

Institution: University of Kent
Unit of Assessment: 9: Physics
<p>1. Unit context and structure, research and impact strategy</p> <p>1.1 Overall Strategy and Structure</p> <p>Physics at Kent is a vibrant community embedded with Chemistry and Forensic Science in the interdisciplinary School of Physical Sciences (SPS). For most of the REF2021 period, SPS was part of the Faculty of Sciences, becoming part of the new Division of Natural Sciences in autumn 2020. Following REF2014, Physics expanded significantly, resulting in three well-resourced research groups: the Applied Optics Group (AOG); the Centre for Astrophysics and Planetary Science (CAPS); and the Physics of Quantum Materials (PQM). SPS also has a small Forensic Imaging research group, one staff member from which is included here as part of our policy of integrating related, smaller, multidisciplinary fields with their most scientifically relevant discipline.</p> <p>The Physics research groups are aligned with the UK's long-term strategic needs. AOG emphasises health care, a key strategic area for the EPSRC. PQM is aligned with quantum technologies and advanced materials, again key areas for the EPSRC. CAPS is aligned with the themes defined in the STFC roadmaps for astronomy and planetary science. Forensics research develops techniques to support societal development and justice.</p> <p>Strategic growth has resulted in a large increase in the number of staff submitted (19 FTE) vs. REF2014 (5 staff from one research group (CAPS)), comprising 18 staff members, including a Royal Society Fellow (a permanent appointment post-fellowship has been agreed), plus one fixed-term Leverhulme Fellow. Another Physics staff member conducts research in chemical physics and is included in the University's Chemistry UoA. This growth results from significant strategic investment by the University, creating six new research-active Physics positions in the REF2021 period (two in AOG, three in CAPS, and one in PQM), plus another three new posts in PQM, appointed in 2013 as part of the long-term strategy to grow our Physics research base.</p> <p>In 2019, Physics undertook a major strategic review, delivering a rolling three-year programme focused on: improving quality; interdisciplinarity and networking; having clear scientific and impact goals; continuing to increase grant income; and communicating work to stakeholders and public audiences. All three of our main research groups will be developed further during the next REF period, advancing their current research and moving into new (interdisciplinary) areas. Forensic research will also grow, exploiting links with AOG and developing new themes.</p> <p>The head of each research group ensures the group implements the strategic plan, developing a viable research, enterprise, and innovation portfolio. A high priority is increasing impact in each group. The head reports to the School's Research Committee, which monitors research effectiveness. SPS also has a Director of Innovation and Enterprise, who helps staff develop enterprise and industrial applications (including grants and contracts).</p> <p>Physics benefits greatly from membership of the South-East Physics Network (SEPnet). This has helped to coordinate growth in Physics across the region. SEPnet has several research-focused strands, including Astrophysics, and Atomic and Condensed Matter, relevant to CAPS and PQM.</p> <p>1.2 Objectives</p> <p>Our post-REF2014 strategy was to develop CAPS and to grow Physics. This has successfully been implemented by:</p> <ul style="list-style-type: none"> • Growing the three key areas (AOG, CAPS, PQM).

- Increasing the number of research staff (new positions and attracting fellowships) and PGR completions (5 in REF2014; 33.5 in REF2021).
- Increasing external funding (excluding income in kind, grant income rose from £1.5m in REF2014 to £5.7m in REF2021).
- Accessing leading external research facilities; e.g. Diamond (PQM) and major telescopes (CAPS).
- Developing new collaborations; e.g. European-funded ITNs in optics (AOG), and bringing to Kent the EC H2020-funded Europlanet project (CAPS).
- Investing in improving internal research facilities; e.g. the CAPS impact laboratory and on-campus observatory, both now transnational, networked facilities via Europlanet.
- Engaging with SEPnet partners; e.g. via GRADnet, which closely coordinates PhD training across SEPnet.

The current areas of strength have led to the outputs and case studies selected for REF2021. Specifically:

Applied Optics Group (AOG)

AOG develops advanced optical devices and instruments for imaging and sensing, particularly for biomedical applications, and is known internationally for its pioneering work on Optical Coherence Tomography (OCT) as both a research and an applied tool (collaborating with domestic and international universities, industry, hospitals, etc.). AOG has four staff members (Podoleanu, Dobre, Hughes, Bradu), the latter two strategically appointed in 2017. Core areas of expertise include:

- Optical Coherence Tomography (OCT) Technology and Applications (Podoleanu, Bradu, Dobre, Hughes).
- Endoscopic and Point-of-Care Microscopy (Hughes, Podoleanu).
- Functional and Multimodal High Resolution, Non-invasive Measurement and Imaging, including Forensic Imaging (Bradu, Dobre, Podoleanu).

AOG's principal future aim is to exploit its existing advanced optical systems, applying them in areas such as forensic art, document inspection, security and identification, and medical applications (linking AOG to the Forensic group and the University's new Medical School).

Centre for Astrophysics and Planetary Science (CAPS)

CAPS has 8 staff members (Burchell, Froebrich, Lowry, Mason, Price, Smith, Urquhart, Wozniakiewicz; with Mason, Urquhart, and Wozniakiewicz filling positions created during the REF2021 period). CAPS research is aligned with key STFC objectives, and includes:

- Planetary Science (Burchell, Lowry, Mason, Price, Wozniakiewicz): covering small solar system bodies; hypervelocity impact processes; astrobiology; and astrochemistry; via laboratory studies and analysis of telescope/space mission data.
- Astrophysics (Froebrich, Smith, Urquhart): including galaxy structure, Young Stellar Objects (H₂ outflows and variability), massive star formation, and astrophysical fluid dynamics. Staff lead or are co-investigators on major international observational programmes and conduct theoretical/modelling studies.

