Institution: University of Oxford

Unit of Assessment: UOA09 – Physics

1 Unit context and structure, research and impact strategy

1.1 Overview

Department overview

The mission statement of Oxford's Department of Physics (Oxford Physics) is to: *"apply the transformative power of physics to the foremost scientific problems, educate the next generation of physicists, and promote public engagement with physics."*

We address those foremost scientific problems where the experience, skills, and intuition of a physicist can make most difference.

We are committed to equal, fair, and respectful treatment of all our members. We encourage an environment where all work together as **One Team**, a "can-do" attitude thrives, a strong sense of the common good prevails, and all share pride in our successes.

Our nine major scientific themes – Accelerator Physics • Astro- and Planetary Physics • Biological and Soft Matter Physics • Climate Physics • Particle Physics • Plasma Physics and High-Energy-Density Science • Quantum Condensed Matter • Quantum Optics, Quantum Information, and Cold Atoms • Semiconductor Materials, Devices, and Nanostructures – are described in §1.2. We work closely with cognate disciplines across Oxford, particularly in the Mathematical, Physical, and Life Sciences (MPLS) Division (one of Oxford's four academic divisions). This submission comprises 132 academic faculty, 33 early-career and 16 independent researchers, all from Oxford Physics. While academic staff numbers have remained stable since REF2014, there has been significant growth in research income, activity, and outputs.

	REF2021	REF2014
Published Papers (WoS) (average per year for period)	988	782
Permanent Academic Staff (FTE)	123.6	124.7
Doctoral Students (average per year for period)	406	383
Postdocs (average per year for period)	198	174
Average Annual Research Income	£32.9M	£23.2M
Research grants held (snapshot, final year)	£166M (2020)	£89.5M (2013)
International Prizes	38	20

Note that statistics quoted are for 01/08/2013-31/07/2020 unless otherwise stated, hereinafter "REF2021"; "REF2014" refers to "01/01/2008-31/07/2013".

In 2018, we opened the £50M Beecroft building (§3.2.1), comprising ultra-stable laboratories and a new home for theoretical physics. During REF2021, we also invested £8.3M in other labs and rehomed the Infrared Multilayer Laboratory from the University of Reading (§3.2.2).

The Beecroft Building © Jim Stephenson

We have six sub-departments, each with its own Head (HoSD). Every researcher is a member of a sub-department and works in one or more of our nine research themes. This devolved structure enables efficient interactions, and productivity. We strive to empower; decision making is devolved wherever possible. Over £1.2M annually is assigned directly to the research themes to invest. Research is supported by 160 technicians and administrative staff ("support staff").

Responsibility for Oxford Physics lies with the elected Head of Department (HoD), Ian Shipsey, who is assisted by five Associate Heads (AHoDs):

- **E**quality, **D**iversity, and **I**nclusion (AHoD-EDI)
- **G**raduate Research and **E**ducation (AHoD-GE)
- **U**ndergraduate teaching
- **R**esearch **I**nfrastructure (AHoD-RI)
- **E**nterprise, **I**nnovation and **B**usiness. (AHoD-EIB)

All departmental strategies and policies are developed and considered by PMC (the Physics Management Committee), which advises the HoD. Minutes are available online. Ordinarily, PMC meets nine times a year, but during the pandemic, weekly online. Membership comprises:

- HoD*
- Five AHoDs*
- Head of Administration*
- Head of Finance*
- Six HoSDs
- Two elected members (for three-year terms)

Day-to-day operation is overseen by the Senior Management Team (marked *) which meets weekly.

The HoD is elected every five years and is usually a previous HoSD or AHoD. AHoDs are appointed by the HoD. Sub-department Heads are elected for terms from three to five years.

