin, Da Como, Dale, Ilie, Mucha-Kruczynski, Nogaret, Rusimova, Snow, Takashina, Valev, Wolverson*). The *Bath/Bristol Condensed Matter CDT* has furthered this integration through a joint postgraduate training programme and increasing PhD co-supervision. Other research areas include: scanning probe engineering of novel atomic structures (*Ilie, Rusimova, Sloan*); biomedical nanoscience (*Gordeev, Ilie, Nogaret, Zeidler*); liquid and amorphous materials (*Salmon, Zeidler*); theory of 2D materials and plasmonic waveguides (*Crampin, Gorbach, Mucha-Kruczynski*). The group has grown with the appointments of *Dale* (Royal Society URF), *Rusimova* (University of Bath Prize Fellow) and *Zeidler* (Royal Society Dorothy Hodgkin Fellowship). It currently has 15 core staff, 6 postdocs and 16 PhD students. The group operates facilities ranging from the synthesis to the characterisation of nanomaterials which were for example implemented in pioneering studies of ReS_2 as a novel low symmetry 2D material (*ACS Nano* **8**, 11154 (2014)) and to control molecular reactions on the femtosecond scale (*Science* **361**, 1012 (2018)). The group also demonstrates novel device concepts such as optimal solid-state neurons (*Nature Comm.* **10**, 5309 (2019)) and superconducting spin valves (*Nature Phys.* **12**, 57-61 (2016)). Nanoscience staff lead the Centre for Nanoscience and Nanotechnology (CNAN), which coordinates nanoscience projects with 9 other departments at Bath, and are regular users of 12 synchrotron, neutron, muon and high magnetic field facilities in Europe, Japan and the USA.

The Photonics group embodied as the Centre for Photonics and Photonic Materials (CPPM) investigates the science of light from its most fundamental aspects to cutting-edge applications. Since 2014, the Centre has actively diversified its research portfolio beyond its pioneering work on micro-structured photonic crystal fibre for which it became established as a world-leading photonics centre. This diversification has been driven by the recruitment of high-quality ECRs, many of whom have won prestigious research fellowships: *Bowman* (Royal Society URF), *Nunn* (Royal Society URF, now Reader), *Rusimova* (University of Bath Prize Fellow), *Stone* (EPSRC-UKRI Innovation Fellow) and *Valev* (Royal Society URF). This has resulted in a more resilient and dynamic Centre with a research portfolio that encompasses six core themes: speciality optical fibres (*Birks, Knight, Stone, Wadsworth*); medical photonics (*Birks, Knight, Stone*); quantum photonics (*Gorbach, Mosley, Nunn, Valev*); nanoscale photonics (*Da Como, Gorbach, Rusimova, Valev*); theory & modelling (*Bird, Gorbach, Skryabin*); instrumentation (*Birks, Bowman, Rusimova, Valev, Wadsworth, Wolverson*). The CPPM has 14 core academic staff working alongside 6-8 postdoctoral researchers, 20 PhD students, and 2 technical staff. Landmark achievements include: the demonstration of a new class of hollow-core optical fibre laser (*Optica* **3**, 218 (2016)); the world's first fully-fibre-integrated source of high-purity heralded single photons (*Optica* **3**, 1270 (2016)); a new noise-free quantum memory protocol, now the foundation of a spin-off company (*Phys Rev A* **97**, 042316 (2018)); hyper-Rayleigh scattering (*Phys Rev X* **9**, 011024 (2019)); polariton topological insulators (*Phys Rev Lett* **119**, 253904 (2017)).

The Theoretical and Computational Physics group spans fields from condensed matter (*Crampin, Mucha-Kruczynski, Souslov, Walker*), photonics (*Bird, Gorbach, Skryabin*) and mathematical biology (*James*) to astrophysics (*van Eerten, Tsang*), with a major focus in studying far-from-equilibrium physics. Such systems are ubiquitous in nature, including those driven by external forces (explosions, intense light fields or harvested sunlight) and those with an

internal source of energy (living systems, nanodevices). The group, which currently comprises 10 academics, 3 postdoctoral researchers and 12 PhD students, identifies itself as consisting of "applied theorists", with much of the research being in collaboration with experimentalists, and observational astronomers in other research groups and research centres. Research highlights include the design of active-liquid metamaterials with topologically protected sound modes (*Nature Physics* **13**, 1091 (2017)); a two-dimensional topological polariton laser (*Physical Review Letters* **122**, 083902 (2019)); an ion transport mechanism for hysteretic phenomena in perovskite solar cells (*Energy & Environmental Science* **9**, 1476 (2016)); odd elasticity (*Nature Physics* **16**, 476 (2020)).

Research and impact strategy

Our strategic vision is to deliver world-leading research in Physics and Astrophysics by identifying and promoting the emergence of novel research themes, especially at the interface with other disciplines, while fostering research depth and rigour in our core research areas. These areas have grown into critical masses of researchers from the priorities identified in REF2014. This vision is implemented through the following actions.

To re-organise the unit into a leaner research structure the Unit's research committee has been streamlined in line with a wider review of the department's leadership structures, guided by the Athena Swan action plan, with the aim of creating effective committees that reflect the breadth and diversity of the Unit. The research committee's ex officio posts are the Director of Research (*Nogaret*), the four research group leaders (*Wuyts* (Astrophysics), *Wolverson* (Nanoscience), *Mosley* (Photonics), *Mucha-Kruczynski* (Theory)) and the Director of Studies for PGR students (*Da Como*). *Dale* and *Zeidler* (both Royal Society Fellowship holders and ECRs) have been appointed via an open call for expressions of interest.

The research committee supports the development of current and emerging research themes by organising grant pipeline discussions, relaying grant calls to relevant groups, engaging with sponsors beyond research councils (alumni, industry), managing research communication, and facilitating international engagement. 70% of our submitted outputs have international co-authors. The research committee shares best practice in publishing, grant applications and advises the department on academic staff recruitment. It promotes a culture of collaboration and inclusion that supports the development of ECRs by mentoring fellowship applicants and shortlisting candidates for PhD prizes. The research committee also has specific ED&I responsibilities and monitors data related to PGR student admissions, retention and attainment, postdoctoral researchers, and external seminar speakers, for reporting to the department's Athena Swan team.

The Unit has also appointed an Impact Director (*Wadsworth*), a Research Promotion Champion (*Valev*), and an Open Access Champion (*Blondel*). These roles provide support and a point of contact with central University services for academics seeking help in these areas.

To support the emergence of multidisciplinary research the Unit has prioritised the development of two themes during the assessment period: *Healthcare* and *Energy Materials*. These areas offer outstanding opportunities for fundamental discoveries at the interface with biology and chemistry, and for translational research. Both themes align our research strengths with UKRI priorities and are increasingly supported by a widening network of national and international stakeholders. Our healthcare research stream builds on our strengths in photonic materials for medical diagnostics (EPSRC-PROTEUS) and semiconductor physics for bioelectronic medicine (H2020 CresPace). The energy materials stream encompasses solar cells, batteries and innovative methods for scavenging or converting energy. Walker leads the modelling effort of these materials within the three networks she coordinates. This area has

been reinforced by the recruitment of Asadi (who joined after the REF census date) to lead a new experimental group on ferroelectric materials.