CAPS' future aims are:

- Continued involvement in solar system missions such as *Comet Interceptor Mission*, *Juno*, *Juice*, and the NASA/ESA *Deep Space Gateway*, with ongoing analysis of data from *Rosetta* and *Stardust*.
- Develop a planetary radar programme, including machine-learning methods for data analysis, with potential impact applications outside astronomy and planetary science.

- Exploit leadership in international Galactic plane surveys and take active roles in ALMA, JWST, SKA, UHS, and LSST.

Physics of Quantum Materials (PQM)

PQM is a new research group, formed in 2019 from existing staff. It has 7 staff (Carr, Ghosh, Möller, Pugh, Quintanilla, Ramos, plus Mountjoy, who is returned in the Chemistry UoA). Möller is a Royal Society Fellow (joined 2016). Ghosh (previously a PDRA in the group) is a Leverhulme-funded independent researcher (awarded 2020). The group applies experimental, theoretical, and computational expertise to probe novel properties of quantum materials, enabling future quantum technologies, a key EPSRC strategic objective. PQM was a founder member of the Hubbard Theory Consortium, and collaborates with universities and institutes worldwide, including Cambridge, Oxford, Paul Scherrer Institute, various Max Planck Institutes, Zhejiang. PQM's current research activities include:

- Theory of Quantum Materials (Carr, Ghosh, Möller, Quintanilla): Application of computational, field-theoretical, and phenomenological approaches to strong-correlation problems, including unconventional superconductors, topological insulators, mesoscopic devices, low-dimensional systems, frustrated magnets, quantum Hall systems, and optical lattices.
- Experimental Condensed Matter Physics (Pugh, Ramos, Mountjoy): Utilisation of large central facilities providing neutrons, synchrotron X-rays, and muons, as well as in-house low-temperature facilities to investigate magnetic and superconducting materials, quantum phase transitions, energy materials, and nano-materials.

The group's principal future aim is to conduct research at the interface between Condensed Matter Physics and Quantum Technologies, becoming a leading centre for the study of properties of quantum materials for application in future quantum technologies, with close integration between theoretical/experimental research programmes and industrial needs.

Forensic Imaging

The multidisciplinary Forensic Imaging group covers image processing and chemical spectroscopy. There are three staff members, Gibson and two Chemists (in the Chemistry UoA). Gibson focuses on the design and application of image processing (originally applied in AOG and CAPS) and machine learning for novel security and policing technologies. The group's current activities include: forensic facial identification, deep neural networks for robust Raman spectrum matching/analysis, detection and tracking of illicit objects in security screening technologies, making CAPTCHA systems resilient to deep learning attacks, with recent joint research with AOG on document security inspection for non-destructive testing. The group's future research aims include:

- Developing an AI-based analysis method for the interpretation of Surface Enhanced Raman Spectroscopy data, with Cambridge and the University of Haifa.
- Extension of photonics tools to forensic applications (with AOG).
- Developing the first facial composite system to use a witness's brain waves as input, using Innovation funding already secured.

1.3 Impact Development (see also 3.4 and 4.2)

Each research group has an impact development plan, and all Physics staff annually review their work for possible future impact cases. Staff also regularly work with external/industrial partners. They hold industrial contracts and host industrial visit/taster days on campus. Physics staff attend events off-campus with potential industrial partners, including events organised by Innovate UK. Successes include:

AOG's research in OCT (Impact Case Study 1) is driven by, and in partnership with, industry and external users. It is licensed to industry based on intensive Intellectual Property Rights protection

supported by the University. Six new patents have been awarded since REF2014, with a further three at the application stage.

CAPS held contracts from the US and Europe throughout the REF2021 period, and currently has an industry-linked PGR co-funded by the University. Citizen science use of the on-campus Beacon Observatory (see 4.3) is being developed as a possible future impact case study.

PQM actively seeks industrial partners (via the University's Knowledge Exchange and Innovation team) to help shape and exploit its work on quantum devices. Members attend national meetings such as 'Developing quantum technologies in the UK – funding, technical challenges and commercialisation' (Westminster Forum, January 2020).

Forensic staff work with companies and Innovate UK, developing applications of their work, and currently have an industry co-funded PhD student. Supported by the University, their work has led to technology transfer to a spin-out company (Visionmetric Ltd) and worldwide uptake by law enforcement agencies of a facial identification technique developed at Kent (Impact Case Study 2).

1.4 Interdisciplinary Research

The structure and ethos of SPS encourages interdisciplinary research. Research groups share specialist equipment and PhD supervision. Group boundaries are loose, permitting cross-group involvement; e.g. PQM has several chemists as associate members and Mountjoy works closely with Chemical Physics and is being returned in the Chemistry UoA. Staff are encouraged to work with other Schools, holding joint grants, PhD studentships, and enterprise projects. Work with external partners in industry is specifically encouraged. Examples of internal and external interdisciplinary collaboration include:

AOG

- Imaging work with the Medway School of Pharmacy, and the Schools of Anthropology and Conservation, Computing, and Engineering and Digital Art, leading to joint outputs respectively on embryology, photoacoustic, tattoos, GPUs, and wavefront sensing.
- Actively collaborating with all major medically oriented HEI's in London: UCL Institute of Ophthalmology and Moorfields Eye Hospital (imaging the eye); Imperial (robotics and endoscopy imaging of lung); and KCL (medical imaging and networking in the UK on image guided therapy), as well as with the NHS: Northwick Park Hospital London (ENT), Maidstone and Tunbridge Wells NHS Trust (Basal Cell Carcinoma), and East Kent Hospitals University Foundation Trust (imaging the eye).

CAPS

- Developing a new Machine Learning approach to asteroid shape modelling from planetary radar with Computing.
- Astrobiology experiments include joint PhD supervision and grant-writing with Biosciences.
- Joint PhD supervision and publications with Mathematics.
- Several collaborative papers in biology and chemistry journals.

PQM's associate membership for other research groups strengthens their access to complementary expertise, particularly in theoretical and experimental Chemistry (SPS) and quantum computing (Computing). Joint seminars are held with Mathematics.