1.2 Strategy and Research Themes

To deliver our mission statement we aim to:

- Identify areas where we can make the most scientific impact;
- Recruit globally, and retain, the best physicists, supported by the best technical and administrative staff;
- Recruit and nurture the best ECRs, postdocs, and graduate students;
- Increase total graduate student numbers from 400 to 500 via focussed fundraising, enabling academics to supervise on average four, and enabling ECRs to supervise graduate students;
- Develop and enhance our technical infrastructure and support services;
- Embed Equality, Diversity, and Inclusion (EDI) in all our activities, naturally fostering a supportive environment enhancing excellence;
- Value and support research, irrespective of its scale;
- Encourage interdisciplinary research both within Oxford and with other institutions, nationally and internationally;
- Play a leading role in major international experiments, in the exploitation of international facilities, and in the development of the next generation of scientific programmes;
- Ensure, by working closely with the UK community, access to all relevant scientific facilities (both national and international) through their use and development, shared projects, joint appointments, and visitor programmes;
- Enhance collaborative research links with industry.

Strategy is developed transparently through internal consultation via PMC, which is responsive to ideas from the entire department, and by annual one-day retreats and termly Research Fora involving all permanent academics. In 2018, we involved all academics and senior technical staff in a year-long study of future strategy (including faculty hiring) with a ten-year vision. Scientific cases for the 12 highest-priority faculty appointments were reviewed by PMC in 2019. Six were selected; and these were filled in Spring 2020. We also draw on external benchmarking and advice: in February 2020 we appointed an External Advisory Board (EAB), comprising 12 highly regarded international/UK research leaders. They scrutinised our ten-year vision and current operations during a multi-day in-depth site visit. We are implementing their valuable suggestions.

Below, we review the plans for the REF2021 period laid out in our REF2014 submission and how we have met them; and articulate our current priorities and vision for the next decade.

1.2.1 Accelerator Physics:

[Headcount: 7 researchers (incl. 0 ECRs)]

The John Adams Institute for Accelerator Science (JAI) is a joint venture between Oxford, RHUL, and Imperial; Oxford hosts the Director, six faculty, three visiting professors, 13 staff, and 20 PhD students.

Our JAI priorities in 2014 were “to work in partnership with RAL, ASTeC, and other UK and international institutions, such as CERN and DESY, and in R&D for major facilities”.

The current Oxford research programme is founded on expertise in beam dynamics, beam instrumentation, feedback and control, RF systems, metrology and alignment systems, lasers and plasmas, and medical beamlines. We collaborate with national and international labs in R&D for major facilities, including leadership roles in designs for a Higgs factory, energy-frontier proton-proton colliders, advanced acceleration techniques, and particle-beam therapy. These activities fulfil our 2014 priorities and guide the JAI's future.

In particle physics, JAI will be prominent in addressing the recommendations of the 2020 European Strategy Update by continuing our energy-frontier collider programmes. The JAI plans to lead in other future facilities, including low-emittance, high-brightness electron beams, high-energy/high-intensity hadron beams, and advanced acceleration techniques, including laser- and beam-driven plasma-wakefield acceleration. The JAI prioritises societal applications and plans to collaborate with industry and the medical community to deliver particle-beam therapy using electron, proton, and ion beams, including improving treatment access in low-/medium-income countries (LMICs). Several new appointments are currently in train.

1.2.2 Astrophysics and Planetary Physics:

[58 researchers (16 ECRs)]

In line with our 2014 objectives, we have focussed on leading and exploiting major international astronomical surveys with the goal of understanding key questions in cosmology, galaxy and star formation and evolution, accretion, and comparative planetology.

Within cosmology, activities include establishing the strongest limits on alternative theories of gravity which arose from the detection of gravitational and electromagnetic waves from the same event. We have made significant contributions to, and will exploit the data from, Euclid, Rubin, and the Simons Observatory. Observational cosmology was strengthened by a new appointment [Alonso].

Research in relativistic astrophysics, including time-domain studies of connections between accretion flows, winds, and relativistic jets was strengthened by a new appointment [Kocsis]; it has entered a new era with the routine detection of gravitational-wave bursts. Our research on galaxy formation and evolution benefits from astronomical surveys from 8-metre-class telescopes, and the citizen-science Zooniverse project; whilst galaxy dynamics benefits from theoretical and simulation work and our participation in GAIA.

