**Institution:** University of the West of Scotland

**Unit of Assessment:** 9: Physics

## Section 1: Unit context and structure, research and impact strategy

### 1.1 Context and structure

The Physics subject group sits within the School of Computing, Engineering and Physical Sciences (CEPS) and its research is structured into: (1) Experimental Nuclear Physics Research Group (ENPRG) and (2) Institute for Thin Films, Sensors and Imaging (ITFSI). UWS physics community has over the current REF period developed concentrated world-class research capabilities, including our:

- significant contribution to the Laser Interferometer Gravitational-Wave Observatory (LIGO) large-scale physics experiment),
- significant contribution within the UK and international Nuclear and Particle Physics Community,
- substantial commercialisation capabilities with award-winning spin-out development in the area of functional thin films,
- Continuously publishing in highly-recognised journals, including Physical Review Letters, Applied Optics, Nature Physics, and Classical and Quantum Gravity.

These achievements have resulted from:

- large investments focused on creating scalable and signature research capabilities, including the new GBP12,000,00 ITFSI laboratories that are home to a unique suite of 9 thin film deposition methods using specialist and tailor-made equipment, and,
- exemplary collaboration between Scottish Physics departments within SUPA (i.e., SUPA began in 2005 with UWS being one of the six founding members and over the past 15 years, the alliance has provided collaborative funding, networking, and PhD student training opportunities through a strong inter-institution Graduate School, offering access to a pan-Scottish development curriculum).

### 1.2 Research objectives

#### 1.2.1 Current REF period: Review of REF2014 objectives

In this REF period, physics has been firmly positioned as the leading area of research focus for UWS, exemplified by (1) physics strengthening through the School 2015 to 2020 Research & Enterprise Strategy that was developed by the then Assistant Dean Research & Enterprise who has since taken the position of Vice-Principal Research, Innovation & Engagement (VPRIE) and more recently by a new GBP12,000,000 ITFSI laboratory, formally opened by Scotland's Chief Scientific Adviser, Professor Sheila Rowan, in 2020 jointly with the UWS Principal and VPRIE.

**Institute of Thin Films, Sensors and Imaging (ITFSI)**

The UWS' flagship Institute was formed in 2014 from two earlier research groups: the Thin Film Centre and the Microscale Sensors Research Group. ITFSI research covers a range of areas in thin films, sensors and imaging. The key objective was an increased involvement in gravitational wave research, based on the improved understanding of the performance of thin-film mirror coatings. This work has significantly expanded since 2014, developing three new thin-film plasma-based deposition technologies with funding support from a Science and Technology Facilities Council (STFC) Consolidated Grant (**Reid** and **Gibson**) with results from this work having been published in journals such as Physical Review Letters, Applied Optics, and Classical and Quantum Gravity.

ITFSI research is conducted in partnership with the Institute of Gravitational Research at the University of Glasgow and other UK and international academic partners. Work in gravitational-wave research has been stimulated by first observation of gravitational waves in 2015 by the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration, of which UWS (**Gibson)** is a member. Our research and development has a specific focus on next generation optical coatings

utilised within LIGO interferometer mirrors. ITFSI research has pioneered new plasma assisted deposition of thin films, producing the most stable amorphous structure of pure $Ta_2O_5$ reported at room temperature and the world's lowest optical absorption amorphous silicon for use in multilayer optical thin film mirrors deployed in laser interferometric gravitational wave detection. In addition, the use of hydrogenated microwave plasma assisted sputtering based on ITFSI research is a world first for optical thin films produced using room temperature sputter based deposition processes, providing high throughput compared to currently used processes. The resulting plasma assist deposition intellectual property (IP) being protected via four patents, covering process variants and associated applications and is being commercialised through the spin-out company Albasense Ltd (www.albasense.com).

Our plasma-assisted optical thin film deposition technology is being used at the Laboratory for Laser Energetics, Rochester University, USA, for the deposition of optical thin films utilised in the laser optics. Also in the USA, the technology is being used in laser inertial confinement fusion development at the Lawrence Livermore facilities. Access to our facilities has enabled the partnership with Glenrothes-based semi-conductor foundry Semefab Ltd that has used our novel thin film technology, leading to improved performance of infrared detectors embedded in non-contact thermometers, receiving orders for more than 12,000,000 chips during the COVID-19 pandemic. Another example involves commercial exploitation of UWS research by Helia Photonics Ltd of patented plasma-assisted deposition technology for which this KTP was recognised in winning the Centre for Engineering Education and Development's (CEED) Knowledge Exchange Award 2020.

Together with the Universities of Glasgow and Strathclyde, ITFSI is a founding partner in the National Manufacturing Institute Scotland (NMIS) with a sponsored project Excellent Performance Optical Coatings valued at GBP2,000,000. This facility provides world-class capabilities in ion-beam-sputtered optical coatings for gravitational waves research and industrial use. In the assessment period, ITFSI has published 97 peer reviewed publications, generated five patents and secured GBP3,500,000 funding, (STFC, Royal Society, Innovate UK, Scottish Enterprise, Royal Society of Engineering, SRPe) a 60% increase since REF2014, along with six KTPs.

In response to industry demand from research partners and collaborators, ITFSI created in 2017 a new PGT programme in Advanced Thin Film Technologies. In partnership with Changchun University of Science and Technology, China, ITFSI established a joint undergraduate optoelectronics programme at which **Gibson** is an adjunct professor. Other collaborations include Tong Ji University (Shanghai), Fudan University (Shanghai), Rochester University Laboratory for Laser Energetics, Stanford University (California) and UK-based universities including Glasgow, Strathclyde, St Andrews, Lancaster, Birmingham, and Cambridge. Extensive industrial collaborators include Qioptiq, Teer Coatings, Helia Photonics, Wideblue, Gas Sensing Solutions, Novosound, Leonardo, Thales, Integrated Graphene, Pyreos, Alphasense, Key FM, CST Global, Umicore Coating Services, Gooch & Housego, and Rolls Royce.