1.5 Open Science

Physics strongly supports open publication of its research. This includes fully Open Access journals where appropriate, and placing full publisher versions of manuscripts onto the University's academic repository. University funds pay for gold Open Access. Staff use pre-print servers such as arxiv. Our staff work with publishers and our Corporate Communications team, regularly developing press releases to accompany new papers, widening the impact of the work. Most staff

have ORCID IDs and make use of ResearchGate etc., improving the reach of their outputs. As well as providing access to stored digital, physical data products such as targets in the Impact Laboratory are retained and made available on request.

1.6 Research Integrity

The training and mentoring of staff and PGRs includes advice on research integrity and ethics. All PGRs have a second supervisor, with whom they can discuss such matters, and are regularly reminded that they can approach the SPS Director of Graduate Studies if they have concerns. SPS has a Research Ethics approval officer, who liaises with the main University committee to ensure high standards are maintained. All projects and grant applications have to consider if they need ethical approval: assistance is provided on this, and, if it is needed, staff are assisted in obtaining approval; e.g. AOG often requires approval for its work on imaging human tissue, especially the eye. All our projects and grant applications relating to human participation or use of tissue samples are cleared with the Human Participants Committee.

2. People

2.1 Staffing Strategy and Staff Development

Policy and processes in SPS are guided by the Concordat to Support the Career Development of Researchers. Except for externally funded fellowships and short-term needs (e.g. maternity leave cover), all of the academic positions in Physics are permanent, with flexible and fractional working available. Positions are externally advertised, and filled on an open, criteria-driven basis. Most permanent staff are on contracts that include research to help generate critical research mass. However, three Physics staff (not included in this submission) were hired directly into permanent teaching-focused posts. All processes regarding probation, promotion, and study leave apply equally to these staff. Taken together, there are 21 permanent Physics staff in SPS. Six were appointed during the REF2021 period (five Lecturers and one Professor), and there were five promotions: one to Professor, and four to Senior Lecturer.

Age profile of submission

Age (years)	<40	40–50	50–60	>60
% of submission	16%	47%	21%	16%

63% of our staff are < 50 years old. Given our recent growth and age profile, extra effort has gone into supporting early career staff. The standard University probation procedures are followed (see REF5a). In addition, new staff also benefit from:

- Reduced teaching workloads in excess of University guidelines (a 66% reduction in year 1 and a 33% reduction in year 2, vs. the standard 50% and 25%);
- A fully funded PhD studentship (with a consumables fund) in their first few years;
- Access to all SPS equipment to help kick-start their careers;
- Targeted support for travel to conferences and networking events;
- Guidance on grant targeting and writing from colleagues.

After completing probation, staff agree a further five-year plan with the Head of School. Staff are not expected to hold senior School administrative roles immediately after probation, giving them time to develop their research. Training is provided for a wide range of transferable skills; all staff and PDRAs are required to attend at least one activity a year. Study leave of at least 1 term's relief from teaching was taken by four Physics staff in the REF2021 period.

There are annual appraisals of all staff, including PDRAs and technicians. In addition, given the age profile of Physics, research staff also meet annually outside the appraisal process with the Head of School and the School Director of Research to discuss their individual research plans (IRPs) and career development needs.

Staff can self-nominate in the annual Promotion round: there are no quotas and staff can apply whilst still on probation. Along with teaching and research, promotion criteria include citizenship, innovation, and impact activities; e.g. industrial contracts are considered equally with research grants. The various declarations about the dangers of journal impact factors, etc. are accepted, and staff are invited to build a picture of success across a variety of achievements and measures. SPS runs an annual call for staff thinking about promotion to seek assistance and mentoring. Given the age profile of the team, particular care is taken to mentor ECRs in advance of promotion. For more established staff, during the REF2021 period the Head of School was required to report to the Dean of the Faculty that all staff who had not applied for promotion for over five years had been interviewed, and their careers explicitly discussed along with potential support for development.

PDRAs are increasingly integrated into structures and policies. Having listened to their feedback, they can now apply for promotion irrespective of whether their external funder will provide the necessary funds. Two Physics PDRAs have been promoted during the REF period. PDRAs are supported to attend conferences and relevant workshops each year. Faculty research seed funding was also opened to PDRAs wishing to develop independence (resulting in some awards to Physics PDRAs, for networking visits to other labs, a field trip to Scotland to collect rock samples, etc.).

Supporting our staff to achieve career development is central to our staffing strategy. Given the age profile, a bespoke future senior leadership course was run in SPS (2019); attendees included three female Physicists (one in this submission and two teaching-only). Leadership of two research groups (CAPS and PQM) is currently undertaken by relatively junior staff supported by more senior colleagues, thus aiding succession planning.

2.2 Equality, Diversity, and Inclusivity

Physics takes EDI very seriously. It participates fully in University-led initiatives, has its own equality committee, and is a Juno Practitioner. All SPS staff undergo EDI training, including University training such as 'Valuing Everyone', and on unconscious bias and mental health issues. Senior academic staff undergo training to sit on/chair appointment and promotion panels. SPS also annually runs its own internal courses for staff (these being open to PDRAs and PhD students). Topics include: Mental Health Awareness; Autism Awareness; Imposter Phenomenon/Syndrome; and Unconscious Bias.

Core working hours (including scheduled meetings) respect family life. There is female representation on all committees awarding PhD scholarships, and all PDRA and staff appointment panels. SPS academic management posts are appointed through an open call for volunteers, with appointments made by a panel and not by a single person.

During the REF2021 period, maternity leave was taken twice by one Physics staff member (supported by a replacement fixed-term post to cover all duties) and once by a PDRA (whose fixed-term contract was extended so that she had the same duration of active work as originally planned). Paternity leave is available but was not taken. Staff are supported after return to work (e.g. one Physics staff member was supported to attend a European workshop to help restart research networks after maternity leave). When fixed-term staff are hired (e.g. to provide maternity cover), they are provided with appropriate training; e.g. in teaching tools (Moodle), health and safety, and mental health.