In astronomical instrumentation, we have expanded research into superconducting quantum devices. In 2019, we incorporated the Infrared Multilayer Laboratory into Oxford Physics (§3.2.2). In 2020, we made a new appointment in space instrumentation [Howett]. The HARMONI and WEAVE optical instrumentation projects, which we lead, will be exploited on E-ELT and WHT, respectively. Further projects include CBASS (CMB polarimetry) and antenna/pulsar-survey-analysis design for SKA.

In solar-system physics, the SEIS-SP seismometer we co-developed now operates on Mars as part of the NASA InSight mission (2018). Our studies of the clouds and atmospheric dynamics of Neptune and Jupiter are fundamental to the interpretation of observations by the NASA Juno mission. Our instruments were selected for future missions including NASA Lunar Trailblazer, ESA Comet Interceptor, and ESA ARIEL. Extrasolar planets research has been strengthened by new appointments [Pierrehumbert as Halley Professor, Parmentier, Birkby].

We plan to consolidate our existing strengths with hires in machine learning and astro-statistics, ensuring optimal project exploitation; and to expand high-priority science and instrumentation areas (e.g. optical transients), shaped by new appointments [Savilian and Wetton Professors, several lecturers].

1.2.3 Biological and Soft Matter Physics:

[8 researchers (1 ECR)]

We use the tools of physics to address biological problems; and biology to create new tools for physics. Our research emphasises molecular biophysics, self-assembly, and active matter. We study molecular mechanisms of rotary biological motors, gene expression, ion channels, biosensors, membrane transport, mechanisms and structures of viruses (including influenza and SARS-CoV-2), biomimetic molecular machines, molecular and cellular mechanics, and evolution. We develop experimental and theoretical methods, including novel light microscopies, scanning probe microscopy, single-molecule fluorescence, self-assembly, statistical physics, and algorithmic information theory. Work by Yeomans on tissue mechanobiology has initiated much research on topological defects in biological systems. Our research is highly interdisciplinary and new links are frequently forged (§4.1.2).

Our 2014 strategy was to strengthen biological physics, especially active-matter research and synthetic biology, and to plan a new interdisciplinary biosciences centre with new posts. This has been achieved. We fundraised to create the Mosley Professor of Experimental Biophysics, to be appointed in 2021. Two lecturer posts will be filled in 2021/22, when most research moves to the new state-of-the-art Kavli Institute for NanoScience Discovery (KINSD) building, co-locating collaborating physical and life-science groups; KINSD (Deputy Director: Kapanidis) aims “to catalyse discovery by bringing the physical sciences into the cell”. The Rosalind Franklin Institute at Harwell provides new opportunities for collaboration in imaging and structural biology; joint appointments will be explored.

1.2.4 Climate Physics:

[17 researchers (4 ECR)]

Our 2014 aims were to strengthen work in the underlying physics of climate and, through partnerships, to integrate that knowledge into climate models. We achieved this by appointing Pierrehumbert, (fundamental climate physics of Earth and other planets) and Christensen, (uncertainty in weather and climate prediction and the role of small-scale processes). We merged several research directions to establish a strong programme in cloud-physics of Earth and other planets, encompassing theory, remote sensing, and cloud resolving; and established a new machine learning programme. Highlights include a new paradigm for overturning in the subpolar North Atlantic, a physics-based explanation for aerosol effects on precipitation, and assessment of meat consumption on the environment. We now have a central role in the Oxford Climate Research Network, which connects over 70 faculty across 18 units.