ITFSI has also created two spin-out companies. With a GBP5,000,000 investment and employing 30 staff, Novosound Limited (www.novosound.net) is aimed at commercialising patented thin-film based ultrasonic transducers. Albasense Ltd is progressing patented ultralow power consumption photonic-based methane sensors, originating from our research in photosensitive IV-VI thin films. It has secured a GBP500,000 contract with US company Gasclip Technologies Inc. for prototype development with projected sales of GBP4,000,000.

ITFSI comprises seven full-time staff: one professor (**Gibson**), two readers (**Morozov** and **Song**) and four lecturers (**Birney, García Núñez, Hutson** and **Meeten**). There are currently ten externally funded PhD students. The current research themes include:

- gravitational waves (**Gibson, Birney** and **García Núñez**)
- non-dispersive infrared gas sensors (**Gibson** and **Hutson**)
- nano-structure sensors (**García Núñez** and **Gibson**)
- hyperspectral imaging (**Song** and **Gibson**)
- plasma sources (**Gibson**)
- ultrasonic imaging (**Hutson, Gibson** and **García Núñez**)

- batteries (**Gibson**)
- energy harvesting (**García Núñez** and **Gibson**),
- IV-VI photo responsive thin films (**Gibson** and **García Nunez**),
- Modelling and simulation for ITFSI research (**Gibson, Song** and **García Núñez**)
- photonics modelling (**Morozov** and **Meeten**)

**Experimental Nuclear Physics Research Group (ENPRG)**
Staff submitted to REF2021 as part of ENPRG in UOA9 were submitted to UOA15: General Engineering in REF2014. Over the review period, we have reinvigorated the group with three research-active staff recently appointed and all submitted to REF2021, which has led to the increase from to five staff. We have achieved the objectives in our REF2014 submission with some notable expansions. The objectives were: i) to maintain the established research programmes in fundamental Nuclear Physics, exploiting equipment at JYFL (Finland), Argonne (USA), ISOLDE-CERN (Switzerland), ILL-Grenoble (France) and RIKEN (Japan), and ii) to work with collaborators in SUPA to develop research with SCAPA – the Scottish Centre for the Application of Plasma-based Accelerators, with a view to leading a laser-induced Nuclear-Physics programme. Notable changes: research at TRIUMF (**Bowry**) and GSI (**Bondili**) facilities represents our expanding commitment post RIKEN and our research objectives related to SCAPA have importantly changed scope with our research moving from reactions of astrophysical interest (**Spohr**) to lifetime measurements and medical isotope production (**O'Donnell**).

In Nuclear Physics research, our primary objective is to maintain and develop our research programmes in the study of exotic atomic nuclei. The external drivers are strategy documents such as the STFC Nuclear Physics Advisory Panel (NPAP) Roadmap 2019, the Nuclear Physics European Collaboration Committee (NuPECC) Long Range Plan (2017) and the US DOE/NSF Nuclear Science Advisory Committee (NSAC) Long Range Plan (2015). Our research addresses, for example, key questions identified in the STFC NPAP Roadmap: *"What determines the limits of nuclear existence and are there new forms of structure and symmetry at the limits of nuclear binding?"* and *"What mechanism drives the emergence of simple patterns in complex nuclei?"*. We have therefore continued and further strengthened our research at international facilities such as University of Jyväskylä Accelerator Laboratory (JYFL) (Finland), ISOLDE-CERN (Switzerland), Legnaro National Laboratory (Italy), Argonne National Laboratory (USA), ILL Grenoble (France), GSI (Germany), and TRIUMF (Canada). Our research in this area has been continuously funded for more than 25 years by UK research councils (EPSRC and STFC). Our most recently appointed staff (**Bowry** and **Bondili**) carry out experiments at GSI (Germany), NSCL (USA) and TRIUMF (Canada). Over the past five years, we have increased experimental capabilities in our own laboratory at UWS. We now have several different radiation detectors (investment of GBP60,000; **O'Donnell** is leading a programme of measurements of lifetimes of excited states populated in alpha and beta decay, using fast-timing techniques with novel scintillators.

Within the broad area of the study of exotic nuclei, more detailed objectives can be stated in terms of the Physics issues being addressed. Our main areas of interest include:

- Reflection-asymmetric (octupole) deformations (**Smith** and **Scheck**)
- The nuclear dipole response (**Scheck** and **O'Donnell**)
- Lifetime measurements using fast timing techniques (**O'Donnell**)
- Spectroscopy at the proton dripline above $^{100}$Sn (**Smith**)
- Nuclear astrophysics relevant to hydrogen burning and capture (**Bondili**)
- High resolution beta-gamma coincidence spectroscopy of neutron-rich nuclei (**Bowry**)
- Neutron-proton interactions in the A=70 region (**Bondili**)

**1.2.2 Strategy: Next Five Years**
**Vision:** Physics research at UWS is internationally leading in broad areas of functional thin films and experimental nuclear physics. With the synergistic interface between theoretically driven and fundamental in nature ENPRG, and the highly applied and industrially-focussed ITFSI, the aim is to continue developing signature capabilities of strategic importance to tackle global challenges. This vision has already delivered increases in funding, investments, sector-leading increase in

Knowledge Transfer Partnerships (KTP), spin-outs and wider recognition, all in the spirit of long-standing UWS physics tradition dating back to George Y. Haig (physics academic at Paisley Technical College – predecessor to UWS – and inventor of the Haig Mount) and Lewis Fry Richardson (Principal of the Paisley Technical College 1929-40, a pioneer of modern mathematical techniques of weather forecasting). Keeping with the tradition, physics research at UWS will continue its significant contributions to major alliances and networks (SUPA, SCAPA, ISOLDE-CERN, TRIUMF, JYFL, GSI, NSCL, Argonne NL, Legnaro, ILL Grenoble) and expand the volume of activities. In the longer-term, we will include chemists and mathematicians from within the Division and secure theoretical developments (e.g., **Morozov** and **Meeten** are currently developing theoretical models of thin films using both theoretical and practical approaches to real life problems). One area being specifically targeted is novel radiation sensors for the nuclear industry.

