

Institution: University of Surrey
Unit of Assessment: 9 Physics
<p>1. Unit context and structure, research and impact strategy</p> <p>CONTEXT</p> <p>The Department of Physics at the University of Surrey has an exciting, diverse and inclusive environment in which researchers — at all levels from undergraduates to professors — can thrive. We pursue excellence in science, supported by a strong funding base that is aligned with the research strategy of the University, UKRI, European and international funding bodies. We nurture existing talent and attract new high-flyers, working to ensure that all our staff are integral and valued members of the team. We engage with the broader public, promoting our research successes in national and international media, and working with schools and communities to nurture the next generation of physicists. We place diversity and inclusivity at the heart of everything we do.</p> <p>Our research strengths are in five areas: Astrophysics (AP), Nuclear Physics (NP), Photonics and Quantum Sciences (PAQS), Radiation and Medical Physics (RAM), and Soft Matter (SM).</p> <p>We pride ourselves on our ability to connect pure science with technology and to work across the boundaries between disciplines. This is exemplified by the Advanced Technology Institute (ATI) that brings together electronic engineers and physicists to solve grand challenge problems in quantum information, nanotechnology, energy and advanced materials, and by our new Quantum Foundations Centre (QFC) that brings together physicists and mathematicians to tackle fundamental questions at the heart of quantum physics. The QFC hosts the world's first Leverhulme Quantum Biology Doctoral Training Centre (QBDC). The Department is also part of a new interdisciplinary Innovation for Health Centre that leverages our expertise in medical physics, medical imaging and digital health to improve diagnosis, treatment and prevention of disease. We lead the new Research England-funded SME-DTN Doctoral Training Network that will drive a whole new way of running collaborative PhDs with small-to-medium enterprises.</p> <p>The Department is outward facing, with many local, national and international partners. Key partners include the South East Physics Network (SEPnet), the National Physical Laboratory (NPL), the Atomic Weapons Establishment (AWE), the Royal Surrey County Hospital (RSCH) and the Winchester Science Centre and Planetarium (WSC).</p> <p>A key feature of the Department's research is international collaboration. Some 71% of our publications in the REF period were with international co-authors. We are the lead representative for UK users of the ISOLDE experiment at CERN and the FELIX laser. We regularly lead experiments at major nuclear facilities worldwide, including Argonne National Lab, FRIB, TRIUMF and GSI/FAIR. We are members of leading international astronomy programmes, including the LSST/Rubin observatory, S5 survey, DELVE, SMASH and LISA.</p> <p>This document presents the work of all 34 academics and fellows and their research teams in the Surrey Physics Department over the REF2021 period. All of these are submitted to the Physics UOA, except four: Drs Jurewicz and Steer, and Profs McDonald and Razal, who – in line with the interdisciplinary nature of our Department – work at the interface between physics and engineering, and so are entered into the Engineering UOA.</p>

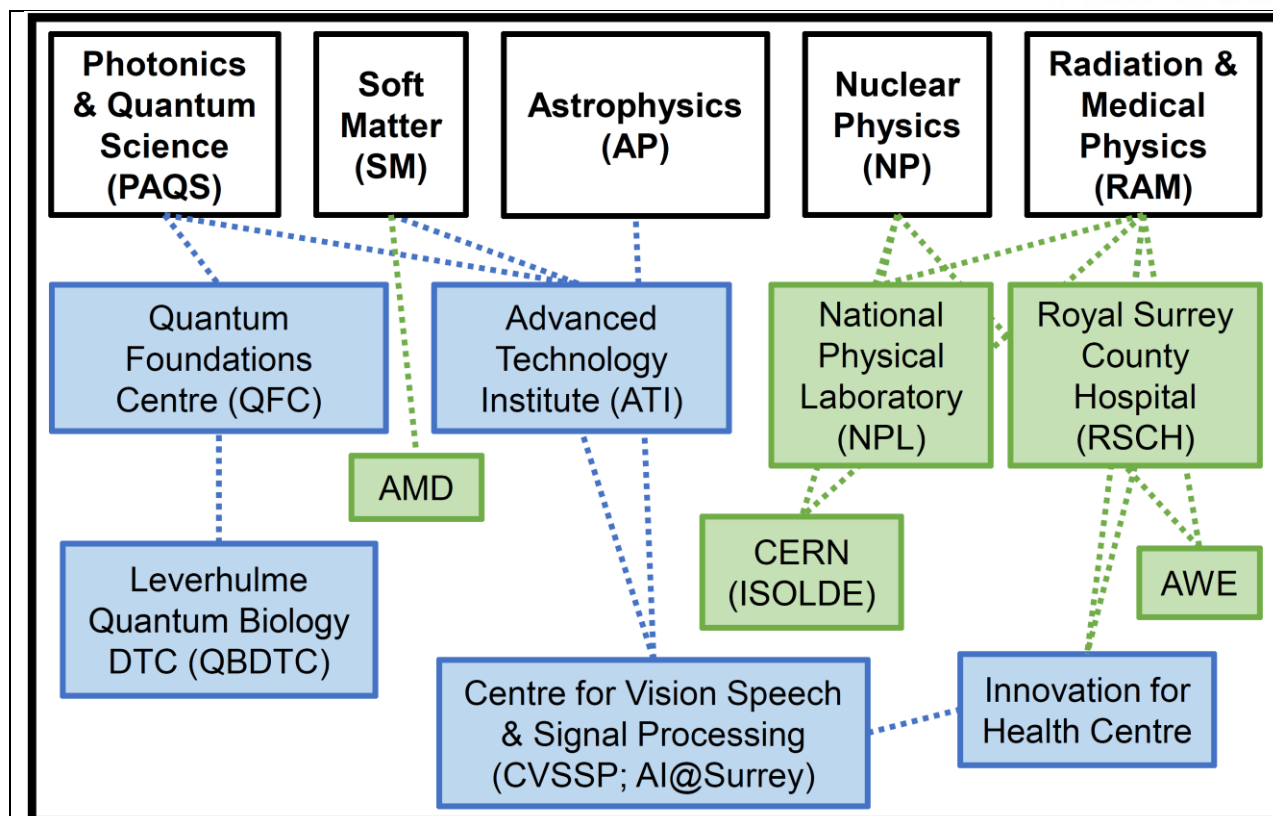


Figure 1: A schematic overview of how research is structured in the Department, showing our key internal (blue) and external (green) partners.

STRUCTURE

Research in the Department of Physics is split across five research groups: Astrophysics (AP), Nuclear Physics (NP), Photonics and Quantum Sciences (PAQS), Radiation and Medical Physics (RAM), and Soft Matter (SM). These connect to three interdisciplinary centres: The Advanced Technology Institute (ATI), the Quantum Foundations Centre and the Innovation for Health Centre, and to our national and international partnerships – see Figure 1.