Alongside these developments, broader interdisciplinary research has continued to thrive across the Unit: 22% of our submitted outputs have a co-author from the Life Sciences, Chemistry or Engineering. Twenty UoA staff are further engaged in collaboration with another Bath department (eight in total across three Faculties) or research centre (Centre for Therapeutic Innovation, Centre for Sustainable & Circular Technologies, Centre for Networks and Collective Behaviour). For example:

- Walker's theory group collaborates extensively with Chemists and Material Scientists from the UK (EPSRC-Supersolar) and Europe (EXTMOS, MAESTRO, DESTINY). These cross-disciplinary collaborations are essential to making photovoltaic materials with greater conversion efficiency and flexible organic light emitting devices. Two of her publications are jointly with chemists and have received over 200 citations (*Energy & Environmental Science* **9**, 1476 (2016), *Journal of Physical Chemistry* C **119**, 3456 (2015)). Walker has been appointed to the REF2021 panel as an interdisciplinary advisor for UoA9.
- Dale's Royal Society Fellowship is highly interdisciplinary as it focusses on manipulating the electronic properties of 2D materials using electrochemical methods. By utilizing a chemical doping method called ionic liquid gating, she aims to modify the interactions between the ionic liquid and the 2D material to induce novel electronic, magnetic and superconducting states.

UoA staff have contributed to the University's Institute for Mathematical Innovation through participation in its research panel (*James*), internal secondment scheme (*Blondel, James, Nogaret, Salmon, Villforth, Wilding*) and the Undergraduate Research Experience scheme, where undergraduate students undertake an eight-week summer project (nine academics have hosted students).

To maximise the impact of our research the Impact Director (*Wadsworth*) and the research committee support academics in developing awareness of the commercial value of their research and partnering with industry and third sector organisations to translate it successfully. Actions have included: informing eligible grant holders of calls for the Impact Acceleration Account (EPSRC) and the H2020 Launchpad, and about the availability of internal University funds to build prototypes, commissioning market studies and writing business plans; exploiting iCASE [2] and CASE [3] conversion PGR studentships; engaging in consultancy as a route towards securing research projects funded by industry [9], DSTL [2], InnovateUK [3], Knowledge Transfer Partnerships [5]; encouraging and supporting staff in disclosing patentable inventions to University commercial managers, protecting and licencing IP; engaging with the award-winning Bath SETsquared business incubator via their iCURE programme to prepare and pitch business plans to investors.

The Unit supports impact creation by (i) recognizing that interdisciplinary research opens up important avenues for impact especially when done in collaboration with clinical partners, and (ii) by treating impact as having an equal value to research in making academic appointments, in recommending sabbatical leave, promotions, and within the workload model.

The submitted impact case studies represent examples of research translation come to fruition.

- *Blondel* has worked with Seiche Ltd and British Standards to develop remote sensing technology to minimise the effects of man-made sounds on wildlife. Impact generation was enabled by three KTPs and an impact-focussed sabbatical in 2015.
- *Watson* has sought to translate his research on mapping the free electron density of the ionosphere to hand-held devices for the detection and location of GPS jammers. The

enabler of impact was a 10-year long collaboration with Chronos Technology Ltd supported by InnovateUK grants.
- *Birks, Knight, Stone and Wadsworth* have commercialised microstructured optical fibres. Impact was created by filing a family of patents on supercontinuum generation (WO2009098519A1) subsequently acquired by Fianium Ltd (now part of NKT Photonics) and through fruitful partnership with Fianium. Glophotonics was spun-out to commercialise new hollow-core fibre technology exploiting Bath IP (WO2006077437A1, WO2009044100A1).

The Unit's impact strategy, and its close linkage with our promotion of multidisciplinary collaborations, is illustrated by early-stage ventures with substantial potential for future impact:

- *Ilie* and colleagues in Pharmacy & Pharmacology patented a graphene-based sensor for non-invasive, transdermal glucose monitoring, prior to its publication in *Nature Nanotechnology* (**13**, 504 (2018)). The patent is now licenced to Bioelectric devices, San Jose, CA for exploring the commercial potential of the device.
- *Nogaret*, in collaboration with cardiologists at Bristol, has founded Ceryx Medical, a spin-out company aimed at commercialising Central Pattern Generators to provide novel therapies for cardiorespiratory diseases such as heart failure and sleep apnoea. The venture is based on research on implementing neuronal central pattern generators as pacemakers (*Nature Communications* **10**, 5309 (2019); patent WO2013175171A2). Since its incorporation in 2016, Ceryx Medical has raised £1.3M from investors and is developing its first-in-man pacemaker following successful animal trials.
- *Nunn* is a co-founder and chief technical officer of two quantum computing start-ups: ORCA Computing and Veriqcloud.
- *Stone* is working on three multidisciplinary projects grouping clinicians, physicists and electrical engineers at Bath, Edinburgh and Heriot Watt. Two involve building optical fibre-based endoscopes for accurate cancer diagnostics, one of which is fully funded by Boston Scientific. The third is the EPSRC-funded PROTEUS project (with *Birks* and *Knight*), creating diagnostic tools for pneumonia. Bath's contribution is to develop a fibre bundle that combines imaging, sensing and drug delivery and that is small enough to reach the distal airways. This fibre is being trialled in several clinical studies, including diagnosis of COVID-19.

To foster an open research environment the Open Access Champion and research committee monitor all published papers to ensure that 100% of research preprints and data sets are posted on the University's open archive within 3 months of publication. At group level, many researchers develop software and designs on platforms such as GitHub and GitLab:

- The OpenFlexure Microscope has been developed within GitHub and GitLab for both its hardware and software, enabling Bowman's group to engage scientists, entrepreneurs and enthusiasts in a worldwide community. They uphold the highest standards of open and reproducible science, where each publication is accompanied by an archive of raw data, interactive notebooks explaining the analysis and plotting codes, hardware designs, assembly instructions, and scripts to run automated experiments.
- The software developed by van Eerten for analysing relativistic astrophysical transients is publicly available online; further development and dissemination of these tools is funded by a H2020 grant for integrated activities within the high-energy astrophysics community. The software has been used by all the teams involved in the breakthrough observation of the relativistic jet accompanying the GW170817 gravitational wave event.

Forward look

Over the next five years we will build on the key research and impact strategies outlined above. A priority will be to develop further the cross-cutting research themes in Healthcare and Energy Materials; these will inform our recruitment strategy and will be the focus of major funding bids

for people and infrastructure. Alongside this, we will support the four research groups to sustain critical mass in their core areas by targeting major funding programmes (e.g. ISCF, GCRF, Quantum Technologies) and access to international facilities (e.g. 4MOST, CTA, Vera C. Rubin Observatory, SKA), and by continuing our successful initiatives to attract external Fellowship holders. Key research themes will be the dynamic Universe, the physics of two-dimensional systems, atomically-engineered structures, quantum photonics, open-source instrumentation and topological materials.