**Strategy:** Physics subject group has developed world-class reach and significance in signature areas of research. Over the next assessment period, we will expand the scope of our research to include new facilities and opportunities. Key objectives are:

- to increase research active staff, underpinning world-class signature research across the two research groupings;
- to enhance international standing through grants, collaborations and publications, addressing global challenges;
- to demonstrate exemplary working with industry in knowledge exchange including our own spin-out companies;
- to continue our programme of the study of the structure and properties of exotic nuclei in experiments at international facilities, exploiting new facilities and opportunities;
- to continue our programme of research both at the SCAPA facility, and with our in-house array of radiation detectors;
- to extend the scope of our research by making use of our expertise in radiation detection and measurement in applied or industrial research;
- to continue supplementing our core STFC-funded research programme with funding for applied research from other research councils and from new funding sources;
- to further strengthen overseas research partnerships, spanning academic activity and include the development of joint teaching programmes across all areas of physics.
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Specifically, the following actions are of particular early focus:

- The development of the Advanced Gamma Tracking Array (AGATA), which is being constructed to be the most powerful gamma-ray spectrometer in Europe. UWS is one of four UK partners (with University of York, University of Liverpool, Daresbury Laboratory) to be awarded an STFC Project Grant (GBP810,000) to support the UK development of AGATA, making UWS a key partner.
- Experiments with AGATA and the new radioactive-ion beam facility SPES at Legnaro National Laboratory will be expanded to become a significant part of our programme of research over the next assessment period. In addition, we will expand our international collaboration at other new facilities such as HIE-ISOLDE (CERN, Switzerland), FRIB (USA), FAIR (Germany), and ELI-NP (Romania).
- The two existing and all new spin-out companies are key to utilising company connections to support research-informed teaching through provision of projects, invited talks and site visits, and through this we will make a substantial contribution to the development of future skills, supporting the national clean growth and industrial strategy agendas.

**1.3 Achievement of impact**

Early drivers for the expansion of the SUPA remit were knowledge exchange and impact development. The University extensively supports impact development with a Business Innovation unit that assists staff in intellectual property discovery, protection, and exploitation. This includes working with industry and the development of spin-out companies. The Scottish Enterprise infrastructure provides with access to specific High Growth Business Funding and has led to the formation and on-going development of the two spin-out companies. The open-door-to-industry approach of UWS and ITFSI facilitates the development of productive and beneficial ongoing relationships,

and ITFSI's unique facilities provide a strong foundation to develop strong partnerships.

**1.3.1 Impact Case Studies and Impact Approach**

Focusing on impact at the outset is at the heart of our strategy to develop signature research. The ITFSI research themes are industrially informed primarily through Innovate UK (four), Knowledge Exchange Partnerships (six) and two spin-out companies. Core funding to develop fundamental research impact is provided by Innovate UK, Scottish Enterprise, SUPA, CENSIS Innovation Centre, Royal Society Industrial Fellowships and Royal Society of Engineering. The two Impact Case Studies (ICS) presented in this submission are based on work relevant to a wide range of national and international (e.g., US, China) industrial partners. The first includes the spin-out company Albasense Ltd which involves medical devices for breath analysis for diagnosis/management of chronic respiratory conditions and non-contact thermometry for COVID-19 diagnosis; agritech with hyperspectral imaging for detection of crop disease and optimised plant growth; and industrial ultralow power consumption autonomous gas sensors. The other ICS is based on plasma-based processes emerging from gravitational waves fundamental research now deployed in large-area plasma assisted deposition (Laboratory for Laser Energetics, Rochester University, USA, with four plasma sources deployed); plasma assist technology also deployed for production usage within three UK companies, one Chinese company and two Chinese universities. Applied research from ITFSI has also informed the Impact Case Studies submitted to UOA12: Engineering.

**1.4 Interdisciplinary research**

Our School and Division structure naturally leads to opportunities for interdisciplinary research. Over the past decade, Physics has existed alongside engineering, fostering synergies between the two. Following a University restructuring in 2018, the disciplines of Chemistry and Mathematics joined Physics in the new Division of Physical Sciences.

**1.5 Open research environment**

We work towards an open and accountable research environment, alongside staff in Research Services and the UWS Library, providing advice and guidance in the management of research data. We use the research networking system PURE for research knowledge management and to ensure compliance to the REF open access policy. In addition, staff in Physics use the arXiv open-access preprint repository at Cornell University. Our applications for funding from research councils require the submission of a Data Management Plan and a number of our collaborations have their own data management and sharing policies. For example, the AGATA gamma-ray tracking array has its own data policy: http://npg.dl.ac.uk/agata_acc/AGATA_Data%20Policy.html and is regularly reviewed by the AGATA Collaboration Council.

**1.6 Research integrity**

University Ethics Committee and the School Ethics Committees are the key stewards of research integrity, providing codes, guidance and monitoring. Staff, thus, need to adhere to the University Code of Ethics, attend training courses and be conversant of ethical issues, fairness and integrity. The School's Ethics Committee has representation from Physics (**Bondili**) and all research projects are subject to ethical review.

**2. People**

**2.1 Staff Development Strategy**

Staff in Physics are appointed based on their research strengths and potentials, providing exceptional opportunities for Early Career Researchers. Training and development is focused on developing abilities to: (1) lead independent research, (2) manage projects, budgets and staff, and (3) balance academic portfolio by maintaining world-class research alongside excellent teaching. The size of our research groupings enables close interaction and we maintain highly effective additional support through two Emeritus Professors (**Chapman** retired 2010 and **Placido** retired 2014).

All staff are encouraged to take full advantage of staff development opportunities within the School and the University. New staff are required to enrol on the PGCert in Academic Practice offered by the UWS Academy. This programme incorporates research practice as well as research-informed

teaching and learning. All staff undertake relevant training courses, including Time Management, Managing Projects, Risk Assessments, and Building and Leading Teams. Staff have access to a training portal to manage personal training: this includes a Development Toolkit offering a wide range of resources, guidance and advice through short videos and podcasts.

UWS has signed up to the Concordat to Support the Career Development of Researchers, based on the Vitae framework. The University has a steering group for the implementation of the Concordat, chaired by the Vice Principal for Research, Innovation, and Engagement. The steering group includes a Professor (**Smith**) and Post-Doctoral Research Assistant (PDRA) (**Keatings**).