Photonics and Quantum Sciences (PAQS) (five academics), led by Murdin, is based in the interdisciplinary Advanced Technology Institute (ATI). PAQS research on photonic materials and devices ranges from basic physics through to commercial applications. Topics include THz non-linear optics, silicon quantum technologies, spintronics, and efficient photonic devices, such as photovoltaics and lasers for energy, communications and sensing applications. Sweeney is CTO of ZiNIR Ltd, a photonics SME and has held major commercial projects with Airbus and Huawei. Clowes led a project with Plastipack Ltd that won the IOP Business Innovation Award in 2018.

We are part of the UK's Quantum Technology Hub for Quantum Computing and Simulation. There is a strong emphasis on collaboration with engineers in the ATI, for example on focussed ion beam techniques for nanoscale device fabrication. We recently demonstrated giant THz optical nonlinearities in doped silicon and predicted the highest 3rd order susceptibility for any material at any wavelength.

PAQS led two consecutive EPSRC Programme Grants, COMPASSS and ADDRFS (PI: Murdin, 2010-2022) which have shown THz coherent control of the orbital trajectory around qubits made from silicon impurities and a variety of quantum interference effects needed for gate operations.

Murdin is the Director of the EPSRC (NRF) for THz lasers (FELIX) in the Netherlands, making Surrey one of only two Universities to lead two EPSRC NRFs.

Soft Matter (SM) (five academics and a Vice-Chancellor's Fellow) led by Sear, specialises in fundamental soft matter research with real-world applications. Examples range from applying cutting edge nanotechnology to develop strain sensors for biomedical applications (2014 paper cited over 500 times), to reducing the environmental impact of cement manufacture. Cement is responsible for an estimated 8% of global CO₂ emissions. In each case, we lead an international and interdisciplinary collaboration, publish highly cited work, and work closely with industrial partners. Industry co-funded eight PhD students during the period. SM is a partner in Innovandi, the dominant global network in cement research; of the five largest cement manufacturers in the world, four are in Innovandi.

Research on colloid stratification, which grew out of a €2.1 million FP7 SME project (BARRIER-PLUS) led by the Group, has achieved both academic impact (75 citations) and is being exploited in collaboration with a leading coatings manufacturer (Allnex). Discoveries were presented by Keddie in the 2017 RSC/SCI Graham Lecture. The group leads one EU Innovative Training Network (ITN) (ERICA) and is a member of another (RAMP).

During the period, the Group has built a tissue engineering and bio-sensing collaboration together with both Surrey's new and expanding School of Veterinary Medicine, and the SME Advanced Material Development Ltd (AMD). This was recognised by the group's Dr Jurewicz and AMD being awarded a £1.6 million Future Leaders Fellowship (FLF). The appointment of the Vice-Chancellor's Fellow Prof Razal (Deakin University, Australia) has strengthened the Group and brings complementary expertise in nanofibres and 2D materials, such as MXenes.

Astrophysics (AP) (seven academics/fellows), led by Gualandris, was established in 2013. The Group's research focuses on objects and phenomena at all scales in the Universe, from individual stars and stellar populations to star clusters, supermassive black holes and gravitational waves, nearby galaxies, and the Universe as a whole. A key novel aspect of the group is the overlapping interests between each faculty member that allows for exciting new work to flourish. Examples include a solution of the "final parsec problem" for merging supermassive black holes, a novel probe of the inner dark matter density of the smallest galaxies in the Universe, and the first evidence for an "intermediate mass black hole" in the nearby Large Magellanic Cloud. Read's work on dark matter and near-field cosmology has recently been recognised by a prestigious Simons Foundation Lecture and his election as a foreign fellow of the Royal Physiographic Society of Lund in Sweden, one of only 13 worldwide.

The original group was formed to apply state-of-the-art numerical techniques to solve key problems in astrophysics. Several strategic appointments over the REF period have grown the group to consolidate strengths in near-field cosmology and galactic archaeology (Erkal, appointed in 2016 and Das, appointed in 2020), to provide a new strength in stellar physics, with associated links to the nuclear physics group (Izzard, 2016), and to grow a new observational astrophysics activity (Collins and Noël, 2014 and 2016, respectively). With the arrival of a prestigious UKRI Future Leader Fellow, Das, in 2020, the group has also gained new expertise in machine learning and data science. This aligns well with Surrey's internationally recognised Centre for Vision, Speech and Signal Processing and its new AI@Surrey initiative.

Nuclear Physics (NP) (12 academics/fellows), led by Catford (experiment) and Stevenson (theory), is amongst the largest UK groups in the field (£7.3 million in consolidated grants awarded during the period). The group leads experiments at the world's leading nuclear physics facilities. The experimentalists employ gamma-ray and charged particle spectroscopy using beams of accelerated radioactive ion species to test the limits of nuclear stability, and to measure nuclear reactions that underlie key processes in stars. A recent highlight of this effort has been the series of four Physical Review Letters plus other Letters reporting new ground-breaking measurements of key reactions in stellar nucleosynthesis (carbon and hot-hydrogen burning).

The Surrey NP group undertakes many leadership roles. Podolyak and Regan lead projects in the NuSTAR nuclear structure program at GSI/FAIR, the largest facility in Europe, and Lotay has the largest portfolio of nuclear astrophysics experiments at Canada's world-leading nuclear laboratory, TRIUMF. Catford sits on steering and advisory committees for several European initiatives (PARIS, GRIT, LNL Legnaro, ISOLDE/CERN). The recent recruitment of a prestigious UKRI Future Leaders Fellow, Henderson, brings access to his experimental programme at FRIB in the USA that will confirm Surrey's high profile at this world-leading nuclear laboratory.

Surrey's leadership in theory is evident from the initiatives taken by Barbieri, Rios and others to lead research workshops at key centres in both Europe (ICT Trento) and America (INT Washington). Stevenson is the William Penney Fellow at AWE, consolidating shared interests in nuclear reaction theory. The theorists have expertise in many-body methods for nuclear structure and reaction dynamics, with an emphasis on supporting and guiding experiments in local and worldwide collaborations. The impact of the group's work in theory and in experiment was recognised by the election of Al-Khalili to be a Fellow of the Royal Society in 2018, and the award to Walker of the 2019 Ernest Rutherford medal and prize by the IOP.