All promotion committees are mixed gender. Part-time working and maternity leave are taken into full account in the promotion process (one Physics staff member took maternity leave and was promoted during the REF period). External invitations are accepted as a measure of success in promotion applications, but acceptance of such, or delivery at external events, is not necessary, as this may selectively impact staff with children/caring responsibilities. The promotions procedure explicitly allows staff to declare (confidentially) if they have health or personal circumstances that have adversely impacted their performance. The University monitors promotion success rates by

gender, ethnicity, etc. At Lecturer to Senior Lecturer level, there is equal performance for male/female proportionate to numbers, but there are still more male staff overall. At higher grades, the number of female Professors in the Faculty (now the Division) has increased, and in SPS one woman was promoted to Professor and another to Reader in the REF period.

Currently, 24% of the 21 permanent Physics staff are female, but Physics is lagging behind with no female Readers or Professors. In Autumn 2020, 55% of final-year MPhys UGs were female. To help accelerate change, a Women in Physics group was set up in 2019 to support female physicists. It arranges regular meetings, external speakers, and offers mentoring support, careers advice, etc. It is open to UG, PGR, PDRAs, and academic staff.

The physical and mental wellbeing of staff and students is important to SPS, and 'All staff' surveys monitor these at School level. Occupational Health is available for self-referral, or the Head of School can refer staff. Where physical conditions are reported, SPS supports staff by refashioning their office/lab/IT to their needs; e.g. some staff suffer from joint pain, so keyboards have been changed and their IT use reviewed to rearrange for best use (posture, arm and hand rests, etc.). Optician appointments are provided free at a local optician as required.

SPS has a local team to support students, and there is a central team who help draw up individual learning plans (ILPs). We recruit independent of circumstances, and several Physics PGRs had ILPs during the REF period. In addition, science PG representatives have had wellbeing as a core activity for several years now.

SPS supports flexible working with an annual reminder to staff to make flexible-working requests, most of which relate to childcare. Staff are supported for home working if needed for health reasons. SPS does not support presentism; there is no signing in/out during the 'normal' working day. Work is done where and when required, and can be undertaken remotely if appropriate, at times convenient to the worker. SPS has an LBGT+ officer who circulates literature, details of meetings and support groups, etc. SPS has several times during the REF2021 period reviewed who it invites as external speakers, broadening the range of those invited.

When selecting outputs and impact case studies for this submission, the University's Code of Practice was strictly adhered to. All staff suggested papers and were asked for impact examples. External specialist referees were then asked to grade the papers. This was considered by the local REF committee and preliminary selections made. These were communicated to the individuals, who were asked to comment, with several changes then made. A review of the distribution of selected outputs from female/male staff was then undertaken (to within 1 paper the number of selected papers reflects the % of submitted staff who are female). The selection of outputs and impact case studies was agreed by a central University committee, which explicitly checked processes against the agreed Code of Practice.

2.3 Achieving Impact and Joining Industry

Staff are encouraged to develop contacts with industry via centrally organised meetings, bilateral contacts, site visits to companies, etc. Interaction with spin-out companies is encouraged, and we provide support for Innovate UK applications. Impact and Enterprise work are explicitly recognised equally with pure research in promotion criteria and the workload allocation model. In the REF2021 period, former Forensic group members moved into industry (one academic, one PDRA, and one PhD have joined Visionmetric), and Gibson is embedded in the company as Technical Director. AOG has helped provide industry across the UK and Europe with staff trained in OCT, with input from industry and clinics (via its Marie Curie Doctoral Training Schools, and its own PhD and PDRA cohorts). A former CAPS PDRA and PhD now work in the aerospace industry.

2.4 Research Students

In autumn 2020, Physics had 28 registered PhD students, with a further 6 in their writing-up year, and 6 awaiting examination. Robust recruitment procedures are in place for PhD studentships,

including external advertising for all positions. Women are members of all selection panels; EDI training is required, including on unconscious bias. External funders include EPSRC and STFC quota awards, Marie Curie (EU), industry, SEPNet, etc. There are also international PhD studentships, including a cotutelle studentship jointly with Lille (CAPS).

A School Board of Graduate Studies (including student representatives) oversees PG matters. Each student has a supervisory panel in addition to the primary supervisor (enabling junior staff members to gain experience and broadening the links between staff). SEPnet-funded students have joint supervisors from another SEPnet institution. The University's Graduate and Researcher College (formerly the Graduate School) implements overall postgraduate strategy and coordinates the Researcher Development Programme for postgraduate researchers in line with the Researcher Concordat. All Physics PGRs and PDRAs participate in this programme, which is mapped onto the four areas in the national Researcher Development Framework, including formal research training, career development elements, and structured supervision by the supervisory team.

All new PhD researchers attend a workshop introducing the University's Researcher Development Assessment, and start by considering their existing portfolio of skills, as well as the skills that they hope to acquire. A full range of workshops is offered, including writing and presentation skills, research methods, scientific programming, qualitative methods training, viva training, time management, leadership, knowledge exchange, entrepreneurial resources, publishing, and career planning.

PGRs attend weekly research group meetings, give at least one talk per year in their group's seminar series, and are required to attend at least six SPS colloquia in their first year. They must also attend the Annual SPS Postgraduate Colloquium, presenting a poster (first year) and talk (second year). SEPnet provides workshops and video-conferenced lectures and seminars. Research students and staff have had increased opportunity to participate in public engagement activities through SEPnet funding for outreach. Physics PhD students are supported to attend major international conferences.

The University operates progression monitoring with online collation of monthly supervisor/student meetings, and review points at induction, 3 months, 1 year, 2 years and pre-submission. Reviews are carried out by the supervisory team, and the outcomes have to be agreed by both the School and Faculty (now Divisional) Directors of Graduate Studies.