Collaboration with the Met Office has been strengthened as a member of the Met Office Academic Partnership. We have strong links to the European Centre for Medium-Range Weather Forecasts, the Max Planck Institute for Meteorology, and the NERC National Centre for Atmospheric Science (Gray served as Director of Science), actively contributing to three weather and climate models; as well as with ESA, RAL Space, and the NERC National Centre for Earth Observation (NCEO), contributing to operational and scientific satellite retrievals. We work on the effect of CO_2 emissions and shorter-lived climate pollutants such as methane in a cumulative budget framework, feeding into global (e.g. IPCC) and national climate policy and driving ambitious initiatives, such as *Oxford Net Zero*.

We are fundraising to create an endowed professorship in climate science to strengthen our work in the application of machine learning, and to enhance our societal impact.

1.2.5 Particle Physics:

[37 researchers (6 ECR)]

Our 2014 goals were to play a leading role in experimental design, technology development, fabrication, and data analysis; and to advance superstring theory (joint with Mathematics), QCD methods, and Beyond Standard Model (BSM) model building. These have been achieved as outlined below.

We exploited ATLAS-LHC data to discover the copious but elusive Higgs decay to b-quarks, observed first hints of Higgs decay to muons, and established limits for dark matter and SUSY particles. In the LHC-b experiment, we led first observation of CP violation in charm mesons. We played an important role in finding the first hints of CP violation in the neutrino sector in the T2K experiment. We completed the first model-independent calculation of the photon content of a fast-moving proton, developed a natural SUSY theory of the weak scale consistent with present LHC limits, and established the consistency of neutrino deep inelastic scattering with QCD up to 980 TeV. We carried out the first 3-loop QCD calculation.

We lead next-generation neutrino experiments (DUNE and Hyper-Kamiokande) and investigate the Dirac/Majorana nature of neutrinos by searching for neutrinoless double-beta decays using SNO+ and for dark matter with LZ, strengthened by the appointment of the LZ physics coordinator [Palladino]. Oxford particle and astrophysicists form the only UK Rubin group involved in instrumentation (the camera), software, and preparing dark-energy analyses. We joined Mu3e; $\mu \rightarrow 3e$ discovery would give unambiguous evidence for new physics. We are developing quantum-sensor dark-matter/gravitational-wave experiments, including the now-funded AION interferometer, and plan wide deployment of quantum technologies in particle physics.

The ultra-violet completion of low-energy-physics theories is a key element of our theory programme, which encompasses the interface of phenomenology and quantum gravity, construction of viable superstring theories, and implications of gauge-gravity correspondence. Our QCD methods and machine learning algorithms enhance understanding of the Standard Model from precision Higgs data. New appointments: [Salam, RS Research Professor; Caola (QCD); and Agrawal (BSM physics)].

Exploiting experience building the silicon ATLAS-SCT, we made major contributions to the LHCb-VELO upgrade (a silicon-pixel detector) and are building the ATLAS-ITk silicon-strip and pixel systems for the High-Luminosity LHC in the new Oxford Physics Microstructure Detector facility (OPMD). The ultra-light HV-CMOS tracker for Mu3e is being built in OPMD, where the Rubin CCD work is also based. We lead the DUNE DAQ. We are developing TORCH, a novel detector for particle ID for a further LHCb upgrade. With the JAI, we lead studies for major new collider facilities that will shape the field for decades to come.

We plan to create a laboratory for non-accelerator physics instrumentation and strengthen the programme through new hires including the Perkins Professorship.

1.2.6 Plasma Physics and High-Energy-Density Science (HEDS):

[9 researchers (0 ECR)]