Our PDRAs are essential and provide a synergistic link between academic staff and PhD students. We have typically two or three PDRAs working at any one time. Normally funded by research council grants, they are fully integrated into research groups. They are also involved in undergraduate labs and lectures, giving them valuable teaching experience.

New and early career staff are involved in the University's development programme:

- UWS Crucible – a programme to develop research, widening perspectives, understanding roles and building networking skills.
- Propel – a programme introducing the principles, concepts and techniques of knowledge exchange, and to develop an engagement plan for working with industry.
- Grant Accelerator – a programme designed to develop and enhance the knowledge and skills needed to develop successful grant applications for external funding agencies.
- Aurora/Women in Leadership - Aurora is Advance HE's leadership development initiative for women. Women in Leadership is the UWS in-house programme introduced in 2019.

**2.2 Staffing and Recruitment**

Physics at UWS currently has 12 FTE permanent academic staff, eight of whom are submitted to UOA9: Physics and three to UOA12: Engineering. All members of the Nuclear Physics Research Group are being submitted to UOA9, together with three members of ITFSI.

Of the 12 members of staff, only four were in post prior to REF2014. The change in staff profile and recruitment over the review period has reinvigorated the community. We have aimed to recruit the best possible candidates to strengthen our research groupings, and these new staff will also make an impact on our teaching. For example, a member of staff was appointed in 2018 (**Birney**) with expertise in gravitational waves to enhance that theme within ITFSI, and in 2019, we appointed another staff member (**Bowry**) with a strong track record of conducting nuclear-Physics experiments at the TRIUMF laboratory in Vancouver.

**2.3 Support for Early Career Researchers (ECRs)**

The University is committed to supporting all ECRs. They are included in supervisory teams to develop capability prior to becoming lead supervisors. The Propel scheme allows ECRs to work through grant-submission development in a safe and supported environment. The Crucible Scheme is a dedicated programme to develop future leaders in an interdisciplinary context. The School provides ECRs with a workload allowance to establish their research and there are numerous funding opportunities, such as the Vice Principal's Research Fund, an annual call for studentships, pledged support in institutional letters of support for external funding and Crucible Prize fund. ECRs are also included in the Consolidated Grant applications with collective support from other group members. Along with all staff, ECRs take part in the annual MyContribution review process and have an activity plan to ensure fair allocation of duties with allowance for personal development and training.

**2.4 Academia – Industry Exchange**

A major strength in Physics at UWS is its links with industry. The Director of ITFSI (**Gibson**) had a previous career in industry before appointment in 2014. Business Innovation at UWS supports partnerships between academic staff and industry, as well as helping with commercialisation, consultancy, continuing professional development, and knowledge transfer partnerships (KTPs). UWS is currently top in Scotland for the number of live KTP projects which are administered

through its own dedicated KTP Centre. UWS also has an open access policy for companies to access unique and specialised deposition equipment via the ITFSI labs and this helps build and sustain productive relationships.

**2.5 Research & Impact Rewards**

The Staff Appreciation and Reward Scheme (STARS) was created specifically to recognise outstanding staff contribution. Since 2014, the STARS award for Outstanding Research and Enterprise has been won twice by staff in Physics with a further five awards as Highly Commended. ITFSI (**Gibson**) has also been in receipt of funding from the Vice Principal's Research Fund (Section 3).

**2.6 Research Students**

**Postgraduate Research Community:** Our physics postgraduate research community is among our key strengths as we are contributing to the vibrancy of the discipline, developing excellent scientists and leaders of tomorrow. There are presently 104 postgraduate research students in the School, of which 18 students are associated with Physics: within the review period, 29 PhD students have been recruited to Physics with 18 to UOA9. There have been 33 PhD completions (17.5 submitted to REF4a) within this period, following strenuous institutional efforts to ensure students complete within the maximum period of registration. The strategy for the next few years is to increase the recruitment of high-quality research students to 8 annually through UWS studentships calls, industry match funding and other sources as appropriate. In the assessment period, a number of prestigious externally funded studentships have been awarded: seven studentships have been funded by STFC Doctoral Training Grant Awards, five in nuclear Physics and two in sensors research. Two PhD students have been funded by STFC Nuclear Physics Consolidated Grants. One student has been funded via a highly competitive SUPA Prize Studentship, with match funding from UWS. Students have also been funded through competitive internal studentship calls (15% success rate). Recently, and specifically in ITFSI, several KTP Associates have been recruited, who have enrolled as PhD students due to UWS' strategic approach in support of KTPs. Approximately half of our research students are self-funded, with an increasing number in recent years from China, via our MSc Advanced Thin Film Technologies programme.

**Recruitment and Progress Monitoring:** In addition to a targeted approach through funded studentships, we also regularly communicate with potential self-funded applicants, particularly from our partner institutions, of available research projects. Our School webpage provides information for over 70 research projects. Interested applicants are invited to discuss with potential supervisors and online applications are made through a central online system. The recruitment includes an interview and the decision for successful applicants is ratified by the PGR Coordinator or Head of Division. All potential supervisors undergo unconscious bias training. Issues related to equality, diversity, and inclusion are considered in all University procedures (see REF5a), and Equality Impact Assessments are completed regularly and when appropriate. Appointed students are assigned a supervisory team which includes a Lead and Second Supervisor, along with an independent Assessor. Since 2014, UWS has operated an online postgraduate student research management system called MyPGR Platform. Rigorous monitoring, Progress and Award Boards (PAB), overseen by the Doctoral College Board, and training have subsequently led to more than 90% of PGR students completing within the maximum period of registration, significantly improving our completion rates. The PGR Coordinators approve progression (monitoring) forms, including viva arrangements, inform staff and students of their responsibilities in terms of process, and appoint Chairs for viva examinations as well as providing pastoral support. In addition, they have an independent overview of research student progress and are required to approve satisfactory progress following PABs, interim reviews and transfer events. School Research and Finance Coordinator, on the other hand, is responsible for all postgraduate research student administration.