Radiation and Medical Physics (RAM) (five academics) is led by Schettino. The group has internationally leading expertise in applied radiation physics. RAM has been instrumental in the development of silica based thermoluminescent dosimetry, leading to the creation of a spinout company (TRUEinvivo) to commercialise this technology for radiotherapy and other applications. The group has been part of the UK's consortium for developing X-ray imaging technology, the HEXITEC (High Energy X-ray Imaging Technology) collaboration, since its inception. HEXITEC partners include both industry, and hospitals including the Royal Surrey County Hospital (RSCH), allowing it to directly bring cutting-edge research results into medical practice.

A major focus of the RAM group is proton therapy for cancer; estimates are that about one in two of us will be diagnosed with cancer during our lives. Proton therapy can deliver very high doses to cancer with greater selectivity than conventional radiotherapy. The RAM group is working with the NHS (UCL Hospital) on proton therapy projects on dosimetry, radiobiology and imaging. The group also works with the Clinical Translational Radiotherapy Group (CTRad, part of the National Cancer Institute) to develop advanced radiotherapy modalities. This includes both more basic research and clinical trials.

RESEARCH AND IMPACT STRATEGY

Our goal is to be world leading in each of our key research areas. To achieve this, we focus on four key themes:

- 1) Building critical mass;
- 2) Growing our innovation pipeline;

3) Public engagement and outreach;

4) Open research with integrity.

1. Building critical mass Achieving “critical mass” in a research means delivering sustained world-leading science. We achieve this through: A) strategic appointments; B) partnerships and interdisciplinary research; and C) attracting and nurturing talented early career researchers (ECRs).

a) Strategic appointments Over the REF period, we have bolstered our strengths in nuclear physics through the appointments of Shenton-Taylor, Diaz-Torres and Doherty, and UKRI FLF Henderson. In medical physics, we have appointed Profs. Schettino and Nutbrown, who are driving forward clinical and pre-clinical work for state-of-the-art personalized radiotherapy – part of the NHS Long Term Plan. In astrophysics, we have appointed Collins, Noël, Erkal, Izzard and UKRI FLF Das. These appointments have cemented our collaborations with AWE (Shenton-Taylor), NPL (Schettino) and RSCH (Nutbrown), opened new partnerships with CERN (Doherty) and CVSSP (Das), and initiated a new collaboration at the interface between the nuclear and astrophysics groups (Izzard).

Over the next five years, we will attract world class fellows and make targeted appointments to further build on these strengths. We will seek new opportunities in applied nuclear physics; we will grow critical mass in our Soft Matter group, leveraging the appointment of Vice-Chancellor Fellow Razal, Jurewicz’s new UKRI FLF grant, and the University’s strategic investment in a state-of-the-art Transmission Electron Microscope (£900,000). Finally, we will grow our strength in photonics and quantum sciences and single atom electronics through a new lectureship in applied quantum technology.

b) Partnerships and interdisciplinary research We recognise that no one university can sustain research at the highest level alone, and so we emphasise research with partners. The highest impact is almost always achieved by working with partners, and so we actively promote this. Much of the most innovative research is interdisciplinary, and so we build on our strengths here.

Over the next five years, we will continue to build on our partnerships with NPL, RSCH and AWE to establish at least one more joint position with these partners. We will seek new partnerships in applied nuclear physics and materials science. We will pitch to continue the success of SEPnet through its extension to SEPnet-IV, evolving and expanding the network to include other STEM subjects. We will further develop the interface between our nuclear and astrophysics groups. And we will work with our partners, NPL, RSCH, CERN/Isolde, CVSSP, the Faculty of Health and Medical Sciences and the new Innovation for Health Centre to support our growing strength in medical physics. Finally, we will further develop our new interdisciplinary Quantum Foundations Centre. Building on our joint appointment with FHMS (Rocco), we will add a joint position with the Maths Department and set up strategic joint PhD positions, using these investments to leverage further funding through research grants.

The Department’s research is inherently interdisciplinary, as demonstrated by our collaborations detailed in Section 4. We support interdisciplinary working via several mechanisms including joint appointments (six in this REF period), and PhD supervision. Twenty-three of our PhD students in this REF period worked in collaboration with an external partner.

Our interdisciplinary research expanded in 2018, when the Leverhulme trust funded the world’s first Leverhulme Quantum Biology Doctoral Training Centre (QBDTC) at Surrey,

co-directed by McFadden (biosciences) and Al-Khalili (physics). To further support this new activity, we made a joint appointment of Rocco (50% physics, 50% biosciences) and set up the new Quantum Foundations Centre within which the QBDTC now sits. The centre crosses disciplines and boasts the UK's first lecturer in quantum biology, Dr Youngchan Kim. This interdisciplinary centre complements the Department's longstanding membership of the Advanced Technology Institute (ATI) in which leading physicists and engineers collaborate to advance quantum information, nanotechnology, energy and advanced materials, and our new Innovation for Health Centre, founded in 2020, that draws together expertise across campus in medicine and digital health.

- c) **Early Career Researchers** are the future of the UK science base and of the Department, so we embrace the need to nurture ECRs.

Over the REF period, we have established Surrey Physics as a prime location for Early Career Researchers (ECRs), as evidenced by our strong track-record of fellowship wins (see Section 4). STFC commended our careers advice and employer engagement in both the 2016 and 2018 validation of our PhD student training. Over the next five years, we will build on our successes to attract and nurture the next generation of diverse scientific leaders. We will organise a yearly "research culture" event to enhance the inclusivity of our research environment, showcase our talented researchers and provide space for new interdisciplinary ideas. We will set up a visitor programme where ECRs can choose leading academics from all over the world to join us on sabbatical, or as visiting faculty. Finally, we will work with our Alumni office and the Daphne Jackson Trust (whom we host within Surrey Physics) to set up a new named Research Fellowship and PhD Scholarship, targeted at talented researchers from under-represented backgrounds.

2. **Growing our innovation pipeline** A key strength of Surrey Physics is our strong ties with industry. Over the REF period, we have developed an end-to-end innovation pipeline, which we call "Physics Minds". This is a one-stop shop for innovation, enterprise and commercial activities in the Physics Department, signposting how we take fundamental research through to innovative products and spinout companies.

Our Research and Innovation Services Team advise academics on the next steps, be it UKRI follow-on funding, Knowledge Exchange grants, Innovation Vouchers, or a direct move to set up a spinout company. We can provide further support through SETsquared, the S100 club and our in-house commercialisation fellowship. We have now set out this pathway both for academics and industry through a new public-facing Physics Minds website. Finally, in 2016 we set up commercialisation training for both staff and PGR students. All our EngD and ITN PGR students gain industrial experience during their PhDs, and in addition about 10% of our PGR students go on a three-month SEPnet industrial placement.