Our strategy centres on creating strong synergistic links with national/international laboratories hosting world-class facilities. Our plasma-physics research ranges from fundamental (plasma turbulence, transport, many-body quantum plasmas) to applied (inertial and magnetic-confinement fusion, plasma accelerators). Highlights includes laboratory demonstration of magnetic-field amplification by turbulent motion ("IoP Top 10 Physics Breakthrough of 2014"); first numerical evidence for turbulent dynamos in a collisionless plasma and first experimental evidence of a dynamo in the laboratory; new theories of non-linear firehose and mirror instabilities in a moving plasma; reconnection-mediated MHD turbulence; demonstration that shocks in radio-galaxy lobes are a likely source of the highest-energy cosmic rays; demonstration of thermal disequilibration of ions and electrons by collisionless plasma turbulence; and design of an optimal plasma shape to induce rotation in tokamaks. We articulated the case for DiPOLE (a high-power, high-repetition-rate, diode-pumped nanosecond laser developed at RAL, operating at European-XFEL) that will allow solid-state matter to be generated at TPa pressure and probed via femtosecond X-ray diffraction. This opens new regions of the phase diagram of matter, relevant to e.g. exoplanet research by recreating planetary cores in the laboratory and materials science.

Our Plasma Theory Group is key to the TDoTP grouping on turbulence and transport in MCF devices. The HEDS group exploits the new generation of XFELs to unravel the quantum behaviour of matter at extreme conditions, optimising inertial-confinement-fusion capsule design by machine learning, demonstrating first steps towards an energy-recovery plasma accelerator and first experimental hints that non-classical radiation loss may be measurable with laser-accelerated electrons. We will play a key role in the ExCALIBUR exascale computing programme and undertake kinetic simulations for astrophysics and fusion science including STEP.

New appointments have strengthened HEDS/Plasma Physics [Vinko, with CLF], MCF Theory and Simulation [Barnes, with UKAEA], and magnetised plasmas for nuclear-fusion energy [Parra-Diaz]. Further joint appointments and fundraising for endowed professorships in plasma physics and HEDS are planned.

1.2.7 Quantum Condensed Matter:

[18 researchers (2 ECR)]

Our 2014 strategy centred on theorists and experimentalists collaborating on emergent and non-equilibrium phenomena in many-body quantum systems, using external facilities such as ISIS and Diamond, – achieved by recent breakthroughs in strongly correlated electronic systems and quantum magnets, and employing novel theoretical and experimental methods. These included understanding the roles of nematic fluctuations in high-temperature superconductivity and of distinct interaction in frustrated magnets displaying Kitaev-type physics. STM/spectroscopy techniques complement existing expertise exploiting Diamond (e.g. ARPES and resonant X-ray scattering) and the ISIS neutron and muon sources. Magneto-transport and other techniques in strongly correlated materials are also important. Recruitment of a world-leader in scanning tunnelling microscopy and spectroscopy (STM/spectroscopy) was planned; and achieved [Davis] via the attraction of our state-of-the-art experimental facilities in the new Beecroft building.

Significant breakthroughs have been made in topological materials, including observation by ARPES of features in Dirac semimetals and materials hosting Weyl fermions, observation of vortices and merons in antiferromagnets, and development of novel methods to measure winding numbers in Skyrmions. Moiré and other van der Waals materials have been a fertile direction for theory, combining topology with strongly correlated physics.

A third strand is quantum many-body dynamics out of equilibrium, which requires re-evaluation of many principles of statistical physics. We have made key theoretical advances in the field of non-equilibrium phases of matter related to “many-body localised” insulators, Floquet systems, and the physics of thermalisation.

We will exploit our outstanding new experimental facilities to attract a specialist in materials synthesis to enhance our capability to discover and develop new families of quantum materials; and recruit a world-leading theorist in quantum condensed matter to the Wykeham Professorship.

1.2.8 Quantum Optics, Quantum Information and Cold Atoms:

[19 researchers (4 ECR)]

Our 2014 objective “to use our breadth of expertise to undertake research across the gamut of QIS from foundational questions to [Quantum Technologies]” has been fulfilled. Oxford [PI: Walmsley, since 2018 Provost at ICL] led the Networked Quantum Information Technologies (NQIT) Hub. We designed and built the UK’s first quantum network, achieving the best combination of fidelity and speed worldwide. We have demonstrated the world’s first sub-microsecond logic gates for trapped-ion qubits, combining the leading fidelities of this platform with the MHz speeds of solid-state technologies; the first demonstrations of “mixed-species” quantum logic and tests of Bell’s Inequality; and the first high-fidelity electronically-driven logic gate for trapped-ion qubits. We lead the follow-on Quantum Computing and Simulation (QCS) Hub [PI: Lucas] and its ion-trap work package; and have excellent links with the National Quantum Computing Centre (NQCC) at Harwell.