2. People

Academic staffing and recruitment

Academic staff numbers have grown substantially during the assessment period, underpinned by the introduction of the new Astrophysics group. 15 category A academic staff have joined since August 2013: *Bowman* (University Prize Fellow, followed by Royal Society URF), *Dale* (Royal Society URF), *van Eerten, Mundell, Nunn* (Royal Society URF), *Rusimova* (University Prize Fellow), *Schady, Scowcroft* (University Prize Fellow), *Stone* (EPSRC-UKRI Innovation Fellowship), *Souslov, Tsang, Valev* (Royal Society URF), *Villforth, Wuyts, Zeidler* (Royal Society Dorothy Hodgkin Fellowship). 14 are on long-term contracts, and *Rusimova* should move to a long-term contract at the end of her Fellowship. In the same period, *Coleman* retired, *Jack* and *Wilding* left and *Bird* reduced his FTE to 0.4. Clark joined and left. Mundell is currently seconded to the Foreign and Commonwealth Office as their Chief Scientific Adviser; she retains a 0.4 FTE post at the University.

This expansion was brought about by four strategic developments:

- Establishment of a new research group in Astrophysics. Four new posts were created in 2014/15 and *Mundell* was hired as the founding leader of the group. *Wuyts, van Eerten* and *Villforth* joined in the first wave of appointments, followed by *Scowcroft, Schady* and *Tsang*. As discussed in section 1, these appointments have enabled us to develop a coherent programme of research in high energy and time domain astronomy, galaxy formation, supermassive black holes and cosmology, with strong links to UK and international consortia.
- The University's Prize Fellowship programme is designed to support outstanding early career researchers to become tenured academics in strategically important areas. Two years of research enable Fellowship holders to establish an independent research group, before being considered for an academic position. *Bowman, Scowcroft* and *Rusimova* have been appointed via this pathway, joining *Mucha-Kruczynski* who was appointed in 2013. *Mucha-Kruczynski* has since been promoted to Senior Lecturer and currently is Head of the Theory group.
- The University is extremely supportive of appointing externally-funded fellowship holders. The Unit provides a strong mentoring programme to develop their outstanding potential to contribute to the research and impact environment and to move to permanent positions. *Dale, Stone* and *Zeidler* have been appointed through this route. All our Fellowship holders have permanent contracts or are expected to transition to one.
- We have used the opportunity of departing staff to allow replacements to align more closely with the research strategy. For example, the departure of *Jack* and the reduction of FTE for *Bird* enabled the department to recruit three new Lecturers in Astrophysics (*Schady, Tsang*) and topological physics (*Souslov*).

In making appointments we have sought to: (i) enhance research excellence and the potential for ground-breaking impact (*Bowman* and *Stone* are already generating impact from their research, and *Asadi*'s appointment is impact- as well as research-focussed); (ii) ensure critical mass and sustainability in our activities; (iii) target emerging research challenges; (iv) forge new

intra- and inter-disciplinary links. The Unit's strategy has had a strong emphasis on the appointment and development of outstanding early career researchers: 13 of the 15 appointments in the assessment period were ECRs.

We have also made a concerted effort to improve the Unit's gender balance. All search committees and interview panels have women members. All members of these panels have undertaken unconscious bias training, and panel chairs have received specific ED&I training. We have used relevant networks to advertise posts (for example the *AASWomen* newsletter). Search committees, in drawing up lists of people to approach, included women and BAME Physicists with a strong research profile. For example, the top two candidates shortlisted for an Astrophysics lectureship were both women who had been invited to apply. We have also encouraged and supported our post-doctoral researchers to apply for Fellowships that could lead to tenure-track appointments (*Dale*, *Rusimova* and *Zeidler* were research associates in the department before obtaining their Fellowships and academic posts). At the start of the assessment period only two category A academics were women (*Ilie, Walker*). Seven of the 15 newly appointed staff are women (*Dale, Mundell, Rusimova, Schady, Scowcroft, Villforth, Zeidler*).

Future academic recruitment will focus on the interdisciplinary themes outlined in section 1. The appointment of*Asadi* (from MPI for Polymer Research, Mainz; started 01/09/20) to a Chair opens up new research opportunities in energy materials, with substantial potential for funding and impact. The recruitment process started before the COVID-19 pandemic, but the contract was finalised during lockdown, with a major start-up package, demonstrating the University's commitment to Physics. Two expansion posts in Theory are already in the pipeline. We continue our successful initiative to attract externally-funded fellowship holders.

Staff development and recognition

Career development of researchers at all levels benefits from a strong network of departmental and University support structures. These include dedicated support for ECRs, well-resourced research support and staff development units, a flexible sabbatical leave scheme, transparent promotion criteria, an effective workload model and a supportive departmental staff development and performance review (SDPR) process. Technical and support staff are supported in their professional development by the GW4WARD multi-university program and by the Technician Commitment Action Plan that helps technicians to achieve recognition and visibility.

Our strategy to focus academic recruitment on exceptional ECRs is backed up by continuing support for their research careers. Start-up packages enable them to rapidly establish their research activity, with support for equipment, consumables and facility access. They are prioritised in the allocation of University-funded and EPSRC DTP studentships; all the open-ended, category A staff appointed during the assessment period have had at least one PGR student supported in this way. Probationary staff receive substantially reduced teaching and administrative duties during their first three years. They have regular formal meetings with the Head of Department where their funding, research and publications are discussed and where further support may be agreed. They take the Bath Course in Enhancing Academic Practice which introduces best practice in doctoral supervision, grant development and research dissemination. Successful completion of the Bath Course leads to an HEA Fellowship. Newly appointed staff are also assigned a senior academic as a mentor. The research of ECRs is showcased annually at the Vice Chancellor's Research day; *Nunn*, *Schady* and *Valev* have presented their work in this forum.

The University is committed to implementing the Concordat to Support the Career Development of Researchers and has a regularly updated action plan and Code of Practice for the

Employment of Research Staff. *Nogaret* is the department's Research Staff Coordinator and has the responsibility to ensure that the code of practice is being enacted. Scowcroft takes the lead on induction for new postdoctoral research associates (PDRAs) and for our mentoring scheme. She also coordinates the SDPR process for research staff. The SDPR reviewer is selected from a team of experienced academics and is distinct from the PDRA's line manager; this policy has been instigated to focus the discussion on career development and to pick up any difficulties between PIs and their research staff. Our PDRAs have taken advantage of many of the University's staff development opportunities, including the Kick Start to HE Teaching programme and the Academic Career Academy (*Rusimova* obtained her Prize Fellowship after attending this programme).

To complement this Institutional support, *Villforth* has initiated and organised a series of ECR lunches (attended by around 10 postdoctoral researchers and probationary academics, with a senior academic guest) to share research experiences and to encourage peer support. The scheme has been taken up by other departments and was highlighted at a Faculty of Science Networking event in 2018.