**Training:** Research students in Physics at UWS receive broad training in subject specialisms and transferrable skills. Students in Nuclear Physics have access to courses via the UK Nuclear Physics Graduate School for which the director is **Smith.** Students are required to attend biennially a residential STFC Nuclear Physics Summer School. The School is organised by two members of the UK Nuclear-Physics community, which has previously included **Smith** and **O'Donnell**. The

SUPA Graduate School is another sector-wide mechanism in Scotland and it provides training in physics and transferrable skills. As the largest Physics graduate school in the UK, the SUPA Graduate School has a major impact on physics research and graduate education. Our staff deliver a highly developed and closely integrated programme of graduate education within the framework of the SUPA Graduate School. This offers over 60 advanced technical courses for Physics PhD students across Scotland, as well as professional development training. Courses, accessing the knowledge and skills of world leading researchers drawn from across the eight partner universities, are mostly delivered by live video links using SUPA's e-learning portal with dedicated state-of-the-art video classrooms. There are also tutorials, lab classes, workshops and international summer schools (SUSSP). These courses are aligned to pan-SUPA research themes (Astronomy and Space Science, Condensed Matter and Material Science, Nuclear and Plasma Physics, Particle Physics, Photonics) and two impact themes (Energy and Physics & Life Sciences) that cover all areas of physics and astronomy research. Each student is required to complete at least 40 contact hours of advanced physics courses and 20 hours of professional development (skills) courses in their first two years. Staff in Physics at UWS provide SUPA courses in Introductory Data Analysis and in The Nuclear Fuel Cycle. UWS has a dedicated video-conferencing room for participation in lectures from the SUPA Graduate School. SUPA also offers an annual three-day residential course in Entrepreneurship attended by our students. The University through the Doctoral College and UWS Academy provides training for staff and research students. The Doctoral College, with its focus on Wellbeing, Interactions and Behaviours, is helping students maintain progress in a highly stimulating and professional environment. There are regular courses in academic writing and “writing retreats”. The UWS Academy further provides a PGCert Academic Practice programme for new academic staff and PhD students, preparing them for a potential academic career. We provide opportunities for students to gain teaching experience and to publish. In 2018, a PhD student of theoretical physics taught an undergraduate “Maths for Physics” module and subsequently won the STARS Award for Outstanding Lecturer (**Meeten**). The Doctoral College operates an annual Research Conference at which students present their research to a wide audience, providing presentation and networking skills. The UWS Careers Team offers a range of support to research students about their future careers, offering one-to-one appointments as well as an Online Careers and Skills Centre.

**2.6 Equality and diversity**

We operate within School and University policies and procedures which ensure that we work towards the promotion of equality, diversity and inclusion. We operate a family-friendly flexible working environment, to allow staff to achieve an appropriate work-life balance, and, for example, to accommodate caring responsibilities. All staff are entitled to request part-time or reduced hours, compressed working, job sharing, annualized hours, and home working. Staff in Physics have requested parental leave, or individual requirements such as extended parental leave. Staff can also apply for the Returner’s Scheme after a long term period of absence due to long term sickness or pregnancy and maternity. This fund supports staff to get their research career back on track.
The University has a dedicated Occupational Health Manager accessible by all staff members and research students. This service provides advice and support for mental health and wellbeing. Staff are also able to join a peer led staff network group. We have staff networks that support ethnic minority staff, female staff, LGBT+ staff and disabled staff.

In terms of gender balance, all committees have female and male members including committees related to recruitment. In student recruitment, we are actively seeking to increase ethnic minority, diversity and gender balance. For example, in physics, recognising that female students may be discouraged from taking physics at secondary school level, we reduced the requirement for physics as an entry qualification but maintaining the requirement of mathematics, which is more widely offered. This was a project supported by the Equality Challenge Unit. Within the School, female staff have completed the Aurora Women’s Leadership Programme and have participated in the UWS Crucible programme.

Presently, half of the academic staff in the University are female. Within the School, 18% of the academic staff are female although there are presently no female staff in Physics. There have

been seven female research students in Physics in the period under assessment (24%). We recognise that the gender balance needs to be addressed and four staff in Physics have served on the School's Athena SWAN Self-Assessment Team. We are also committed to submitting an application to the IOP Project Juno within the next 12 months. UWS has held an institutional Bronze Athena SWAN award, and we are presently working towards a departmental (School) award. The School has an Equality, Diversity and Inclusion champion who chairs the Athena SWAN SAT. The Dean of the school is also represented on the EDI Committee. This structure ensures that information is cascaded within the school.

**3. Income, infrastructure and facilities**

**3.1 Research Income and Funding Strategy**

The total combined value of the UWS share of grants for physics across all research groupings has grown from GBP512,000 in 2013/14 to GBP1,100,000 in 2019/20 with an average over the past 5 years at GBP705,000 (*i.e.,* a total of GBP4,000,000 for this REF period). The data for the ITFSI comprise UOA12 (**García-Núñez, Hutson**, and **Song**) and UOA9 (**Birney, Gibson**, and **Morozov**) while for Nuclear Physics Research Group includes all members of the group. The total refers to all staff.

| Grant awards | | | | | |
|---|---|---|---|---|---|
| Academic Year | ITFSI | | Total | Nuclear Physics | Total |
| | UOA12 | UOA9 | | UOA9 | UOA9 |
| 2013-14 | 78,000 | 2,000 | 80,000 | 0 | 2,000 |
| 2014-15 | 0 | 362,000 | 362,000 | 149,000 | 512,000 |
| 2015-16 | 104,000 | 446,000 | 550,000 | 149,000 | 595,000 |
| 2016-17 | 3,000 | 214,000 | 217,000 | 21,000 | 235,000 |
| 2017-18 | 0 | 315,000 | 315,000 | 830,000 | 1,145 |
| 2018-19 | 116,000 | 450,000 | 566,000 | 11,000 | 461,000 |
| 2019-20 | 59,000 | 284,000 | 343,000 | 805,000 | 1,089 |
| **Total** | 359,000 | 2,072 | 2,432 | 1,967 | 4,039 |

The awards are from various funding sources including research councils and other funding bodies. The ITFSI's awards are primarily from sources related to industrial applications such as Scottish Enterprise and Innovate UK, with some from STFC relating to gravitational waves research and the Carnegie Trust. The majority of the funding for Nuclear Physics is from STFC, with smaller awards from the Carnegie Trust, Leverhulme Trust, and Royal Society. Over the assessment period, we submitted grant applications totalling GBP22,000,000 with approximately GBP14,000,000 from the Nuclear Physics Research Group, GBP9,000,000 from ITFSI staff included in UOA9, and GBP3,000,000 from the ITFSI staff included in UOA12.