Our work on out-of-equilibrium quantum systems is both fundamental and directly relevant to quantum technologies. We made appointments in quantum optics [Lvovsky], many-body physics [RSmith], and microwave quantum devices [Leek], and plan more across QIS, cavity QED physics, ion-trap quantum science, and quantum sensing for fundamental physics. We will explore new joint positions with NQCC and recruit a world-leading experimental quantum physicist to the Hooke Professorship. We are fundraising for an additional endowed professorship in experimental quantum physics. The new UKRI “Quantum Technologies for Fundamental Physics” (QTFP) programme (§4.1) will support a new experiment (AION) on atom interferometry in the Beecroft laboratories, building on our strong links with NPL.

1.2.9 Semiconductor Materials, Devices and Nanostructures:

[8 researchers (0 ECR)]

Our strategy, as set out in 2014, is to investigate the properties of organic and inorganic electronic materials (particularly fundamental understanding and device fabrication) using THz, time-resolved and excitation spectroscopy, to discover and understand new semiconducting materials with transformative applications such as green energy production.

Recent highlights in achieving this strategy include bio-mimetic porphyrin nano-rings, dye-sensitized solar cells, organic photovoltaics and solar concentrators, non-polar InGaN quantum dots, GaAs quantum rings, and photonic crystals for quantum information. This research is underpinned by outstanding nanoscience infrastructure (§3.2.2) and much is interdisciplinary e.g. with Oxford Chemistry and Materials. A new initiative in material modelling using density functional theory has been launched via a recent appointment [Filip]. The National Thin-film Cluster Tool (NTFCT) will open in Oxford Physics in 2021 (§3.2.2).

Perovskites have proven to be excellent photovoltaics. Achieving more efficient multifunctional perovskite cells, stand-alone perovskite thin films, and composite devices with other emerging photovoltaic materials, such as organic compounds, pose interesting physics challenges. Understanding and overcoming losses and instabilities in both wide-gap and narrow-gap perovskite materials is vital.

New appointments in the physics of nanostructured devices and in interface energetics in functional materials and devices are planned, alongside fundraising to create an endowed professorship in energy. These will extend collaboration with RAL and MPI; and via NTFCT will develop new, multilayer device architectures and new compound semiconductors inspired by metal-halide perovskites.

1.2.10 Research Themes: Sustainability and Synergies

Our thematic structure is a key mechanism for ensuring sustainability. Staff are free to pursue their own research agendas, while themes provide the identifiable critical mass and leadership required to attract high-quality staff and students, maintain significant networks of collaborators, lead national and international research initiatives, and secure long-term funding.

Synergies abound between the themes: e.g. quantum devices are as relevant to astrophysics and particle physics as to quantum computers; astrophysicists and particle physicists work side-by-side on Rubin; climate science and HEDS informs (exo)-planetary research; and statistical physics can be applied to biological systems.

Our involvement in large instrumentation projects across astro-, planetary, and particle physics benefits from common elements including shared technical infrastructure and technical software expertise. For example, silicon-detector research cross-fertilises particle physics, astrophysics, and photon science; and has also led to interdisciplinary collaborations with Oxford Chemistry, Materials, and Archaeology. Machine learning is now ubiquitous, resulting in a department-wide community and new seminar series.

1.3 Impact Strategy

Our impact strategy follows our mission statement:

(i) *"to apply the transformative power of physics"* through translation of our research and expertise to create products, services and companies that meet business and societal needs, and through embedding innovation and entrepreneurship into our teaching and training programmes;

(ii) *"to further public engagement with science"* and to increase participation in STEM;

(iii) to communicate our scientific knowledge and to advise UK and international policymakers; and

(iv) to embed EDI, which maximises science and impact reach.