Our PGRs have won various prizes, including the inaugural Pierazzo International Student Award 2014 (Planetary Science Institute Arizona), Springer Thesis Prize (2016), and Best Student Abstract at LPSC (NASA, Houston) 2016. They also win travel/conference bursaries from bodies such as Europlanet, the Optical Society of America, and the Hypervelocity Impact Society. Our PGRs are supported in forming links to industry; e.g. they attend 'meet an industrialist' events run by SEPnet and UKRI bodies, and work on projects with industry/spin-out companies (see 2.3).

3. Income, infrastructure and facilities

3.1 University Investment

During the REF2021 period, the Faculty coordinated University investment, with annual monitoring of each School's research strategy, and ran annual Faculty-wide seed-corn funding competitions (circa £70k per annum, with a different main aim each year; e.g. ECR support, forging enterprise/industrial links, preparatory work for large grant applications, improving individual pieces of work, international travel). Usually, seed-corn grants (approx. £1,000 each) have been awarded each year to Physics staff. The Faculty also typically awarded SPS 3-4 University-funded PhD studentships each year.

Major building works in the REF period included updating the SPS building (£3.64m, completed 2016) and various capital works, including refurbishing existing, and creating new, labs and offices

(£5.584m). In 2015, the Beacon Observatory was established on-site with £120k of University funding, to conduct astronomical research, outreach, and Citizen Science. It featured a new dome and weather station, a 17" Astrograph from Plane Wave Instruments with a 4k x 4k CCD, a BVRI-Halpha filter set, and a 90 frames per second camera.

3.2 Grant Income

Central support for grant writing includes workshops, mentoring schemes, on-campus meetings with representatives of funding agencies, circulating details of grant calls, and internal reviews of all large grants. Inside research groups, grant brainstorming sessions and internal reviews of proposals/submissions are standard. Support also included the Head of School making funds available for one (female) staff member to make several visits to a UK university to use facilities and work with staff there. Similarly, when another staff member was planning maternity leave, her mentor worked with her on a time-critical externally funded project, enabling the project to start on schedule on her return. Similar support was given on a time-critical enterprise contract, facilitating its successful conclusion.

Over the REF2021 period, Physics research income (including income in kind) was £7.2m, with annual income increasing 46%. Large awards have been secured from major funders, including:

- EPSRC: Podoleanu (£429k); Quintanilla (£338k).
- BBSRC: £484k (Podoleanu).
- STFC: Burchell, Lowry, Price, Wozniakiewicz (£880k and £840k).
- National Institute of Health Research: Podoleanu (£178k).
- Royal Society: Möller (£307k).
- European Commission: Podoleanu (£891k); Price (£247k); Mason (£116k).

In addition, Mason secured a major EC H2020 award, to run Europlanet 2020-24. This is a 10m euro project with the administrative team based at Kent, the University due to receive several million euros over the course of the grant. Minor grants (<£100k) have been awarded by the Leverhulme Trust, STFC, Royal Society, EPSRC, etc.

The Physics strategy requires each group to establish a sustainable income stream:

- AOG has secured a wide portfolio of major research grants covering basic science (EU-ERC Advanced Grant), routes to commercialisation (2 ERC Proof of Concept grants and an Innovate UK grant), as well as two Marie Curie Doctoral School ITNs (with major industrial components).
- CAPS: Mason is Chair/President of the Europlanet-2024 project (2020-24), which supports and fosters planetary science activity in 53 institutions in 23 countries. The HQ is in SPS.
- CAPS has held an STFC Consolidated grant in Planetary Science throughout the REF period, and has also undertaken funded development work for instruments for future missions for both ESA and NASA (Burchell and Wozniakiewicz).
- PQM members have successfully generated grant income (current funders include the Royal Society, EPSRC, and Leverhulme). There are funded links to the University of Bristol, the Technische Universität Munich, University of Osaka, and the Diamond Light Source, Ltd. Looking ahead, PQM has already secured three highly competitive EPSRC New Horizon grants starting in 2021 (Möller, Pugh, Mountjoy).

3.3 Infrastructure and Facilities

Physics staff regularly win highly competitive major awards for access to 'beam-time' facilities and international telescopes. Beam-time awards include those from national laboratories: e.g. Diamond Light Source, ISIS Neutron, and Muon Source, as well as international neutron and synchrotron radiation facilities; e.g. the Institut Laue-Langevin, European Synchrotron Radiation Facility. ESRF use was 6 nights in 2016 and 6 in 2017, total income in kind: £230k. PQM also

makes use of national computational facilities, including the Tier2 Computational Hub in Materials and Molecular Modelling (T2MMM).

Telescopes used include: the European Southern Observatory (Chile), UKIRT (Hawaii, USA), Gemini North (Hawaii, USA), Isaac Newton Group of Telescope (La Palma, Spain), Liverpool Telescope (La Palma, Spain), Palomar Observatory (California, USA), as well as space-based facilities, including the Kepler and Spitzer space observatories. Lowry played a leading role in several international Large Programmes conducted at the European Southern Observatory, directed at understanding the YORP effect on asteroid motion. Urquhart led the science exploitation of the ATLASGAL survey and is Co-PI of the SEDIGISM survey (both performed with the APEX telescope and completed in 2016 and 2020 respectively, with ~1600 hours telescope time provided by Chile, ESO, Sweden, and the Max Planck Group). Urquhart is Co-PI of the APEX OGHReS, an ~1400-hour survey of the outer Galactic plane, 2017-22. This is a partnership between the MPIfR and ESO, and ESO has allocated 150 hours' observing time to Urquhart as PI. Froebrich has led the international UWISH2(+E) survey since 2009, which resulted in the doubling of known Young Stellar Object outflows, allowing them to be studied statistically for the first time. There has been a total of over 800 hours' PI time on UKIRT(UWISH2) and APEX(SEDIGISM), and over 2500 hours and 80 nights as PI/co-Is on various surveys and projects.