Our staffing strategy has been implemented, in part, in order to increase our research income (Section 2). In ITFSI, we have rationalised the number of professorial staff to release capacity to deploy replacement ECR staff in areas of strategic importance with high grant-earning potential. We recruited a Lecturer in the area of gravitational waves in 2018 and appointed a Lecturer in Theoretical Physics in 2020. Within ITFSI, collaboration with industry is of paramount importance in ensuring growth in research income. In Nuclear Physics, our strategy has been to appoint staff who operate in different areas of nuclear-structure physics, working on different topics and at different laboratories, in order to widen the scope of the STFC Consolidated Grant funding. We have therefore appointed one member of staff with a background in studying proton-emitting nuclei in the A=160 region of the nuclear chart at JYFL and with experience in the use of SCAPA (**O'Donnell**, appointed in 2015), another member of staff with a track record in studying shape coexistence and mirror nuclei at GSI (**Bondili,** appointed 2018), and another member of staff with a track record of decay spectroscopy with radioactive ion beams at TRIUMF (**Bowry**, appointed 2019). These appointments were designed to increase the number of research themes within our STFC

Consolidated Grant applications and maximize the scope of our funding. The appointments are part of a longer-term strategy and are expected to bear fruit in the next REF period.

**3.2 Institutional Investment**

There has been significant recent University investment in a laboratory facility in ITFSI. With a total value of GBP12,000,000, the new laboratory on the Paisley campus includes a clean room and full-service infrastructure. The laboratory houses a suite of coating equipment, providing a unique research facility in Scotland. Additionally, and while we carry out much of our experimental research at international laboratories, we maintain a radiation detector laboratory on the Paisley campus with some capabilities for measurements, experiments, and testing. The laboratory includes a small array of $LaBr_3$(Ce) scintillators and associated digital electronics which were purchased with funding from our SUPA2 award from the Scottish Funding Council. The detectors were purchased for use in experiments with SCAPA, but when not used with SCAPA they are being put to use in explorative experiments on the Paisley campus. Regardless of the size of the laboratory and the array, a recent result from the experimental set up led to a high-impact publication in Nature Physics [Chishti et al. (2020), Nature Physics 16, 853]. The Nuclear Physics Group also has an air-conditioned data laboratory which houses four RAID servers, offering over 100 TB of data storage (and in addition to our world-class computing (UOA11) capabilities within the School).

**3.3 Support Staffing and Infrastructure**

The majority of our work is based within a dedicated facility on the Paisley campus, comprising staff offices, teaching laboratories, and most of the research laboratories. ITFSI is supported by two FTE technical staff to operate the scanning electron microscope and to provide general technical support. There are two other laboratory technicians who also support our teaching laboratories. All staff have full access to the University's mechanical workshop which has four dedicated mechanical technicians offering design, prototyping, manufacturing, assembly and testing services. Covering 800 $m^2$, the workshop includes manual and CNC manufacturing, metrology, prototyping, woodwork, welding, a 2000kN universal testing machine, wind tunnel testing, composites and metallurgy laboratories. The School has a dedicated Network Support Analyst to support the computing infrastructure, including the physics laboratories.

**3.4 Specialist Research Infrastructure for Impact**

Research in the ITFSI is predominantly in applied areas of physics with a strong industry collaboration. ITFSI includes medical devices, gas sensors, and optical imaging systems, and similar areas which often translate into industrial, economic, or societal impact. Investment in the new laboratories for ITFSI has been made to maximize the potential impact from this research. Novosound, one of UWS' award-winning spin-out companies from ITFSI has been working since its inception collaboratively in utilising the GBP12,000,000 ITFSI facilities (specifically benefitting from the GBP35,000 Nordiko system magnetron upgrade) for developing novel non-destructive testing technologies with activities spanning across UOA9 and UOA12. The arrangements have been made possible through the UWS' impact-focused spin-out approach, offering operational flexibility within the industrial high throughput setting that co-exists with the academic research.

**3.5 Cross-HEI Infrastructure Collaboration**

Within SUPA, the Nuclear and Plasma Physics theme, comprising physicists at the universities of Edinburgh, Glasgow, Strathclyde and UWS, we have focussed our efforts on the development of SCAPA, the Scottish Centre for the Application of Plasma-based Accelerators. SCAPA is a new facility based in Glasgow (University of Strathclyde) which uses very high intensity femtosecond laser pulses to generate particle beams and radiation. SCAPA has a range of scientific, medical, and industrial applications. Staff at UWS (**Scheck** and **O'Donnell**) are leading the development of a nuclear physics programme with SCAPA, in collaboration with physicists from Strathclyde and Glasgow.

Within the UK nuclear physics community, there is a "cross-community team" of scientists and engineers based at Daresbury Laboratory and at the universities of Manchester and Liverpool.

The cross-community team consists of around ten design engineers, mechanical engineers, electronics engineers, and software engineers who assist with the construction of apparatus, with the implementation of signal processing electronics and with data acquisition and data analysis systems. The cross-community team is funded by STFC to work with staff in the UK academic Nuclear-Physics community. The allocation of resources within the team is managed by a Cross Community Committee, consisting of academic staff, technical staff and STFC representatives. **Smith** was a member of the Cross Community Committee (2017-2020).