The University has a sabbatical leave scheme which aims to advance the pursuit of research, scholarship and impact, leading to the personal development of individual members of staff and to the production of outputs of significant benefit to the University. During the assessment period *Andrews, Bird, Blondel, Ilie, Salmon, Skryabin* and *Zeidler* had periods of leave. *Blondel* used his sabbatical to further develop his collaboration with Seiche Ltd, leading to new KTP awards and providing the foundation for one of the unit's impact case studies. *Salmon* and *Zeidler* spent their sabbaticals at Corning USA, supported by the company's Gordon S. Fulcher distinguished scholars' scheme, which led to high impact papers and a substantial grant. Following *Ilie's* sabbatical at the National Institute of Materials Science in Tsukuba, Japan in 2016-17, she joined Advanced HE's Aurora programme in 2017-18 and was promoted to Reader in 2018.

The Unit recognises achievements in research and impact in a number of ways.

- During the assessment period the department has introduced a promotions committee, whose remit is to support academics in developing their case for promotion, identify colleagues who may have a case for promotion but who have not brought themselves forward assess whether or not cases should be put forward, and report to the department's Athena Swan team on relevant ED&I data. The promotion committee assesses individual cases against transparent promotion criteria set by the University which include a range of research and impact indicators, allowing academic staff to work to their interests and strengths. During the assessment period *Gorbach, Mosley, Mucha-Kruczynski, Sloan* and *Takashina* were promoted to Senior Lecturer, *Ilie* and *Wuyts* to Reader, and *Nogaret, Valev, Wadsworth* and *Wolverson* to Professor.
- The Unit has a long-established and trusted workload model for allocating duties. All academic staff receive a time allocation for research and scholarship in order to develop standard grant proposals or seed corn research ideas. Time funded by external research grants is on top of this, as is an allocation for PGR supervision. Academics can also request additional time for activities such as major grant applications or impact-related activities (for example, in 2019 *Nunn* had a mini-secondment to support his work with ORCA Computing (see section 4)).

Research student training

Research student numbers have grown from 9-11 per annum in REF2014 to 16-19 per annum during the REF2021 assessment period. Factors that have enabled this growth include:

- Success in securing two EPSRC Centres for Doctoral Training in Condensed Matter Physics (joint with Bristol) and Sustainable Photovoltaics (with 7 partner institutions). Unit staff also participate in other Bath-led CDTs in Sustainable Chemical Technologies and Statistical Applied Mathematics, acting as principal or co-supervisors.
- The Unit has secured two EU MC-ITNs, MAESTRO and MicroCOMB, led by *Walker* and *Skryabin* respectively.
- University funded studentships to support newly-appointed staff and large grant applications.
- A Physics PGR open-day with invited talks from Bath PhD alumni and final-year PGR students, targeted at undergraduates to inform them about PhD opportunities.

The number of new PGR starters in the past five academic years are:

2015-16	2016-17	2017-18	2018-19	2019-20
19	17	16	18	17

The primary funding sources for these students are: EPSRC DTP, I-CASE, Quantum Hub (24); CDTs (19); overseas governments (6); EU, including projects and ITNs (4); Royal Society (4); University funded studentships (23). In the same period, members of the Unit have co-supervised 14 PGR students in other departments at Bath and 10 students at other Universities.

In 2017 the University created the Doctoral College (DC), a central department that provides guidance and support for PGR students and supervisors across the University. The DC coordinates the recruitment and induction of students as well as University-wide training including research ethics and data management. The DC provides professional support for the well-being of students and promotes important equality and diversity campaigns such as #NeverOK. It also provides training for supervisors, particularly probationary academics.

Each PGR student has a supervisory team of at least two academics. Its role has been strengthened during the assessment period with the second supervisor having a more substantial role with a time allocation in the workload model. Students have a peer mentor who offers support with periodic meetings and assists the Director of Studies (DoS) in pastoral supervision. Student progress is monitored through 6-monthly reports, with input from the student and supervisors. There is a formal confirmation point assessed by a first-year report and viva, which offers formative feedback on progress and future plans for the PhD project. Other developments in the assessment period include:

- Creation of a Staff Student Liaison Committee for research students. This forum includes eight PGR students (representing different research groups and cohorts) and three academics (including the DoS). Its minutes go to the full department meeting.
- In PRES 2019 the department scored 90% in overall satisfaction.
- We have instigated a new PhD thesis prize supported for the first 10 years by a philanthropic donation.
- We have initiated a new student-led PGR conference with financial support from the Doctoral College, the department and industry.

Group environment

The research groups have a key role in the scientific and career development of PGR students and PDRAs. Groups hold weekly meetings involving research presentations, practice conference talks, journal clubs and external seminar speakers; PDRAs are encouraged to be involved in organising these activities. The groups also provide a supportive research environment to undergraduate MPhys students, who undertake a full-time, semester-long project in their final year.

- As part of the Condensed Matter Physics CDT the Nanoscience group has organised a comprehensive programme of postgraduate lectures, seminars, workshops and training in laboratory and computational techniques jointly with Bristol Physics. Non-CDT students in Nanoscience, Theory and Photonics have also benefitted from this training. The highly successful Frontiers of Condensed Matter Physics conference (www.frontiers-cmp.org) is organised by the CDT and includes a large student-led component. We have agreed with Bristol to continue an enhanced PGR programme (CMP-PhD+) which will build on the CDT-led investment in PGR training.
- PGR students in the CPPM established in 2019 an Optical Society (OSA) Student Chapter which organises academic and social events. The Chapter, alongside the Network of Women in Physics (see below), were instrumental in organising and obtaining funding for the department's Week of Women in Science in February 2020.
- Astrophysics groups across the GW4 Alliance (Bath, Bristol, Cardiff, Exeter) organise a PGR-student only seminar day two to three times each year, with the venue rotating between the four Universities.

Equality, diversity and inclusion

The Athena Swan (AS) team has oversight of ED&I issues across the Unit. The remit of the team goes beyond gender issues and actively addresses issues that could impact on BAME, LGBTQ+ members of staff. It has had an increasingly important role through the assessment period, ensuring the department's committee structure reflects the ED&I strategy, and drawing up a wide-ranging and ambitious action plan. The AS team, chaired through the assessment period by Wuyts, has representatives of postdoctoral, technical and administrative staff and PGR students. Academic members are drawn from the research, teaching and promotions committees, to ensure effective communication and collaboration across areas. All departmental committees have ED&I as a standing item; the AS team reports to the full department meeting and the department executive, and the Chair is an ex officio member of the executive. All committees have academic members who are appointed following an open call for expressions of interest. This provides the opportunity for all staff, and particularly ECRs, to gain experience and be involved in departmental decision making. The department currently has a bronze AS award and is working towards silver.