Over the next five years, we will further build on our Physics Minds initiative. We will ensure that all academics have the time, space, information and support to undertake innovation and commercialisation work. We will seek to attract at least two more commercialisation fellows, and we will work to foster existing industrial relationships and grow new ones. We will work towards all PhD students taking commercialisation training and a 3-month industrial placement as part of their course. We will capitalise on our new SME-DTN to build and grow new partnerships and innovation opportunities, with the goal of the network becoming fully self-sustaining by year three. We will continue to be part of the University's annual Research Culture Week.

3. Public engagement and outreach The Department is internationally recognised for our work in science outreach and public engagement. One of our impact case studies is based on our outreach work, in particular that of Al-Khalili OBE FRS (see section 4 for more details). Al-Khalili is a Professor of Physics and Public Engagement with Science and leads on high profile outreach events for both the Department and the University. Within the Department, this includes opening up our annual “Lewis Elton” Departmental lecture to local schools, and drawing-in well-known speakers such as Maggie Aderin-Pocock and Frank Close. In the future, we will further expand the Lewis Elton lecture to the wider public.

The Department has a dedicated Public Engagement and Outreach Manager (Campbell; 50% funded by the Ogden Trust) and hosts the UKRI-STFC Particle and Nuclear Outreach Officer, Cunningham. During the REF period, we set up a new institution-wide collaborative partnership with the Winchester Science Centre and Planetarium (WSC). Over the next five years, we will build on this new collaboration. We will deliver at least two major joint exhibits promoting Surrey physics research, reaching the over 200,000 visitors to the museum a year. We will work together on a further two projects to bring science and the experience of physics research into underrepresented communities. And, we will seek philanthropic funding to set up a new “scientist in residence” position at the interface between Surrey Physics and WSC.

4. Open research with integrity Open research is vital for the reproducibility of scientific results, for maximising the impact of research, and for making our research accessible to all. Wherever possible our research publications are made freely available, via preprint servers such as arXiv, medRxiv or Surrey’s own Surrey Research Insight. This includes all our work relevant to the 2020 viral pandemic, where sharing results as rapidly as possible was vital.

We develop and promote open-source software packages like the `binary_c` and `GravSphere` codes, which both have global user bases. Our open research plans are supported by our in-house research software specialist, Daniel Nemergut. Over the next five years, we will position Surrey Physics at the forefront of open research worldwide. To achieve this, our software specialist will work with the Research and Innovation Services team to deliver training on open research to all staff. This will include best-practice on version control, how to set up online databases for research data, and how to embed code to reproduce figures in research publications.

The University and Department are committed to the UK Government’s Concordat to support research integrity (2012, updated 2019). The University Research Integrity and Governance Office (RIGO) provides guidance on proposals and ethical review submissions, and the Department works closely with the University’s legal department for contracts, consultants and sub-contracts for research partners. The University expanded its efforts over the period with the appointment of a lead for open research and integrity (Prof Emily Farran), and our Vice-Chancellor Prof Max Lu is chairing the Universities UK Forum for Responsible Research Metrics.

2. People

Our staffing strategy has five key strands:

- 1) To strengthen and grow key research areas through targeted appointments;
- 2) To become more diverse and representative;

- 3) To use joint appointments to strengthen collaborations, especially in interdisciplinary research;
- 4) To mentor and nurture staff, developing their careers;
- 5) To develop and support the next generation of scientists.

1. To strengthen and grow key research areas through targeted appointments

Since the beginning of 2014, we have made a total of 16 appointments. Six astrophysicists: Collins, Noel, Erkal, Antonini, Izzard and Das have been appointed to build combined modelling and observation synergy. With the hire of Izzard, we have built collaborative research on novae, between Izzard and Nuclear Physics's Rios. Our new hire Das brings the use of artificial intelligence in astrophysics, in collaboration with Surrey's internationally renowned Centre for Vision, Speech and Signal Processing and its new AI@Surrey initiative.

In nuclear physics, the appointments of Diaz-Torres and Doherty build on our internationally recognised expertise in nuclear reactions. Diaz-Torres works on the theory of fusion reactions (in astrophysics and super-heavy element synthesis) and Doherty on Coulomb excitation experiments (at the new HIE-ISOLDE nuclear physics facility in CERN). Doherty's appointment also strengthens our USA collaborations, including with the new Facility for Rare Isotope Beams (FRIB) in Michigan. The work with FRIB was boosted in autumn 2020 (so after the REF census date) by the arrival of UKRI Future Leader in Henderson.

We have made four collaborative/interdisciplinary appointments in the SM and RAM Groups. Jurewicz was appointed after winning an EPSRC Fellowship to strengthen the group's experimental research, particularly that at the interface with biosciences and the new Vet School. Razal is a Vice-Chancellor's Fellow (0.2 FTE at Surrey), at Deakin University, Australia, who brings an international collaboration to our tissue engineering and biosensing research. Schettino and Nutbrown strengthened our NPL and RSCH collaborations, respectively. They are both joint appointments with these partners.

Thirteen (approximately 1 in 3 of the total) academic staff members held UKRI, Royal Society, Royal Society of Edinburgh or NASA fellowships in the period. The full list of our fellowships is in section 4.

2. To become more diverse representative and inclusive

Women, minorities and groups with protected characteristics all remain underrepresented in UK physics. This means that we are not making full advantage of the talent-pool that we could draw from, and that we are not reflecting society. The Department recognises this problem and actively works to increase diversity and inclusivity in physics. Our strategy includes unconscious bias workshop training (which Physics has chosen to make mandatory for all staff), diverse shortlists at all levels, and an active and engaged Equality, Diversity and Inclusion (ED&I) Committee (work described below). The Department hosts and works with the Daphne Jackson Trust, the UK's leading organisation dedicated to realising the potential of returners to research careers following a career break. Daphne Jackson was the first woman Professor of Physics in the UK, and the first to be Head of a UK Physics Department, both while she was at the University of Surrey.

Our commitment to growing a diverse and inclusive Department is evidenced by five of our eleven academic appointments over the REF period being women, with two being ethnic minorities. Both gender and ethnicity diversity has improved during this REF period. At the REF2014 census date, 9% of research staff (academics and research fellows) in the Department were women, while at

the REF2021 census date this had increased to 31%. We also monitor both job applications and applications for promotion. For promotion, 80% (4/5) of applications by women were successful, a little higher than the 67% (14/21) of applications by men. For job applications to research, and research and teaching positions in the Department, 32% of women applicants were shortlisted and 11% took the job, both higher than the 23% and 7% for men. So, although 23% of the applications were by women, 32% of positions were taken by women. Over the period, the % of staff who identify as BAME has increased from 12 to 26%. During the period 16 of our 34 academics/fellows took parental leave.