UWS is the only modern UK university to be involved in supplying mirror suspension technology, which holds the Advanced LIGO (aLIGO) interferometer's mirrors in place – an upgrade component which makes the detection of gravitational waves possible. The Veeco IBD (ion beam deposition) system, the key equipment for this development, is now hosted at the University of Strathclyde and shared between the two institutions (**Gibson, Reid**). In addition, together with the University of Strathclyde and University of Glasgow, UWS has invested in state-of-the-art equipment to form the Centre for Extreme Performance Optical Coatings (EPOC) within NMIS. This collaboration will enhance the existing optical coating manufacturing and characterisation capabilities located within ITFSI.

**3.6 In-kind Benefits**

The majority of the research in the Nuclear Physics Research Group is carried out at international Nuclear-Physics facilities. Our use of these facilities is driven by the accelerated ion beams that they provide, along with the available radiation detectors, spectrometers, and other devices. For example, our work at ISOLDE makes use of the new high-energy and high-intensity radioactive ion beams that are available and our work at the JYFL laboratory in Finland often exploits the Jurogam gamma-ray spectrometers, the SAGE electron-gamma-ray spectrometer, coupled to the MARA and RITU recoil separators. To apply for beamtime, we normally submit an experimental proposal which is reviewed by a panel of internationally recognized experts in a Programme Advisory Committee. The facility time, or beamtime, is awarded on a competitive basis. The operation costs of these facilities for the periods of facility time awarded is an in-kind contribution to our research.

| Facility | Experiment (Spokesperson) | Time awarded (days) | Total cost |
|---|---|---|---|
| JYFL, University of Jyväskylä (Finland) | M16 (**Bondili**); M21 (**Bondili**); JM9 (**Bondili**); JM31(**Bondili**); Rb74 (**Bondili**); Fe50 (**Bondili**); JM1 (**Smith**); S16 (**Smith**); S22 (**Smith**); S26 (**Smith**) | 114 | GBP1,885,104 |
| Legnaro National Laboratory (Italy) | 16.30 (**Smith**); 17.45 (**Smith**); 18.10 (**Smith**) | 28 | GBP204,960 |
| ISOLDE, CERN (Switzerland) | IS552 (**Scheck**); IS553 (**Scheck**); IS644 (**Bondili**) | 26 | GBP1,248,000 |
| Institut Laue Langevin, Grenoble (France) | 69531 (**Scheck**); 81086 (**Scheck**) | 23 | GBP220,800 |
| IKP, Köln (Germany) | A=50 (**Bondili**) | 14 | GBP34,447 |
| ELBE, Rossendorf (Germany) | 17100880 (**Scheck**) | 13 | GBP124,800 |
| Argonne National Lab., Chicago (USA) | 1810 (**Smith**) | 7 | GBP364,224 |
| TUNL, North Carol(USA) | 58,60Ni (**Scheck**) | 5 | GBP42,000 |
| | | **TOTAL** | **GBP4,124,335** |

The facility time totalling GBP4,120,000 is awarded to members of Nuclear Physics. These are experiments where staff have acted as spokespersons or co-spokespersons for an experiment. The table above gives an identifier of each experiment with the name of the spokesperson, the total time awarded, and the associated cost of the facility time. Our use of such facilities is dominated by the JYFL laboratory in Finland, with our next being at Legnaro National Laboratory, ISOLDE, and Institut Laue Langevin. The majority are not supported financially by the UK research councils, but the UK pays a direct subscription to ISOLDE (CERN) and Institut Laue Langevin.

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

**4.1 Research Collaborations, Networks and Partnerships**
Staff are involved in large international collaborations, in conference organisation, journal editorships and committee work, as well as memberships of professional bodies:

**(1) SUPA:** The research environment in Physics at UWS is enhanced by our participation in the Scottish Universities Physics Alliance (SUPA) (Section 2.6). With over GBP1,000,000 in funding to UWS, SUPA has provided funds for academic staff posts, studentships, infrastructure support, as well as visitor support, student and ECR travel funds (PEER and PECRE), and graduate school activities. Our participation in SUPA has involved close collaborative working with partner universities and, in particular, the universities of Glasgow, Strathclyde, and Edinburgh. Within SUPA, staff are leading the SCAPA nuclear physics theme. Infrastructure purchased for use with SCAPA (lanthanum bromide radiation detectors) were recently used in a test experiment a UWS which led to a publication in Nature Physics (Chishti et al., 2020).

(**2) LIGO: Gibson** and **Birney** are members of the LIGO Scientific Collaboration (LSC) pursuing gravitational waves research, the collaboration of over 1300 scientists in 18 countries. At the time of this world leading discovery, **Reid**, Gibson and Birney were part of the global team (See: Abbott, B.P., Abbott, R., et al. (2016) Observation of gravitational waves from a binary black hole merger, *Physical Review Letters*, 116(6), 061102). This was first observation of gravitational waves and directly associated with 2017 Nobel Prize; Reid consequently among 13 academics to be awarded 2016 RSE Presidents Medal for leading contribution to this work.

**(3) Advanced Gamma Tracking Array (AGATA):** All of the Nuclear Physics Group are members of AGATA collaboration, to build the world's most powerful gamma-ray spectrometer for use in nuclear-structure experiments. The AGATA collaboration consists of over 40 institutions in 12 countries.

**(4) Laboratories:** Over the assessment period, staff in the Nuclear Physics Research Group have conducted research in a number of international laboratories:

- ISOLDE collaboration (CERN) as well as its subsidiary "Miniball" and the Isolde Solenoidal Spectrometer (ISS).
- GRIFFIN (TRIUMF, Vancouver) and
- FAIR (GSI, Darmstadt).

Our main partners are the universities of Liverpool, Manchester, Surrey, York, Brighton, Strathclyde, and Daresbury Laboratory in the UK, with a wide range of collaborators internationally, including University of Jyväskylä (Finland), Legnaro National Laboratory (Italy), University of Padova (Italy), ILL (France), GANIL (France), ISOLDE (CERN, Switzerland), TU Darmstadt (Germany), TU Munich (Germany), LMU Munich (Germany), Argonne National Laboratory (USA), NSCL, Michigan State University (USA), TRIUMF (Canada), HZDR (Germany), TUNL (USA), Krakow (Poland), MAX Lab (Sweden), and University of Mainz (Germany). In total, we have conducted over 30 experiments at these laboratories, with the largest numbers of experiments at JYFL (Finland), Legnaro National Laboratory (Italy) and ISOLDE (CERN).