Several of the initiatives discussed above are evidence of implementation of the action plan: improvement in the gender balance of academic staff; support for Fellowship applications and proleptic appointments; improved mentoring and SDPRs for postdoctoral researchers. In addition:

- Regular Unit-wide events including research lunches (with talks by academics and PDRAs) and a colloquium series (with talks from prominent external researchers) have improved communication and cohesion.
- We have increased the proportion of female external speakers. Our colloquium series has had 50% women speakers over the last four years (including Sheila Rowan and Julia Yeomans). The department nominated Jocelyn Bell-Burnell and Natascha Forster-Schreiber for honorary degrees as women role models in Astrophysics; both awards were made in 2019.
- *Mundell* was Head of Department for two years before her current secondment, making her the first female head of a science department at Bath. She also chaired the University's Senior Women's Academic Network.
- The Network of Women in Physics (NWP) was founded in 2016 by three undergraduate students with the aim of providing support for female students studying Physics at Bath, whilst also promoting female researchers within the department and beyond. The network is currently run by three PGR and three undergraduate students; it is affiliated with the IoP and has obtained funding from external bodies for workshops and social events. This year

the NWP collaborated with the Bath Student Chapter of the Optical Society to organise the Week of Women in Science. Seven women from academia and industry gave talks about their research and their careers, and participated in a panel discussion: "From the Perspective of Women in Physics".
- One of the Unit's PDRAs (*Laskar*) is an academic staff representative on the organising committee of Kaleidoscope, the University's LGBT+ network. He is the PDRA representative on the AS team and is a co-author of the 2018 report "LGBT+ Inclusivity in Physics and Astronomy: A Best Practices Guide". In 2019 Kaleidoscope organised a well-attended talk by a Bath Physics graduate (Dr James Claverley, currently working at NPL) which combined a discussion of changes to the SI standards with insights into working as an LGBT+ scientist.
- Two incubator workshops funded by an EPSRC Inclusion Matters grant called *Reimagining Recruitment* were organised by members of the CPPM in May 2019 (Imaging & Biophotonics) and February 2020 (Open hardware, organised by a PDRA (*Stirling*)). The goal of these workshops was to encourage collaboration in an inclusive environment, with seed funding enabling pilot projects to be taken forward by more junior participants. Delegates included scientists at all career stages, with a particular emphasis on diversity.

Selection of outputs followed the University's Code of Practice, with reviewers in the Unit (that included ECRs) receiving appropriate training, including ED&I. 19 of the 89 submitted outputs are from female staff (21%, cf 21% of category A staff); 35 of the 89 are from staff appointed as ECRs in the assessment period (39%, cf 33% of category A staff).

3. Income, infrastructure and facilities

Funding strategy and support

The Unit's research funding strategy focuses on alignment with national and international research agendas, leadership of large consortia and programme grants, and support for Fellowships. This is closely linked with our recruitment strategy discussed in section 2 and the development of interdisciplinary research themes discussed in section 1. It is implemented through regular grant pipeline meetings overseen by the research committee, and the organisation of multidisciplinary seminars and workshops to initiate funding bids. University and departmental support for grant funding and generating impact has several strands:

- Large strategic bids (e.g. CDTs, Healthcare Technology) are reviewed and selected by cross-faculty peer-review panels involving external experts. Fellowship applicants undergo mock interviews at Faculty level. At Unit level, all grant applications are internally peer-reviewed by colleagues who have been successful in similar bids or who have sat on relevant grant panels.
- Research & Innovation Services (RIS) supports applicants with alerts of open funding calls from sponsors worldwide, coaching ECRs in proposal writing through "shut up and write" sessions, reviewing drafts of grant applications and costing proposals.
- The commercialisation and legal teams within RIS actively support the translation of Unit research, including: IP protection (*Ilie, Knight, Nogaret, Stone, Valev*); negotiating licence deals (*Ilie*), KTPs (*Blondel*) and University start-ups (*Nogaret*). The University hosts an award-winning business incubator, SETsquared, whose iCURE business development programme was instrumental in founding Ceryx Medical (*Nogaret*) with £500k pre-seed funding from InnovateUK.

Highlights during the assessment period include:

Horizon 2020 consortia. Four new major EU-funded grants have been led by Physics academics (*Nogaret, Skryabin, Walker* x2), with a total value of €17.7M. Details are given in section 4.

GCRF funding. *Bowman* has attracted £1.6M of GCRF funding since his appointment as a Prize Fellow in 2017, including his GCRF-supported Royal Society URF (2018-), to develop high-quality, open source hardware for globally accessible science and healthcare.

UK Quantum Technologies programme. *Mosley* and *Nunn* have received £1.1M from EPSRC, InnovateUK and through the Networked Quantum Information Technologies Hub for research on fibre-based single photon sources and quantum memories.

Medical photonics. *Birks, Knight* and *Stone* have been awarded a total of £1.3M as part of the EPSRC-funded Proteus Interdisciplinary Research Collaboration, to develop new technology for rapid bedside diagnosis and management of lung diseases. *Stone* has also received £1.4M, including his EPSRC-UKRI Innovation Fellowship, to work on next-generation endoscopes.

KTP awards. *Blondel* has received three KTP awards during the assessment period (2013-17, 2015-18, 2019-22, total value £870k) for work on underwater acoustics projects with Seiche Ltd.

New appointments. *Dale, Nunn, Valev* and *Zeidler* have been awarded a total of £2.9M from the Royal Society in support of their Fellowships. *Bowman, Clark* and *Souslov* have received EPSRC New Investigator awards (£550k total). *Scowcroft* and *Wuyts* have received STFC consolidated grant awards (£500k total); *Van Eerten* and *Villforth* have received H2020 awards (£280k total).

University core facilities

The University has organised its core, underpinning research equipment into managed Facilities. These are run by teams of research technical professionals who ensure that the operation of the equipment, analysis and data management are carried out to the highest standards. They induct all users in the appropriate use of equipment and chemical safety. The University invests in the facilities by underwriting the staff and space costs and by supporting equipment purchases and upgrades (through institutional contributions to external equipment grants or 100% funding from the University's Major Equipment Fund (MEF)). All equipment is advertised on national and regional GW4 databases.

Staff and students in Physics make extensive use of four of these facilities:

- CPPM operates a world-class optical fibre fabrication facility that underpins all of our fibre-based research and impact in photonics. A £225k upgrade was carried out in 2017, funded jointly from the MEF and by income generated by the Centre's highly successful Continued Professional Development course in fibre fabrication.
- The David Bullett Nanofabrication Facility provides 150m^2 of class 1000 cleanrooms that provide access to photo- and electron-beam lithography, thin film deposition, wet and dry etching, imaging, device characterisation and packaging. During the assessment period the facility has been upgraded with photolithography and thin film deposition systems with a total value of £985k, funded by EPSRC (strategic equipment and CDT equipment) and the MEF.
- The Material and Chemical Characterisation (MC^2) facility provides high-end imaging (TEM, SEM, scanning probe microscopy, Raman, confocal and light-sheet microscopy) and characterisation (X-ray crystallography, mass spectrometry, NMR) equipment, and related specimen preparation. MC^2 has attracted £7.2M of investment in equipment during the assessment period, from EPSRC (strategic equipment, core equipment, CDT equipment, ECR equipment), Welcome Trust, BBSRC and the MEF. Of particular importance to researchers in Physics are investments in TEM, SEM, X-ray crystallography and two-photon confocal microscopy (£3.7M total).
- The University's high-performance computing (HPC) facility, Balena, provides an integrated environment for running compute, memory and data-intensive jobs. It has 3136 cores and is used extensively by researchers in the Astrophysics, Nanoscience and Theory groups. Balena is operated with a dual access model. Larger runs require funding, but spare capacity

for smaller runs is freely available to all researchers, supporting code development, pilot projects and occasional users. Crampin, Mucha-Kruczynski and Walker also make use of Isambard, an EPSRC-funded Tier 2 HPC facility operated by the GW4 alliance.