To improve diversity at the start of scientific careers, we introduced a *Diversity in Physics* dedicated PhD studentship in 2019, with our 2019 candidate going on to win one of the first IOP Bell-Burnell Graduate Scholarships. We are committed to providing one such studentship every year.

The ED&I committee meets at least once per semester. This is chaired by the Head of Department and has representation from academic staff, undergraduates, PGR students, early career researchers, professional service staff, and technical support staff. The group works to ensure a diverse and inclusive environment that is welcoming to all, arranging training for all staff, PGRs and undergraduates, running events like the recent 'SEPnet Diversity Day', tracking and disseminating diversity data, and developing strategies to further improve.

The Department holds a Juno practitioner award (renewed in 2018) and will be applying for a Juno Champion award in November 2021. While the HoD chairs the EDI Committee to ensure change is enacted, a Juno lead (Gualandris) has been specifically nominated to lead development of the action plan, supported by a dedicated ED&I data lead (Murdin), the HoD and the ED&I committee. Project Juno recognises and rewards positive action to address inequality at all levels and to foster a more inclusive working environment.

The Department actively promotes a diverse and inclusive culture. In our annual ED&I survey, the proportion of women staff agreeing that unsupportive behaviour is not tolerated, has risen monotonically from 40% in 2015 to 95% in 2020, while no BAME staff member has ever disagreed. We ensure ED&I is taken into account in recruitment panels and role advertising. We mandate that all staff involved in recruitment or promotion panels have undertaken unconscious bias training.

The Department encourages staff to take advantage of flexible working for staff with caring responsibilities, providing exceptions to the usual teaching hours. Staff with caring responsibilities can also apply for financial support, e.g. for childcare when making a work trip. In addition, the Department offers a reduced administrative and teaching load to staff returning from parental leave to allow them the opportunity to prioritise their research for at least one academic year. A similar gentle ramp-up of teaching and administration is offered to staff returning from a prolonged illness.

The Department paid considerable regard to ED&I in the construction of the REF2021 submission, with all members of the output selection panel undertaking REF specific equality and diversity training. The output selection panel monitored the gender balance of outputs selected, finding that the number of outputs per female-FTE is a little higher than that per male-FTE.

3. To use joint appointments to strengthen collaborations, especially in interdisciplinary research areas

Throughout the REF period, we have built on and strengthened our collaborations with the Department's three main national partners through joint appointments: the UK's leading metrology

institute, NPL, the UK's lead organisation on nuclear defence and security, AWE, and our local hospital, RSCH. We have also strengthened our growing partnership with AMD Ltd. Dr Jurewicz will move to a 0.2FTE Surrey/0.8FTE AMD position at the start of 2021, meaning we will also have a strong collaboration with a nanotech SME.

Schettino has been appointed as chair of Medical Physics with a joint appointment with the National Physical Laboratory (0.4 FTE). Schettino's appointment strengthens the clinical and medical physics impact of the Radiation and Medical Physics group and initiates new radiation biology activities that link with other Departments within the University of Surrey, including the School of Biomedical Sciences and Chemical and Process Engineering. Regan refreshed his joint appointment with NPL (0.5 FTE) for another five years, winning also a prestigious NPL fellowship. This collaborative work has led to one of our impact case studies.

Shenton-Taylor (RAM group) was appointed Lecturer in Applied Nuclear Physics in 2017, with a research focus on the development of radiation detection within complex environments for nuclear security and environmental applications. This post was fully funded by AWE for the first three years.

Both Sellin (2013-2019, £650k) and Stevenson (2020-) were awarded AWE William Penney Fellowships (WPF). The role of William Penney Fellows is to facilitate academic research collaboration with AWE. During his tenure, Stevenson will grow an exciting new research activity at the nexus of quantum computing and nuclear physics.

The Department, in particular RAM and NP, have longstanding and strong links with the local hospital, Royal Surrey County Hospital (RSCH) (both Prof Andy Nisbet and his replacement, Prof Nutbrown, held/hold a 0.8 FTE position as Head of Medical Physics at RSCH). This supports our Medical Physics research and our interdisciplinary Innovation for Health Centre.

Razal was appointed as a 0.2 FTE VC Fellow in 2019 to work closely with Jurewicz, who with AMD won a £1.6M UKRI Future Leader Fellowship (2020). She will develop our links with this innovative SME to bring nanotechnology for sensor applications to market.

4. To mentor and nurture staff, developing their careers.

We help both researchers and our technicians to develop themselves and their careers at all stages.

- a) Early Career Researchers (ECRs)** We have worked to establish Surrey Physics as a prime location for ECRs, providing a unique package of support and mentoring to develop their careers. This is evidenced by: 1) our strong track-record of personal fellowship wins, hosting two Rutherford Fellowship winners over the grant period (Izzard, Antonini), three UKRI Future Leader Fellows (Das, Henderson, Jurewicz) and a Royal Society of Edinburgh Enterprise Fellow (Steer); and 2) our strong track-record of mentoring these prestigious fellowship holders through to permanent faculty positions, with four out of five of these already holding permanent posts.

Each ECR is assigned a junior and senior mentor within the Department, with additional specialised mentorship where required (for example in public outreach and engagement). The University provides a comprehensive package of training for our ECRs, as recognised by us being shortlisted for a Times Higher 'Outstanding Support for Early Career Researchers' award in 2015. ECRs are represented on all key committees within the Department. We provide all new lecturers with a PhD studentship and we slowly ramp up

their teaching and administrative load over three years to help them establish their new research groups.

- b) Mid-career and established academic staff** Career development of established academics is supported through our Sabbatical Leave Scheme that is an essential feature of the University's commitment to strengthening staff expertise and building new networks and collaborations. Over the REF period, research in Physics has been enhanced through the following sabbatical leaves and (inter)national appointments to other universities/industries: Sellin, (2015), Faux (2016), Keddie (2018), Barbieri (2019), Sweeney (2019), Rios (2020).

These have strengthened both our links with other universities and research labs including Princeton, Wuhan University of Technology, and Los Alamos, and led to funded collaborations with industry, such as Huawei.

- c) Technical Staff** In the REF period, the University signed up to the Technician Commitment, a UK wide initiative endorsed by the IoP to improve career development, recognition and the sustainability of university technicians. The Department has taken a leading role in developing an action plan, and our ability to foster career development is evidenced by the current Faculty technical support manager being promoted from inside the Department.