**4.2 Contribution to Society: Engagement with Users, Beneficiaries and Communities**
Physics researchers are among the most active groups supporting engagement and outreach. In this REF period we have led or been involved in a number of these activities, including:

- Organising and hosting IOP Nuclear Physics Conference (http://nuc18.iop-confs.org/home). Chaired by **Smith**, the conference was held on the UWS Paisley campus (4th – 6th April 2018) attracting over 120 international delegates (conference included a public lecture by theoretical nuclear physicist **Professor Jim Al-Khalili** from the University of Surrey and international speakers from CERN, University of Jyväskylä, and Ludwig Maximillian University of Munich).
- International Nuclear Physics Conference (INPC) (http://inpc2019.iopconfs.org/home), is the largest conference in this field in the world. Chaired by the University of Glasgow (**Professor David Ireland**), the 2019 conference saw **Scheck** on the local organizing committee. A satellite meeting to the conference was held on the UWS Paisley campus entitled "The Nuclear Octupole Degree of Freedom" (25th to 26th July 2019) (https://www.iopconferences.org/iop/frontend/reg/thome.csp?pageID=848877&eventID=1360). Attended by over 40 delegates from around the world, including some of the most prolific experimental and theoretical researchers, the workshop has reinforced the UWS reputation as one of the leading groups for the study of octupole correlations in nuclei.
- IOP half-day meeting on Coulomb Nuclear Excitation of Radioactive Ion Beams (University of Manchester, 2018) and Thin Film Section the Vacuum Expo (University of Strathclyde, 2019).
- **Gibson** has served on the organizing committees for a number of conferences in the area of thin-films research, such as Frontiers of Optical Coatings (Guangzhou, China, 2017), Nanofilms (Cranfield University, 2018), Optical Society of America topical meeting on Interference Coatings (2019).
- Monthly Nuclear Physics Seminar series with invited external speakers.

In the assessment period, we have hosted numerous high-profile visitors including:

- **Professor Witold Nazarewicz** (Michigan State University; 2017),
- **Professor Chavdar Stoyanov** (INRE BAS, Bulgaria; 2014),
- **Dr Thorsten Kroell** (IKP-TU Darmstadt; 2019),
- **Professor John L. Wood** (Georgie Institute of Technology; 2017),
- **Professor Kris Heyde** (Ghent University; 2018),
- **Professor Luis Robledo** (Universidad Autonoma de Madrid; 2019),
- **Professor Holger Waalkens** (University of Groningen).

To disseminate our research to a general audience, we have carried out a range of outreach activities. **Scheck** has presented seminars relating to Nuclear astrophysics and the origin of elements in the universe in public lectures at UWS and also at the Paisley Astronomical Society. **O'Donnell** has carried out outreach activities related to local schools. In 2017, he initiated a Continuous Professional Development (CPD) event for local schoolteachers to inform teachers about contemporary research in Nuclear Physics. He is also a member of the West of Scotland Physics Education Group, which is an avenue to inform local children about our research. **Birney** has attended the Skylab at the Scottish Airshow in Ayr in 2016 and has made presentations at careers events on gravitational-wave detection in local schools. Prior to joining UWS, **Bowry** took part in open-house activities at NSCL (Michigan State University) and TRIUMF (Vancouver) as well as other events such as outreach for the Girl Scouts of America.

**4.4 Discipline, Interdisciplinarity and International Priorities**

Within specific research areas, we occupy a range of roles on external committees and groups. **Smith** is a member of the international AGATA Collaboration Council, as well as a member of the UK AGATA Management Board. **Scheck** is a member of the Programme Advisory Committee at the ILL Laboratory in Grenoble, France (since 2020). **Scheck** and **O'Donnell** are members of the SCAPA Executive Committee, since 2015. **Bowry** chairs a working group for data analysis of data with the GRIFFIN gamma-ray spectrometer (TRIUMF, Vancouver).

**Smith** was a member of the STFC Nuclear Physics Grants Panel (2011-2017) and subsidiary Cross Community Committee (2014-2017). He was a member of the STFC Consolidated Grant Implementation Review Committee. Since 2020, **O'Donnell** has been a member of the STFC

Nuclear Physics Advisory Panel. In 2016 and 2017, **Scheck** served on the STFC panel to evaluate Ernest Rutherford Fellowship applications. Since 2015, **Smith** represents UWS on the SUPA Executive Committee.

Staff have also won various prizes for their research. In 2020, **Gibson** won the CEED Knowledge Exchange Award in conjunction with Helia Photonics Ltd. As part of the LIGO Scientific Collaboration, **Gibson** and **Birney** were awarded the Special Breakthrough Prize in Fundamental Physics (2016), the Gruber Prize in Cosmology (2016), and the Princess of Asturias Award for Technical and Scientific Research (2017) for their part in the discovery of gravitational waves.

**4.5 Wider Influence and Contributions**

Staff regularly perform peer review within their fields. For example, **Morozov** is Associate Editor for the journal Optical and Quantum Electronics since 2018; **Birney** has been guest editor of two issues of the MDPI Coatings journal with special issues “Current Research in Thin Film Deposition: Applications, Theory, Processing, and Characterisation” and “Current Research in Thin Film Deposition: Applications, Theory, Processing, and Characterisation II”. Staff have been reviewers for journals including Physical Review Letters, Physics Letters B, Physical Review C, European Physical Journal, Journal of Physics G: Nuclear and particle Physics, New Journal of Physics, Journal of Physics A: Mathematical and Theoretical, JOSA B, EuroPhysics Letters, Journal of Optics, Optics Letters, Optics Express, Optics Communications, Reviews of Modern Physics, Space and Coatings Technology, Coatings, Vacuum, Materials research Express, Diamond and Related Materials, Applied Optics. MDPI Coatings, MDPI Sensors. Staff have also acted as referees of grant applications both nationally (EPSRC and STFC) and internationally [e.g., NFKI (Hungary), Ministry of Science (Poland) and NRF (South Africa)].