Unit level Facilities

Nanoscience hosts four scanning probe microscopes (cryo-STM, UHV-STM and two AFMs); two optical spectroscopy laboratories; four laboratories investigating the electronic properties of mesoscopic semiconductor, magnetic, superconducting and molecular devices; one laboratory for synthesizing and probing amorphous materials. Each laboratory has unique tools and know-how for structuring materials on the nanoscale using techniques including CVD growth, atomic engineering with local probes, molecular self-assembly and top-down nanofabrication. This equipment is shared within the group to support integrated research programmes on transition metal dichalcogenides and our condensed matter CDT training programme.

The CPPM operates twelve photonics research laboratories as a pooled resource; they contain shared equipment including short-pulse laser systems, optical spectrum analysers and an ultra-wideband grating spectrograph. Major items of equipment purchased during the assessment period include four ultrashort-pulse mode-locked laser systems, two near-infrared single-photon detectors, a wideband optical spectrum analyser and an optical fibre fusion splicer.

The Unit's mechanical workshop provides key support to research laboratories by fabricating bespoke parts and precision tools. Workshop capability has been enhanced during the assessment period by a new CNC mill and an increase in technical staffing to 1.5 FTE. Prototypes are synthesized using our in-house laser cutting and 3-D printing facility. The University glassblower is a key resource for making bespoke glassware ranging from CVD tubes to vacuum parts.

National and international facilities

Astrophysics researchers are integrated into national and international consortia that have secured access to world-leading telescope facilities. Observing time is obtained through competitive peer review and through guaranteed observing time related to instrument development. The array of telescopes exploited spans the full electromagnetic spectrum and includes space- and ground-based facilities.

- Observing time awarded on NASA's Great Observatories over the course of the review period includes 579 orbits on the Hubble Space Telescope (*Schady, Scowcroft, Villforth, Wuyts*), 290 hours on the Spitzer Space Telescope (*Schady, Scowcroft*) and 25 hours on the Chandra X-ray Observatory (*Laskar, Schady*).
- Among optical/near-infrared facilities operated by the European Southern Observatory (ESO), 2033 hours of VLT 8-metre telescope time were allocated during the assessment period (*Schady, Villforth, Wuyts*), and 1700 hours on ESO's 2-4 metre class telescopes (*MPG/ESO, NTT, VISTA: Laskar, Schady*).
- Observations at millimetre wavelengths with ESO/ALMA (60 hours, *Schady, Wuyts*) and ESO/APEX (87 hours, *Schady*) were complemented with an allocation of 1320 hours on the IRAM/30m single-dish and IRAM/NOEMA millimetre array (*Schady, Wuyts*),
- Radio observations, mostly of a time sensitive nature, have been carried out for a total of 254 hours with the NRAO Very Large Array in New Mexico, 272 hours with ATCA in Australia, and 322 hours using GMRT in India (*Laskar, Mundell, Schady, van Eerten*).
- Wuyts gained privileged access as External Collaborator to the SDSS-IV/MaNGA survey at Apache Point Observatory (10,000 galaxies over 2014-20) and to the Hyper Suprime-Cam Subaru Strategic Program (300 nights using the Japanese 8-metre Subaru telescope).

These observations have critically underpinned the group's research output, with 33 papers published within the assessment period receiving over 100 citations, and 21 papers ranking within the top 1% of most highly cited refereed papers in astronomy for their year of publication (source: ADS Abstract Service).

Researchers in Nanoscience make extensive use of facilities on the research-income-in-kind list: ISIS (*Bending, Salmon, Zeidler*); Diamond (*Ilie, Wolverson*); ILL (*Salmon, Zeidler*); EMFL (*Nogaret*). The total value of the time on these facilities during the assessment period is over £3M. Additional usage of synchrotron and neutron facilities includes: Elettra synchrotron (*Da Como, Ilie*); Advanced Photon Source (*Salmon, Zeidler*); SOLEIL synchrotron (*Wolverson*); Spring-8 (*Salmon, Zeidler*); Laboratoire Leon Brillouin (*Salmon*); BER II – Helmholtz-Zentrum (*Salmon*).

Future plans

The Unit aims to substantially increase its research income over the next five years, to boost PDRA and PGR numbers and to further improve the equipment base. We will target the multidisciplinary priorities of UKRI, through the further development of critical mass in areas that cut across existing groups and disciplines (e.g. in Healthcare and Energy Materials) and by building on the activities and pooled infrastructure of the existing Centres, CNAN and CPPM. Over the last year, the Director of Research has organised sandpits for PIs centred on UKRI and EU priorities, and research days aimed to equip ECRs in particular with the tools to prepare large grant applications. Topics have included: co-funding from corporate bodies, understanding the mechanisms of commercialisation of research, partnering with alumni, moving from the sponsorship of PhD students to becoming stakeholders in research projects.

In Astrophysics, access to recent and upcoming international facilities is critically important, and this has been a key driver in recruitment to the Bath group. In time domain astronomy, *Schady* is a member of the ENGRAVE (follow-up of gravitational wave events) and STARGATE (follow-up of gamma-ray bursts) collaborations, and *Mundell* of the Liverpool Telescope collaboration. In galaxy evolution, *Wuyts* is closely involved in surveys leveraging new instrumentation such as IRAM/NOEMA3D, VLT/MOONS and JWST/CEERS. Looking ahead to the UK's strategic investment in the Rubin Observatory (formerly known as the LSST), the group includes four LSST:UK Affiliate PIs (*Mundell, Scowcroft, Villforth, Wuyts*). Funded by a strategic investment of £500k from the group's start-up package, we will also join the 4MOST consortium, providing full data access rights with data acquisition extending over five years from end 2022. This will exploit the unique capabilities of a new, highly multiplexed fibre spectrograph mounted on, and benefitting from the wide field of view of ESO's VISTA telescope and will enable cutting edge science covering all of the key research themes represented within the group.

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

During the assessment period, category A staff have made important and wide-ranging contributions to the research base, the economy and society through their leadership of national and international programs, advisory role on steering panels and by communicating the significance of Physics research to the public.

Senior appointments. *Mundell*: Chief Scientific Adviser at the Foreign and Commonwealth Office (2018-); STFC Council (2015-18). *Knight*: Fellow of the Royal Society (2019). *Walker:* Chair of UK Energy Research Centre's Solar Commission (2019); interdisciplinary advisor on REF2021 subpanel 9 (2018-).