5. To develop and support the next generation of scientists

- a) PhD student research** In the academic years 2013/14 to 2019/20, we graduated 116 PhD students, an increase of 11 over the preceding REF period. We are part of GRADnet, which brings together the nine leading University physics departments that make up the South-East Physics network (SEPnet), to form the largest Physics postgraduate school in England. The benefits membership of GRADnet brings were noted in STFC's 2016 and 2018 accreditations; they praised the "excellent" opportunities and employer engagement. GRADnet works closely with employers to offer a coordinated and bespoke skills training programme for its students designed to meet the needs of students, employers and University researcher groups alike, building links with other key regional players such as STFC, EPSRC and the Harwell Science & Innovation campus.

New to this REF period are placements for PhD students with companies of all sizes. These are already boosting career prospects. For example, Dr Canavan now works at the SME, Crossfield Fusion, where she undertook her SEPnet placement. The Department's PhD and EngD students also benefit from being part of the University's Doctoral College, which provides transferrable skills and employability training, as well as support such as writing retreats to help with PhD thesis writing.

Collaboration is a key feature of PhD education at Surrey. Twenty-three of the 116 students who graduated in the period were part of funded collaborations, with partners ranging from leading international facilities such as TRIUMF, to the NHS, and multinational companies. We supervise EngD students in Surrey's EPSRC Centre for Doctoral Training in Micro and NanoMaterials and Technology. The Department was also a partner in three EU ITNs over the REF period (TRANSCEND, RAMP and ERICA). In 2018, in collaboration with the School of Biosciences and Medicine, the Department established the world's first Quantum Biology Doctoral Training Centre.

Our future plans will build on our strengths in industry collaboration. We have recently won £370,000 funding from the Research England Development fund to lead a SEPnet doctoral

training network (SME-DTN), to run PhDs in collaboration with Small to Medium Enterprises (SMEs). SMEs often find it challenging to fund studentships on their own, but with the additional support of the network, we will build a cohort of PhD students working in partnership with SMEs to drive exciting new research and innovation.

b) Research by students on undergraduate and postgraduate taught programmes

Students on all our taught courses - BSc, MPhys and MSc - undertake research projects. Over the REF period all three project types have led to publications.

All students in our MPhys programme undertake a year-long research project. The unique feature of Surrey's MPhys programme is that we place most of our undergraduates at external institutions, such as national labs, private companies, or a (typically overseas) university. Example placement locations in the period include Canada's particle and nuclear physics facility, TRIUMF, NPL, the Rutherford Appleton Laboratory, AWE, Texas A&M University, the Australian National University, and Oak Ridge National Laboratory (USA). Over the REF period, our undergraduate and postgraduate taught students have published over 40 articles in leading journals, including a paper in *Physical Review Letters* (2019), that was featured in *The Economist*.

In the period, SEPnet have worked with us to expand our student's research opportunities to include ten-week summer placements. These are funded opportunities with diverse host institutions, from SMEs to the UKRI laboratories. They have benefitted over 97 students during the REF period, and despite the pandemic, we placed 24 students in 2020 alone.

New in this REF period is the Department's Undergraduate Research and Innovation Grant. This provides funding for undergraduate students to attend research conferences, undertake summer research internships, participate in international physics competitions, and kick start innovation projects.

3. Income, infrastructure and facilities

Income

The Department's world-class research is evidenced by grant awards over the REF period that total more than £19.6 million. Our largest funders are UK research councils and The Royal Society (£14.2 million), the EU (£3.0 million), and industry (both UK and international; £1.1 million). This represents approximately £600,000 per academic FTE, over the period.

Our research strategy (see section 1) is to build collaborations, from across campus to international, and to expand interdisciplinary research. The success of this strategy is reflected in a significant increase in our grant income. It is almost £6 million more in this REF period than in the previous period, corresponding to an increase of £100,000/FTE. This includes our nuclear STFC consolidated grants (worth £7.3 million) that are built on international collaborations making use of international facilities.

Our strategy of collaboration is also reflected in our £8.1 million EPSRC Programme Grant, ADDRFS (PI: Murdin, 2010-2022). This is led from Surrey and includes UCL, NPL and international partners such as the free electron laser facility FELIX in The Netherlands. We have also promoted joint fellowship applications, and this resulted in Jurewicz and AMD Ltd winning (in 2020) a prestigious UKRI FLF at AMD Ltd. This will allow her to further develop and bring to market her work on nanotech biosensors.

Part of our research strategy is to build our innovation pipeline. As part of this we have held a total of 24 Impact Acceleration Account (IAA) grants, both EPSRC (19 grants £322,000 2014-2020)

and STFC (5 grants totalling £121,000 2019-2020). These allowed us to perform initial commercial exploration of new ideas, including that one that led to a project with Plastipack Ltd that won the IoP Business Innovation Award 2018. This is one of our impact case studies.

With Dr Steer and Geoptic, we were awarded both a Royal Society of Engineering Enterprise Fellowship, and a 2020 IOP Business Startup Award. Research England awarded us £370,000 to develop a new kind of Doctoral Training Network that will allow Small to Medium Enterprises (SMEs) to partner with Surrey and our other SEPnet partners on joint PhD projects. This network is led from Surrey and builds on our successful Radiation Detection Doctoral (RADnet) network, which we and Sussex lead.

Infrastructure

Laboratory infrastructure: The University has invested £2.1 million in the Department's laboratory facilities and equipment, within the period. This includes upgrading laboratories and equipment, ranging from an Atomic Force Microscope (AFM) to High Purity Germanium detectors for gamma-ray spectroscopy. In addition, we expect to be heavy users of the University's £900,000 Talos F200i Transmission Electron Microscope (TEM) when it arrives early in 2021. The EPSRC proposal for the TEM was led by the Soft Matter Group and engineers in the Faculty. The Advanced Technology Institute, including the Department's PAQS group, won a £2.9 million capital grant for quantum technology equipment including single ion implantation (SIMPLE) from the EPSRC Quantum Technology Capital fund.

Computing infrastructure: The Department is one of the largest users of the University's High Performance Computing (HPC) centre, "Eureka", in which the University and Department has invested £480,000 over the period (£140,000 of this is for the Nuclear and Astrophysics groups). The Department's PAQS group shares the UKRI funded (£300,000) ATI HPC centre. Our Nuclear and Astrophysics Groups also use leading national (DiRAC) and international HPC centres. They were awarded £660,000 worth of time on DiRAC, and 60 million CPU hours at Europe's leading HPC centre PRACE (Partnership for Advanced Computing in Europe). HPC work at Surrey is supported by our in-house Research Software Specialist, Daniel Nemergut. Our success at international resources such as PRACE is based on University investment in Eureka and in research software specialists.