Three of our **Impact Case Studies** illustrate the direct commercialisation of our research through licensing (1), spinout creation (4,6), or collaboration with industry (4); a fourth (3) shows how our radio astronomy underpinned development of the UK's Space Communications Gateway and economic regeneration in Cornwall. Four (2,5,9,10) describe public engagement with research, particularly our pioneering involvement in 'citizen science'. Two illustrate (inter)national climate policy impacts (7,8). Our case studies also demonstrate the interrelated nature of our strategy: a citizen science project (10) also influenced policy on the preservation of cultural heritage. EDI underpins all case studies, most clearly seen in 2, 5 and 9.

1.3.1 Impact Strategy: Innovation and Enterprise (I&E)

Over the last two REF periods, the research interests of our academics have evolved to embrace many new creative applications of basic research, notably quantum technologies but also e.g. metrology developed for particle physics. Strategic goals for this period included strengthening relationships with existing partners, reaching new ones, and increasing faculty relationships with industry via:

- raising the profile and visibility of I&E by creating the AHoD-EIB position and strengthening the I&E Committee;
- enhancing delivery of I&E by appointing a full-time I&E Manager, to complement the support provided by Oxford University Innovation (OUI), the University's technology transfer office;
- encouraging researchers to file patents, create their own spinouts and/or license to others, thus providing more options in commercialising our IP.

Our strategy has led to a significant increase in innovation and successful commercialisation. During REF2021, we made 126 new IP disclosures (almost 50% of total inventions to date from Oxford Physics), licensed 37 inventions to companies, filed 67 new priority patents, executed 112 consultancy agreements, and spun out nine companies (§4.3.1) (one in REF2014). We will continue to drive and enhance our innovation culture.

We create new links with business through regular showcase events and user-engagement workshops – e.g. 2018 Space Industry Day (176 delegates, 50% industry) and 2018 NQIT Industry Day (83 attendees, 70% from industry and government agencies) – to engage with future users of our technology, better to understand potential applications. We also are promoting access to our specialist equipment and services (§3.2.2), leading to mutual recognition of expertise and hence wider collaborations (§3.4).

As part of our aim to grow participation, we have embedded EDI into our I&E programmes e.g. initiating a biennial Enterprising Women event (in which women leading physics-based businesses speak).

Local Innovation Ecosystem: The Oxfordshire Local Industrial Strategy recognises quantum computing and space-led data applications as breakthrough sectors, and we have strong links to the Oxfordshire Local Enterprise Partnership (including through NQIT) and to the space-industry cluster (§3.4) at Harwell. We have benefitted from the step-change in commercialisation activity that followed the 2015 creation of venture capital firm Oxford Sciences Innovation plc (OSI): all nine of our spinouts have engaged with OSI.

1.3.2 Impact Strategy: Public Engagement

Public engagement is a core part of our mission. We aim to:

- promote public engagement with physics research, including facilitating researcher-led programmes e.g. Zooniverse;
- increase diversity in STEM by encouraging under-represented groups including BAME and those from less-affluent socio-economic backgrounds to engage with physics, both professionally and as members of society, thus enhancing the subject's vitality and sustainability.

All researchers (including students) are offered guidance and training in PER (e.g. annual Outreach Development Day), while senior academics champion its importance. We run two large-scale public events (Stargazing Oxford, and Physics: Lab to Life), lecture programmes, partnerships with local schools and seed-fund new projects. Activities include articles for national newspapers, television, and radio; YouTube videos (astrophysicist 'Dr Becky' has 250,000 subscribers); workshops sharing knowledge and skills (including with LMIC graduate students, postdocs, and schoolgirls); and festivals. Lintott has co-presented the BBC's "Sky at Night" since 2008. Ten colleagues have written popular books about their science. UKRI funds our project with school children using CERN OpenData, fostering the open-research culture; and our Oxford May Music Festival, which brings science to a diverse international audience. We lead the Zooniverse citizen science platform, with more than two million registered users across 100 projects.