Prizes, Awards & Fellowships. *Birks & Knight*: Rank Prize for Optoelectronics (2018); *Bowman:* Royal Commission for the Exhibition of 1851 Fellowship (2015-18), Royal Society URF

(2018-), IoP Clifford Paterson Medal and Prize (2018); *Dale:* Royal Society URF (2017-); *van Eerten*: Alexander von Humboldt Postdoctoral Fellowship (2013-16); *Knight* (2019) & *Wuyts* (2017): Chinese Academy of Sciences President's International Fellowship for Distinguished Scientists; *Mucha-Kruczynski*: IoP James Clerk Maxwell Medal (2017); *Mundell*: Everywoman in Technology Woman of the Year Award (2016); *Nunn*: Royal Society URF (2013-19); *Salmon & Zeidler*: Gordon S Fulcher Distinguished Scholar Award, Corning Inc (2016-17); *Schady:* Sofia Kovalewskaja award of the Alexander von Humboldt Foundation (2012-18); *Stone:* EPSRC UKRI Innovation Fellowship (2018-21), KTP Best of the Best Engineering Excellence award (2015); *Valev:* Royal Society URF (2014-22); *Wuyts:* Web of Science Highly Cited Researchers List (2019-20); *Zeidler:* Royal Society Dorothy Hodgkin Fellowship (2015-20), IoP/RSC BTM Willis Prize (2014), Sir Alastair Pilkington Award, Society of Glass Technology (2016).

Major research consortia

Collaboration is essential to the vitality and visibility of our research: 70% of our submitted outputs have international collaborators and a further 19% a national collaborator. Senior academics are supported to lead major research consortia, and ECRs are encouraged to join consortia with a view to lead one. Many of the funded programs highlighted below are highly interdisciplinary, particularly those involving *Nogaret, Stone* and *Walker*.

Leadership. *Gorbach:* PI of EU-funded LIMACONA network, investigating light-matter coupling in composite nanostructures (9 institutions, 2013-16, €250k)**;** *Nogaret:* PI of EU-funded CResPace consortium for developing adaptive bioelectronics (8 academic and industrial partners, 2017-22, €4.9M)**;** *Skryabin:* PI of EU-funded MICROCOMB ITN in optical frequency combs in microresonators (16 institutions, 2019-22, €4.0M)**;** *Walker:* PI of EU-funded MAESTRO ITN on the exploitation of perovskite materials in solar power and efficient lighting (17 partners, 2017-21, €3.8M)**,** PI of EU-funded collaboration EXTMOS on organic device modelling (12 partners, 2105-19, €5.0M)**,** PI of EU-funded DESTINY ITN on stable dye-sensitized solar cells (11 partners, 2012-16, €3.8M). *Bending* and *Walker* are co-leads of two CDTs (see section 2).

Membership. *van Eerten***:** EU-funded AHEAD2020 consortium in High Energy Astrophysics (2020-24); *Mundell, Scowcroft, Villforth, Wuyts:* Affiliate PIs for LSST; *Schady:* ENGRAVE collaboration on optical follow-up of gravitational wave events (2018-), STARGATE collaboration on optical follow-up of gamma-ray bursts (2018-), THESEUS consortium developing space telescope mission for ESA (2017-); *Wuyts:* IRAM-funded PHIBSS project (2012-18), KMOS^{3D} team (2012-19), MOONS science team (2018-20); NASA-funded CANDELS project (2009-19). *Bending:* EPSRC-funded critical mass SFM consortium on superconductor / ferromagnetic heterostructures (2012-16); *Birks:* EU-funded OPTICON consortium on optical fibres for astronomical instrumentation (2013-20); *Blondel:* Co-chair of the Arctic Acoustic Environments group of the International Quiet Ocean Experiment (2107-20); *Brook:* Work package lead for ERC and STFC funded TORCH collaboration, developing detectors for the LHC upgrade (2012-); *Mosley, Nunn:* Quantum Technologies Hubs for Networked Quantum Information Technologies (workpackage lead on photonics, 2014-19) and Quantum Computation and Simulation (2019-24); *Nunn:* EU-funded QCUMbER consortium on ultrashort light pulses and pulse trains (2015-18), EU-funded COST action on nanoscale quantum optics (2014-18); *Skryabin:* EU-funded RISE project Soliring (2016-18); *Stone, Birks, Knight:* EPSRC-funded PROTEUS collaboration on optical fibres for medical devices (2013-22); *Walker:* EU-funded EoCoE collaboration on the production, storage and management of clean energy (2015-21), EPSRC-funded Supergen Solar Network and SUPERSOLAR solar energy hub.

Contributions to the economy and society

Engagement with industry and third sector organisations is a core part of the Unit's impact strategy, leading to the submitted case studies and the burgeoning examples of impact

discussed in section 1. In addition, academics are engaged in a wide range of translational projects through CASE studentships, consultancies and industrial funding.

Bending: Oxford Instruments Plasma Technology (supporting a CDT studentship); *Blondel:* NPL (PhD funding 2020-23); DSTL, AWE (iCASE PhD funding 2019-23); *Bowman:* Tech for Trade (UK based charity producing and trialling microscopes in Nairobi); *Mosley:* Chronos Technology Ltd and TMD Technologies Ltd, collaboration to develop compact atomic clocks (2015-date); *Mucha-Kruczynski*: CheckRisk Ltd, a Bath-based SME, funds a PhD studentship on analysing stock market crashes as critical transitions in complex systems; *Nogaret:* Chiesi Ltd funded three consultancies and a £140k project on microfluid chips; *Nunn:* Co-founder and Chief Technology Officer of ORCA Computing, a start-up company based on noise-free quantum memory technology and aimed at building a platform for photonic quantum computing (funding: £650k in venture capital and £1M from InnovateUK); *Salmon:* funding for PhD studentships from AWE (2015-19), ILL (2013-16), ISIS/Diamond (2016-19), Corning Inc (2019-22); *Valev* & *Wolverson:* Collaborative project with Renishaw (2019-23), including iCASE studentship and donation of a Raman microscope (~£200k); *Wadsworth:* Spectrum Technologies (CASE studentship), NPL (funded metrology project).

Public engagement

The Unit has greatly increased its public engagement activities since REF2014 thanks to the appointment of a research promotion champion (*Valev*) and an Ogden Outreach Fellow (*Emma Osborne*) to promote the uptake of Physics by under-represented groups in secondary education.

Public exhibitions: Royal Society Summer Science Exhibition, 2016 (*Mosley & Wadsworth*), 2019 (*Bowman & Dale*); Bath Taps into Science, annually (*Bowman, Dale, Mosley, Wadsworth, Valev*); School Physicist of the Year Awards 2017 (*Bending*); WeTheCurious, Bristol, 2018 (*Blondel*); Quantum Technology Showcase, 2015 (*Nunn*).