Use of international facilities

International facilities: The Department's PAQS group leads the UK's participation in the Free Electron Lasers for Infrared eXperiments (FELIX) facility. Murdin is the most successful of all external FELIX applicants in terms of beam-time granted. PAQS also makes use of the European Magnetic Field Laboratory (EMFL). In the period, PAQS researchers won a total of £2.3 million worth of time on FELIX and EMFL. Murdin also chairs the Scientific Advisory Committee for the Free Electron Laser at the Helmholtz Zentrum, Dresden (2018-).

The Astrophysics group leads large observational programmes at international facilities, and has secured projects at ESO's Very Large Telescope, the William-Herschel Telescope and the Hubble Space Telescope over the REF period, worth £500,000. Our Nuclear Group used £14.4 million beam time in facilities across the globe, plus substantial time at CERN/ISODLE (budgeted within the UK's CERN subscription).

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

Most of our impact, in all areas from science output to economic and social impact, is achieved via collaboration, and 71% of our outputs in the REF period are with international co-authors. A large part of the Department's national impact is achieved in collaboration with two national facilities, NPL and AWE, and the local hospital, RSCH. Our international collaborations range from agenda setting pure research, to participation in Innovandi, the dominant global network for cement research – see the section describing our research groups in section 1.

Our key partnerships are with:

NPL NPL is the UK's National Metrology Institute. Its mission to develop and maintain national primary measurement standards is well-aligned with many of our research goals in Surrey Physics, particularly in radiation and medical physics, where accurate standards are the bedrock of dosimetry and environmental monitoring. NPL's commitment to our collaboration includes renewing the Regan joint appointment (£312,000 in 2018), the Schettino joint appointment and seven joint NPL/Surrey PhD studentships. The group of our joint appointment, Regan, has national responsibility for traceable measurement of radioactive materials within the UK. This has included work on the development of absolute standards of medical radioisotopes for cancer treatments, and the first US-FDA licensed alpha-emitting radiopharmaceutical, ²²³Ra. This work was recognised by NPL's 2016 Rayleigh Award. In medical physics, there is a three-way collaboration between the RSCH, NPL and the Department, coordinated by Schettino.

The Department's work with NPL is part of the University's long-term strategic partnership with NPL. The University's Vice Chancellor (Lu) sits on NPL's Executive Board, and its Provost (Kearney) sits on NPL's Science and Technology Advisory Council (STAC).

AWE The department has a long-standing and strong research collaboration with the Nuclear Threat Reduction team at AWE. Professor Sellin was an AWE William Penney Fellow (WPF) from 2014 – 2020 (worth £650,000 over 6 years). Recently, Dr Stevenson has won an AWE WPF from 2020 onwards. The role of William Penney Fellows is to facilitate academic research collaboration with AWE scientists. AWE provided funded research year placements (£100,000 per year) each year for our MPhys students. AWE also fully funded the lectureship for Dr Shenton-Taylor from 2016-2019. The department hosts the STFC Nuclear Security Science Network (PI Professor Sellin) which has been funded from 2016 – 2021 (£700,000). The formation of the AWE Centre of Excellence in Materials Ageing, Performance and Life Prediction (CoE in MAP-Life) in 2020, has broadened this collaboration.

Innovandi Our leadership in international cement research is recognised by our participation in both Nanocem (2015-19) and its successor, Innovandi. Nanocem was an international cement-research network of 23 academic and 10 industrial partners. The industrial partners included the largest cement manufacturer in the world, LafargeHolcim, (\$28 billion/year). The Soft Matter Group is now a partner in Innovandi which has expanded beyond Europe to be truly worldwide. Innovandi has 28 industrial partners including four of the world's five largest cement manufacturers.

Deakin University Over the REF period, we have established a new collaboration between our Soft Matter group and Deakin University, Australia, through the appointment of VC Fellow Razal (0.2 FTE, appointed 2019). Razal brings expertise in nanotech applications of fibres and 2D materials, in particular to sensor and energy storage

applications. He is already co-supervising PhD students, and we have joint outputs, with even greater opportunities for collaboration scheduled once the COVID-19 situation is resolved.

FELIX Murdin is the Director of the EPSRC National Research Facility beamlines at the Free Electron Laser FELIX (Nijmegen NL). He has coordinated the last four Statements of Need on behalf of the community with unbroken funding since the inception of the scheme (most recently submitted Nov 2020 for 2022-2026, £2.6 million). In the current REF period two new beamlines have been funded (one with Murdin PI for millikelvin experiments and one led by Lancaster).

International nuclear/accelerator facilities Podolyak and Regan of the nuclear Physics group have leadership roles at the nuclear structure program at GSI/FAIR, the largest facility in Europe, and Lotay has the largest portfolio of nuclear astrophysics experiments accepted at Canada's world-leading nuclear laboratory, TRIUMF. Regan sits on the international programme advisory panel at CNRS IPN-Orsay in France, while Catford sits on the equivalent at INFN Legnaro in Italy and was also on the ISOLDE-nTOF advisory committee in CERN. Doherty was elected to be the UK representative for the users group of the ISOLDE experiment at CERN and has played a leading role in consolidating the Surrey position at CERN/ISOLDE. The management of the USA's premier new laboratory for radioactive beam research (FRIB in Michigan) has strongly supported and encouraged the Surrey group's initiative led by Lotay to design and install the infrastructure (known as DRACULA) for measuring nucleon transfer reactions, especially with relevance to nuclear astrophysics, at the new facility.

International partners of the astrophysics group The astrophysics group leads a number of international collaborations, including DELVE-MC (a survey of the faintest and most dark matter dominated galaxies) and EDGE. EDGE is a collaboration with UCL and Lund, Sweden, that uses DiRAC to simulate the smallest galaxies. We are members of PAndAS, the Pan-Andromeda Archaeological Survey of Andromeda, SMASH, the Survey of the Magellanic Clouds and LISA, the space based gravitational wave mission aimed at detecting supermassive black holes. AP staff also lead their own in-house observation and numerical simulation campaigns, including a deep survey of nearby dwarf galaxies, WIGS (PI Collins). The group also develops and publicly releases key community software packages, including the GravSphere mass modelling tool, and the binary_c stellar evolution code.

Contribution to the economy and society

We work with companies of all sizes. PAQS has collaborations with leading electronics multinationals such as Huawei, and SM with AkzoNobel, one of the largest coating companies in the world. We also work with companies via international networks such as Innovandi. We also work with SMEs. Two examples of SMEs we work with are TRUEinvivo and Plastipack. TRUEinvivo is a spin out company making dosimeters for clinical trials. Clinical teams use TRUEinvivo's DOSEmapper™ bead array detectors to measure directly the actual radiation doses received at a tumour during radiotherapy.