Throughout the REF period, Physics has sustained and invested in its research infrastructure, supported by the University. Equipment purchases in the REF period (value £2.3m) include lasers, X-ray diffractometers, a chiller unit, ultra-low temperature freezer, spectrometers (ESR, NMR, optical emission), glove boxes, rheometer, grinders and polishers, coaters, 3D printer, a Vytran glass processing system (followed by its upgrade), 80 GS/s Oscilloscope, a fast KTN scanning system, and an ultrafast camera. Specialised facilities in the research groups are accessible by all Physics staff, and include:

- AOG operates 10 optics labs, equipped with full-sized vibration-isolation optical tables. OCT infrastructure includes several fully functioning systems also available to external visitors from academia and industry.
- CAPS operates a Light Gas Gun and an on-campus observatory (Beacon Observatory). Both are recognised by Europlanet as Trans-National Facilities and are open to annual competitions for fully funded visits by overseas academics. CAPS will continue to invest in these facilities, developing its enterprise/commercial and outreach activities. Modelling and simulations are performed in-house using a computer cluster (50 nodes). CAPS also operates two SEMs and a Raman spectrometer.
- PQM's main in-house experimental facility is a unique double-stage adiabatic demagnetisation refrigerator (dADR), which enables 4-point resistivity and magnetic susceptibility measurements in conditions of high pressure (50 GPa), low-temperature (15mK) and high fields (6T). This is complemented with access to shared in-house facilities such as diffractometers and a SQUID reaching magnetic fields of 7T, as well as free access to a local computer cluster.
- Forensics makes use of in-house computing (a GPU cluster) and bench-top and handheld Raman systems.

Physics also borrows specialist equipment. Long-term loans include a large target chamber (NASA, \$30k), an ultra-high speed camera (another university, ~£250k), sputter coater (Quoram, ~£20k). Short-term loans include items such as lasers (from a variety of companies in the US, Europe, Japan etc., values include £22k, £88k and £160k), ophthalmic camera (£53k), and a spectrometer (Princeton ~£75k).

3.4 Support for Developing Impact (see also 1.3, 4.2)

By investing in AOG (including new staff posts) and developing Forensics during the REF period, we have supported activity that enables impactful research. Furthermore, after a 2019 strategic review, Physics has a clearly articulated goal of increased innovation and knowledge transfer to

partners outside academia, supported by professional advice, contract/patent support, travel money, seed-corn funds, etc. Physics maintains a strategy of protecting technology by patents, enabling commercialisation and developing future impact. All groups have impact strategies, and lab facilities are available equally for impact and pure research. Plans include:

- Forensics has been invited (with a spinout company) to submit a Phase 2 Small Business Research and Innovation (SBRI) grant, to support a Border Force plan for detection of illicit goods in postal items. Broadening the scope of Forensic research with the School of Anthropology and Conservation at Kent to develop an insect tracking system for forensic entomology, and to quantify and predict the impacts of economic development activities on nature. This will utilise our expertise in AI.
- AOG, whilst maintaining the current links with academia and industry in UK, is expanding its international partners in long-term collaborations with industry in Denmark, Germany, Ireland, and Italy, with academia in Denmark, Finland, Germany, Mexico, New Zealand, Romania and the USA, and with research centres such as the one in Linz (Austria), as well as with two of the Extreme Light Infrastructure sites in Europe (Szeged, Hungary; and Bucharest, Romania).
- CAPS is expanding its links with the European space industry and ESA with contracts in 2019 and 2020, and will expand the Beacon Observatory, adding a second robotic telescope, enabling permitting more access to citizen scientists.

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

4.1 Research Collaborations and Partnerships

There is strong institutional support for external partnerships. The School, Faculty (now the Division), and University provide funding for travel, joint PhDs with external partners, and cotutelle PhD students with European institutions. Of the papers submitted in this REF, 85% have authors from >1 institution and 77% have international co-authors. Example of national/international collaborations include:

- Leadership of Europlanet, a network of over 50 institutions providing an international research infrastructure for planetary science.
- CAPS staff are part of space missions and various astronomy surveys (see 3.3).
- AOG's partnerships with leading companies such as NKT Photonics (Denmark), Optos UK (a division of Nikon), Centervue (Italy), Superlum (Ireland), and universities such as the Technical University of Denmark, University of Lübeck, University of Darmstadt, University of Tampere, as well as hospitals in the UK, Europe (in Copenhagen), US (the New York Ear and Eye Infirmary), and in Romania (the University of Pharmacy and Medicine, Timisoara).
- PQM has collaborations with co-authors in five continents. Members are embedded within a supportive set of networks including the International Institute for Complex Adaptive Matter (I2CAM), the Hubbard Theory Consortium, and the South-East Physics Network (SEPnet).
- Bilateral collaborations with institutions such as Diamond, NASA, ESA, etc.

4.2 Development of Impact from Research and Contribution beyond Impact Case Studies (see also 1.3 and 3.4)

SPS encourages staff to develop impact. As well as the impact case studies in this REF submission, since REF2014 examples include:

- AOG: Continuous translation of technology: An OCT system for endoscopy was delivered to St Mary's Hospital (London), supported by Imperial College in 2016, and another system to the Hamlyn Centre for Robotics supported by the EPSRC in 2019. A third system was sent to Optos plc (Scotland), supported by Innovate UK (2015-17). OCT technology

protected by two patents was recently licensed to a manufacturer of ophthalmic diagnostic instruments, Centervue (Italy).