Talks, broadcasts, articles: 16 academics have been invited to deliver public talks about their research. Venues include Bath Royal Literary and Scientific Institution, Pint of Science and other festivals, Institute of Physics. *Mundell* featured on BBC Radio 4's *A History of Ideas* in 2018, discussing the Big Bang; *Walker* presented a TEDx talk in 2014 on organic light emitting diodes and photovoltaic devices. *Blondel, Clark, Mosley, Mundell, Nogaret, Scowcroft, Valev, Walker* and *Wuyts* have contributed articles to The Conversation; *Mundell*'s 12 articles have attracted 1.19M page views.

Press releases: Over 35 press releases highlighting the Unit's research have been made, supported by the research promotion champion and the University's communication team. Two highlights are:

- "Bloodless revolution in diabetes monitoring**"** was based on Ilie's *Nature Nanotechnology* **13**, 504, (2018) paper. It was picked up by over 340 news organisations worldwide, Ilie was interviewed on BBC Radio 4's *Today* and the research was featured on the news feed of the EPSRC and MRC. The paper has an Altmetric score of 1092.
- "World first as artificial neurons developed to cure chronic diseases" was based on *Nogaret's Nature Communications* **10**, 5309, (2019) paper. It was picked up by over 615 news organisations worldwide, with a potential audience reach of 1.6bn, and an Advertising Equivalent Value of £14.8M. Broadcast highlights included interviews on BBC Radio 4, BBC Radio 2, BBC World Service and Australia's ABC. The paper has an Altmetric score of 1384.

Outreach to schools and educational projects:

- Since 2016 *Valev* has led an outreach programme based on his research in photonics and metamaterials and supported by the Royal Society, STFC, Thorlabs, Zeiss and Edmund. 56 workshops have been run with year 5 and 6 pupils in local primary schools; over 1500 children have participated. 16 PhD students have been involved in delivering the workshops, along with *Rusimova* and *Zeidler. Valev* received the Vice-Chancellor's Award for Public Engagement with Research in recognition of this work (2018).
- *Takashina* leads a project on the propulsion of Leidenfrost droplets on structured surfaces. With MPhys students, he produced videos (released in Autumn 2013) of water droplets travelling uphill and around the “Leidenfrost maze”, a demonstrator designed for public engagement. These were featured on Science Friday’s YouTube (2.8M views, >1300 comments) and Facebook channels (6.6M views). The Leidenfrost maze was demonstrated on BBC’s *QI* in 2016.

Membership of advisory groups and grant, fellowship & facility time panels

As discussed in section 3, members of the Unit are encouraged to work with funding organisations and professional bodies to influence policies and forthcoming initiatives, and to join grant, fellowship and facility time panels when the opportunity arises.

Advisory groups. *Bending*: UK Management Committee on EU COST Actions, NanoSC (to 2016), NanoCoHybri (2017-20), Chair of Strategic Advisory Board of EPSRC CDT in Compound Semiconductor Manufacturing (2019-24); *Bird:* EPSRC Strategic Advisory Team on Research Infrastructure (2013-18), Chair of high-level group overseeing EPSRC’s National Research Facilities (2018-); *Blondel:* Scientific Advisory Board for Centre for Innovative Ultrasound Solutions, Norway (2017-20), Management Board for STFC’s Global Network on Sustainability in Space (GNOSIS, 2019-), Underwater Acoustics committee of the British Standards Institute (2012-); *Brook:* League of European Research Universities Deans of Natural Sciences Working Group and a major author of LERU report "The Strength of Collaborative Research for Discovery in Horizon 2020" (2016); *Mundell:* Chair of STFC’s Skills and Engagement Advisory Board (2015-18), UK SKA Oversight Committee (2014-15) and Programme Board (2015-), SKA International Science and Engineering Advisory Committee (2016-); *Salmon:* Member (non-core) of STFC Science Board (2014-17); *Scowcroft:* LSST:UK Executive Group (2017-19); *Walker:* Team Leader, EU Materials Modelling Council (2016-19); *Zeidler:* Society of Glass Technology’s Basic Science and Technology Committee (2015-), International Commission on Glass’ Technical Committee on Diffraction (2019-).

Officers of IoP groups: Superconductivity group (*Bending*, Chair, to 2015); Nonlinear and complex physics group (*Nogaret,* Treasurer, to 2016).

Grant awarding panels: *Andrews* (EPSRC, 2); *Bird* (EPSRC, 9, with 2 as Chair); *Crampin* (EPSRC, 7); *Brook* (Chair of STFC project review panel for GridPP renewal (2015), Canada Foundation of Innovation’s Subatomic Physics Review panels, 3 including one as Chair (2020)); *Mosley* (EPSRC, Royal Society); *Mundell* (ERC Starter and Consolidated Grants 2013-17); *Nogaret* (H2020 Coordination Actions); *Salmon* (ESRF, ISIS, J-PARC); *Schady* (ESO); *Villforth* (Liverpool Telescope (2015-18) and Hubble Space Telescope); *Wadsworth* (Royal Society Newton Fellowships, 2014-20); *Walker* (EPSRC, 8, with 3 as Chair, and EU H2020, 3); *Wuyts* (ESO (3), Chinese Academy of Sciences (2), Subaru telescope (2)); *Zeidler* (Royal Society Newton Fellowship and Newton Exchange Scheme (2017-22), ILL (2019-20)).

Editorial board membership. *Bending* (Physica E Low Dimensional Systems), *Blondel* (Journal of Marine Science and Engineering), *Bowman* (Journal of Open Hardware), *Nogaret* (Scientific

Reports), *Nunn* (EJP Quantum Technology), *Valev* (Proceedings of the Royal Society A), *Walker* (Scientific Reports), *Zeidler* (MRS Bulletin).

Conference organisation. 22 category A staff have participated in the organisation of 84 national and international conferences as members of organising, scientific and programme committees. The University was due to host the National Astronomy Meeting of the Royal Astronomical Society in July 2020; this has been postponed to 2021 because of COVID-19.

Invited talks. Category A staff have given over than 250 invited talks at workshops and conferences; further invitations received since the onset of the COVID-19 pandemic are currently on hold. Highlights include:

van Eerten, 6th Fermi symposium, Washington DC (2016); Gamma-ray bursts in the gravitational era, Yokohama (2019); *Knight*, Optic2015 Taiwan; Asia communications and photonics (2017); *Mundell*, *Plenary* '20 years of Science Diplomacy', World Science Forum, Budapest, (2019); *Plenary* 'The frontiers of knowledge', Congres Futuro, Santiago, Chile (2019); *Nogaret,* RISDA2017, 7th International Symposium on Data Assimilation, Kobe (2017); *Salmon,* 14th international conference on the Physics of non-crystalline solids PNCS-XIV (2015); 8th international conference on borate crystals and melts (2014); *Wolverson,* Energy Materials Nanotechnology, Spain (2015); *Wuyts,* The formation and evolution of exponential disks, Flagstaff (2014); Galactic dynamics in the era of large surveys, Shanghai (2019).