Plastipack is a world leader in innovative swimming pool cover technology. Working in close collaboration with Plastipack, Surrey's research has led to the successful development of polymer-based materials for increased efficiency in solar heating of swimming pools, while preventing the growth of algae. This has led to a substantial increase in revenue for the company (EnergyGuard product sales increased fourfold since launch of Surrey developed formula). The work was

recognised by an Institute of Physics Business Innovation award (2018). This is one of the three impact case studies for this UOA.

Members of the Department also contribute to research of great impact to society, such as the radiotherapy treatment of cancer. Here we work with NPL. Primary standards of radioactive material provide the ultimate traceability for calibrations of dose, which underpin the safe application of the radiopharmaceuticals to the treatment of cancer. Regan (Surrey/NPL) and co-workers recalibrated the radiological standard for Xofigo® (which relies on radium-223), the first of a family of alpha-particle emitting radiopharmaceuticals for the treatment of secondary prostate cancer. This work followed on from concerning discrepancies in the original radiological standard. Together with research at the US-based National Institute for Standards and Technology (NIST), this work led directly to the worldwide resetting of clinical-based calibration factors which are required for the accurate dose administration of this drug. This is one of the three impact case studies for this UOA.

Engagement with the public

The Physics department is at the forefront of the University's outreach and public engagement programmes. One of the three impact case studies for this UOA is based on our work here. Our goals in undertaking public outreach work are to: promote physics as a subject and career to diverse communities, particularly those with low science capital; to publicise, promote and explain our publicly funded research; and to grow a diverse and inclusive physics ecosystem.

We have a dedicated in-house Public Engagement and Outreach Manager (Campbell; 50% funded by an Ogden Trust grant) who leads our outreach engagement activities. We also host the UKRI-STFC Particle and Nuclear Outreach Officer, Cunningham. Our regular outreach activities include monthly stargazing evenings at our teaching and outreach telescope that are always at capacity (~100 people), summer schools and Masterclasses, yearly special events and school outreach programmes. Our monthly outreach events showcase edge research from all of our groups through public lectures and live demonstrations (including in-house interactive software like Izzard's "Window to the Stars").

Our researchers regularly speak at local clubs, societies and events, including Pint of Science, Cafe Scientifique, Institute of Physics events and international events. In 2019, we celebrated *World Space Week* by transforming Guildford's high street into a physics exhibition space, reaching more than 3000 members of the public – 18% of whom had never been to a science event before. We also hosted astronaut Dr Michael Foale to mark the 50th anniversary of the moon landings, and in 2018 we exhibited at the Royal Society Summer Science Exhibition as part of the Gaia collaboration.

During the REF period, we set up a new partnership between Surrey and the Winchester Science Centre (WSC). WSC attracts 200,000 visitors per year, including both families and organised school groups. This partnership has the goals of sparking curiosity in children, families and the broader community in Science, Technology, Engineering and Maths (STEM), promoting the value, opportunities and careers of STEM subjects to all, and raising the awareness of cutting-edge research conducted by the University and its partner institutions. Over the next five years, we will put on new collaborative exhibits at WSC, provide public-speaking and communication opportunities and training to our PGR students and ECRs; and set up new initiatives to bring STEM subjects into communities with low science capital in the South East and London. The first such exhibit, "Physicists Like Us" promotes the rich variety of physics and physics careers both historically and today. It will go up at both WSC and the Physics Department in early 2021.

Most interactions with the Department will start with our website. As such, in the REF period we worked to increase our online presence. This includes a new website with regularly updated research content, an active Departmental Twitter account (@PhysicsatSurrey) that has grown to over 1,700 followers, and new science page contributions to Wikipedia (one of the top ten websites in the world by traffic). Between the pages edited by staff and those by our BSc students, we estimate that every month, pages substantially edited by members of the Department are read by tens of thousands of visitors. Wikipedia's page on "Nucleation" alone has over 120,000 page views/year.

The Department's Al-Khalili OBE FRS is one of the UK's best-known science communicators. Over the REF period, he has presented six TV documentary series on topics from AI to gravity, and 170 radio programmes. The radio programmes include *The Life Scientific*, which has over two million listeners a week on BBC Radio 4.

Al-Khalili also writes highly successful popular science books that have been translated into over 26 languages. His book "*Life on the Edge*" was shortlisted for the Royal Society Winton Book Prize in 2015, while his book "*The World According to Physics*", was shortlisted for a Royal Society Science Book Prize in 2020. Al-Khalili's TED talk has been viewed over three million times on YouTube, and he has given over 80 GCSE Science Live talks, each to approximately two thousand students near the point of considering doing science A levels. Al-Khalili's work has received many awards including the prestigious Royal Society Wilkins-Bernal-Medawar Medal and Lecture (2020) "for his exceptional work in explaining complex ideas in modern physics in an approachable way", and the Stephen Hawking Medal for Science Communication in 2016.

Wider influence, contribution to and recognition by the research base

Fellowships

The Department's Al-Khalili was elected a Fellow of the Royal Society in 2018 and was awarded an Honorary Fellowship of the Institute of Physics in 2019. Walker was awarded the 2019 Ernest Rutherford medal and prize by the IOP. Al-Khalili was chosen as one of EPSRC's ten RISE Leaders in science and engineering. In 2020, he won a prestigious Royal Society Wilkins-Bernal-Medawar Medal and Lecture.

In the period, thirteen (approximately 1 in 3 of the total) academic staff members held UKRI, Royal Society, Royal Society of Edinburgh or NASA fellowships: Antonini (STFC Rutherford Fellowship 2018-2023), Collins (Hubble Fellow - awarded 2014 while at Yale by NASA), Gieles (RS, 2009-2014), Ginossar (EPSRC 2012-2015), Izzard (STFC Rutherford Fellowship, 2015-2020), Jurewicz (EPSRC, 2013-2016), Lotay (STFC Rutherford 2012-2017), Murdin (RS Wolfson Merit Award, 2012-16), Rios (STFC 2011-2016), Sweeney (EPSRC Leadership, 2010-2015), Steer (RSE Enterprise Fellow, 2019-2020), Das (UKRI Future Leader Fellowship, 2020-2024) and Henderson (UKRI Future Leader Fellowship, 2020-2024). In addition, STFC funds Timofeyuk as a Senior Research Fellow.

Grant committees and Invited keynote talks

We play our part in the grant assessment, both via peer review and by sitting on grant committees. A majority (55%) of our academics sat on one or more grant committees in the period. We also contribute to the community through peer review of publications. Our Emeritus Professor Walker has recently been recognised as an Outstanding Referee by the American Physical Society.

On average each academic gave approximately six keynote or plenary talks, at international conferences, during the period. Our academics have also organised and chaired national and

international conferences during the period, some of which we have also hosted, such as the 24th European Conference on Few-Body Problems in Physics.