- CAPS: Industrial work using the light gas gun involves small contracts, circa £15-30k per annum; e.g. a joint PhD studentship with a SME funded by a STFC project (GNOSIS) and contracts from a US SME (Astroacoustics), which provides materials and sends staff to visit each year.
- Forensics: Three innovation successes with Visionmetric (Innovate UK grant numbers 102779, 132200, 131989) to develop and commercialise our deep learning for Raman signal processing. The largest of these, *Optimisation of high value biopharmaceuticals Manufacture using Resonant Raman Observations* (project value £741,456), involved 5 partners, including Biopharma giant Sanofi Genzyme.
- Forensics: Won a SBRI competition sponsored by the GovTech Catalyst and Border Force to detect illicit goods in postal items. This delivered an automated proof of concept detection system based on the YOLO deep learning network mm-wave imaging. The results of this work are currently embargoed.
- Forensics: First demonstration indicating the feasibility of using a Rapid Serial Visual Presentation (RSVP) for Forensic Facial Composite Construction through a behavioural study (2018, EPSRC £82,555). This was in collaboration with the School of Computing.
- Work with colleagues in Psychology and Computing led to an Innovate UK grant to Computing.

4.3 Public Engagement

SPS has a dedicated team for Public Outreach, including a Director of Public Engagement and a Marketing Officer, who vet all research grants before submission, checking outreach/engagement. All SPS academics are given dedicated time in their workload to take part in outreach activities. There is an extensive outreach programme taking science to schools and local people, funded both internally and via grants from bodies such as STFC, Ogden Trust, IoP, Royal Academy of Engineering, and UK Space Agency. Physics-based activities include: operating a portable planetarium, explaining space missions (Rosetta), how wind-powered turbines work, space explained, and supporting local schools to do astronomy on campus. There is also 'Space School', an annual three-day residential event on campus, typically hosting 50 young people who attend lectures (by internal and external speakers) and do mini-laboratory projects on space subjects (20th anniversary session in 2019, suspended in 2020 due to COVID-19).

As well as frequent school visits, outreach activities are held at public bodies such as the IoP (e.g. Burchell was scientist in residence for a day in 2019, part of the IoP's 50th Anniversary of the Apollo lunar landing) and Royal Society (e.g. Lowry was a participant in the Rosetta mission display at the 2016 Summer Exhibition). In 2020, SPS won a silver award for excellence in its strategic support for public engagement, in the first ever round of awards from the UKRI-funded National Co-ordinating Centre for Public Engagement.

Citizen Science: Froebrich (CAPS) operates the Beacon Observatory for Kent staff and researchers (including UG students), and also for local amateurs and citizen scientists across Europe. Meetings and training talks have been organised on and off campus, involving 1,600 people. Data taken by citizen scientists is used in the Hunting Outbursting Young Stars (HOYS) project, led by Froebrich, with ~72 active participants in 11 countries delivering data (over ~31,500 images so far, worth ~830 hours' pure exposure time on a 1m telescope). This has been used in five published refereed papers, with more in preparation or submission; some include citizen scientist co-authors (<https://hoys.space/science/>). Access to the Beacon Observatory has now been expanded as part of the Europlanet telescope network.

4.4 Developing Future Multidisciplinary Research

In 2019-20, a successful bid was made for a £250k Wolfson award to purchase a micro-CT scanner, with matching co-funding by the University. Podoleanu (AOG) and Burchell (CAPS) were Co-Is on the award. The scanner will be housed in an Imaging Centre in the School for

Anthropology and Conservation, and AOG/CAPS staff will use it when it opens in 2021. The Imaging Centre will also be accessible to a variety of external organisations, including archaeological trusts, the Kent Police College, and various industrial partners. It will be the only facility of its kind in the South-East, providing an opportunity to bring together University researchers with professionals and practitioners across many fields.

We also intend to broaden our activities in the health sector, with AOG taking a leadership role in establishing a cross-University research area in 'Health'. This exploits the opening of our new Medical School. AOG is also part of a Wellcome Trust project: Multi-user equipment for surgery with 10 co-investigators in the UK at King's College London (2020-25).

4.5 Networking and Contribution to the Discipline

Physics staff are strongly encouraged to network externally and support their discipline. This good citizenship is used in promotions, and throughout most of the REF period the Workload Allocation Model specifically allocated time for sitting on external panels and committees, etc. Physics staff are encouraged to be members or fellows of professional bodies, including IoP, RAS, RSC, APS, SPIE, OSA, etc. Physics has hosted externally funded Fellows from the Royal Society, Leverhulme, UK Space Agency, and ERC.

Podoleanu received a Royal Society Wolfson Research Merit Award 2015-20. Mason and Podoleanu were named in the top 2% of the world's scientists in the Stanford list (2020).

During the REF period, Physics staff sat on various national international panels, including:

- EPSRC Prioritisation Panel (Möller, 2017, 2019).
- NERC Prioritisation and Fellowship panel (Mason 2015-20).
- STFC Astronomy Grants Panel (Burchell 2013–18, and chair of the Planetary Sub-Division 2016–18).
- STFC Solar System Advisory Panel (Lowry 2012–19, Burchell 2019–22).
- IOP International Strategy Advisory Committee (Mason, 2015 onwards).
- International Commission of Optics (Podoleanu, 2017-21), one of the 8 elected vice-presidents.
- NASA Cassini and New Frontiers Data Analysis Programme Review Panellist (Lowry).
- Access Panels and Scientific Advisory Committee membership of national (Diamond, ISIS, XMaS) and international (PSI) beamtime facilities (Quintanilla, Ramos). Ramos is an invited member and the champion of the working group for the Diamond II Flagship project BERRIES (Bright Environment for X-ray Raman, Resonant Inelastic and Emission Spectroscopies) and a member of the Scientific Advisory Committee for the Muon Facility at the Paul Scherrer Institute (PSI) in Switzerland (2019 onwards).
- Scientific Steering Committee for the International Institute for Complex Adaptive Matter (ICAM/I2CAM) (Quintanilla).

Advising International Bodies and Governments

- Mason: ESF Review Committee of Portuguese Review of Physics Research Units (Chair of the Exact Sciences panel), 2014, and review of Faculties of Physical Science, Life Science and Earth Science of the University of Iceland, 2020.
- Podoleanu: member of the panel: Evaluation of Research Infrastructures for Inclusion in a National Roadmap, the German Council of Science and Humanities (Wissenschaftsrat), providing advice to the German Federal Government and the state (*Länder*) governments on the structure and development of higher education and research, 2016.
- Podoleanu: 2020, appointed by the Education Ministry in Romania to be one of the 5 members of the Selection Committee for Physics, selecting members of the National Council for accreditation of Higher Education titles, certificates, and diplomas (including doctoral titles).

Panel Membership

Staff have reviewed numerous grant applications and sat on allocation panels; e.g. nationally for CRUK, EPSRC, MRC, Royal Society, STFC, UKSA; and internationally for NSF, NASA, ESRF (Grenoble), Czech Science Foundation, Estonian Research Council, Finland Academy of Science, German Research Foundation, Humboldt Stiftung, Israeli Science Foundation, Irish Research Board, National Science Centre, Poland. Membership of panels awarding prizes includes:

- Burchell: member of the nominations committee of the American Physical Society Topical group on Shock Compression (2014–16) and Barringer Medal Committee of the Meteoritical Society (2013–16).
- Podoleanu: Chair of the IUPAP Young Scientist Prize in Optics (2017, 2018, 2019, 2021) and member of the Michael S. Feld Biophotonics Award Committee, OSA, 2016–17.

Conference Organisation

Physics staff regularly sit on committees, act as session chairs, and organise major international conferences. Conferences and workshops hosted at Kent in the REF period include:

- The 14th Hypervelocity Impact Symposium 2017 (attended by 120 academics with the 522-page refereed proceedings published by Elsevier (Burchell, Price, and Wozniakiewicz).
- Image Guided Therapies Network meeting, funded by EPSRC with over 100 members from academia, medicine and industry, 2018 (Podoleanu).
- The 2nd Canterbury Conference on OCT with Emphasis on Broadband Optical Sources, 2017, proceedings published by SPIE (Podoleanu).
- Mason: local Chair of the 2019 International Symposium on Atomic Cluster Collisions.
- Möller chaired the EPSRC-funded EMNEQ Focus Workshop: Algorithmic Perspectives on Complex Matter in 2019.

Our staff also organised numerous external meetings, including:

- Mason (President of Europlanet), major role in organising recent annual Europlanet meetings: Berlin, 2018; Geneva, 2019 (a joint meeting with DPS-US, with over 1,700 attendees, considered to be the largest ever planetary science meeting in Europe), and online in September 2020 (due to COVID-19) with 1,100 participants in 65 countries.
- Podoleanu: co-chair 'International Seminar on Biomaterials and Regenerative Medicine - BIOREMEDI 2017 – Today's research for tomorrow's medicine', Romania (2017), and co-chair Fifth Congress of the World Federation for Laser Dentistry and Sixth International Conference on Lasers in Medicine, Bucharest (2015).
- Quintanilla: chair of the meeting on Unconventional Superconductors: New Paradigms for New Materials (Cosener's House, Abingdon, September 2018).
- CAPS members helped organise several one-day specialist meetings in London at the Royal Astronomical Society, plus a three-day astronomy workshop (2015).

Support for Online Meetings during the COVID-19 Pause

All regular internal meetings moved online to ensure continuity and support for staff during the pandemic. Staff in PQM (e.g. Quintanilla) developed guidelines for external bodies on how to run meetings online, which were adopted by the International Institute for Complex Adaptive Matter for general use. They were used in the Condensed Matter Physics in the City annual conference, re-branded 'in ALL the Cities' in 2020, one of the most highly attended Condensed Matter Physics conferences worldwide that summer (677 participants from 36 countries, with over 500 logged in at peak times). Carr and Möller took the leading role developing the online platform for the meeting, bringing together a conference portal, live zoom sessions, YouTube channel, and open notice board, with 11,000 views of the conference webpage on the PQM website.

Editorial Work

Physics staff hold editor and associate editor roles on journals including: *EPJ Techniques and Instrumentation*, *Int. Journal of Astrobiology*, *ISRN Biomedical Imaging*, *Molecular Astrophysics*, *Photonic Sensors-Springer*, and *Photonics MDPI*, and produced special issues of journals such as *Biomedical Optics Express*, *Journal of Modern Optics*, *IOP Journal of Physics C: Condensed Matter*, and *Procedia Engineering*.

Refereeing

All our staff review papers for journals such as: *PRL*, *Phys. Rev. A, B and X*, *Nature Physics and Nature Comms*, *Nature Scientific Reports*, *Optics Express*, *Optics Letters*, *A&A*, *MNRAS*, *Icarus*, *MAPS*, *Geochemica et Cosmochemica Acta*, and *Geophysical Research Letters*.

PGR Training

AOG organised two Marie Curie training networks that had 20 fully funded PhD positions in Europe. Staff have also organised several PhD summer schools, both at Kent and nationally. These include: Physics by the Lake (for Condensed Matter PhD students) at Windsor Great Park (2016, 2018), and Stirling Univ. (2019); GRADnet workshops on Strong Correlations (2016, 2018) and Advanced Materials (2019); and the STFC Astronomy PhD Summer School 2019 (held on campus).

External Visitors

Research groups have weekly meetings, which include presentations from both internal and external speakers (online during the COVID crisis). Distinguished external speakers give SPS colloquia; e.g. in 2017, Professor D. Queloz (Nobel Laureate, 2019) and, in 2018, Professor Sir Michael Berry. External visitors make research visits for periods from one day or more each year. AOG has attracted numerous ECRs and senior scientists such as 9 Erasmus Exchange students from the Universities of Lille and Brno, two academic visitors each for a year supported by China scholarships, a Marie Curie academic visitor from France for two years, and several other researchers from the US, Denmark, Romania, and Italy on shorter visits. CAPS has benefited from visits by various UK and US researchers (including the Head of NASA's Extraterrestrial Samples Curatorial Facility) and PhD students.