Our work with schools and adults, directly reaching over 200,000 people in the last five years (§4.4.3), has been recognised with multiple awards (§4.6).

1.3.3 Impact Strategy: Communication

In 2019, we appointed a Head of Communications (HC) to improve awareness of our impact agenda and opportunities; enhance our reach and influence outwards, especially to those without a scientific background; and create a new, professionally-designed Oxford Physics website, benefitting both internal and external communications.

Communication with policy makers: We encourage, support, and advise colleagues who have opportunities to engage with policymakers e.g. giving evidence to Parliamentary Select Committees or speaking at Chatham House. Colleagues from Oxford Physics and the wider University with extensive experience and training in this area provide advice to those less experienced.

1.3.4 Impact Strategy: Equality, Diversity, and Inclusion (EDI)

Building on our 2014 strategy, we continue to work to provide a safe and equitable environment where everyone can realise their potential, irrespective of ethnicity, gender, sexuality, or socio-economic background. While our aim is that our composition should reflect society, there remains some distance to travel. Achieving this goal will maximise our reach, because it facilitates connections to diverse communities, which naturally leads to innovations that benefit society. We recently created an AHoD-EDI to ensure EDI principles are embedded in everything we do (§2.4).

1.4 Interdisciplinary Research

Interdisciplinary research is strongly encouraged and supported:

(a) A reduced teaching load is given to colleagues who are: (i) developing proposals for interdisciplinary research (§4.1.2); or (ii) providing leadership in identifying and developing interdisciplinary research opportunities in the wider University e.g. Herz as Associate Head of MPLS (Research);

(b) Since 2019, departmental task forces develop interdisciplinary activities on e.g. machine learning (two new seminars and joint projects with Oxford Computer Science and Mathematics);

(c) Participation in cross-department Oxford networks (§4.1.2);

(d) The capabilities of our Small Research Facilities (SRFs) catalyse opportunities for (interdisciplinary) research (§3.2.2).

We strengthen partnerships and facilitate joint appointments with significant interdisciplinary components with other institutions, e.g. Diamond, the Central Laser Facility, ISIS, and the Max Planck Institutes (§4.1).

1.5 Communication Within Academia: Open Research and Beyond

Open Access (OA) is part of our Departmental culture. Supported by an OA Officer, academics take personal responsibility for Open Access dissemination of their work, via the Oxford Research Archive (ORA), ArXiv, and ‘Gold’ OA publications. Academics provide Open Data via ORA or experiment-specific repositories, and nine Oxford-coordinated EC-funded projects are part of the Commission’s Open Data pilot. Many projects generate software, most shared as Open Source via Github or other repositories.

1.6 Research Integrity

We are committed to research integrity, which is emphasised to new staff and in online courses. We have rigorous conflict-of-interest processes around spinouts and consultancy. The HoD is responsible for ensuring that all research is conducted according to appropriate ethical, legal, and professional standards. The Research Facilitation team and two senior academics independently approve every research grant application. Institutional-level ethics committees (e.g. for some Biophysics projects) and central Research Services provide additional checks. All staff and visitors agree to comply with University and Department regulations.

2 People

2.1 One Team

To ensure our effectiveness as an organisation, we strive to create an environment in which we are all valued members of **One Team**. Our ethos is introduced to new staff at the monthly departmental induction by HoD and HR lead. We emphasise **One Team** at regular faculty meetings and biannual all-department meetings.

To achieve **One Team**, we ensure that **Equality, Diversity and Inclusion (EDI)** is embedded in everything we do (§2.4), and we deploy our highly competent and responsive **administrative and technical support** (§3.3) to reduce the administrative burden on researchers to the minimum possible, maximising their potential to fulfil our mission statement:

1. Maximising researchers time to think and develop new ideas "*to apply the transformative power of physics to the foremost scientific problems"*;
2. Prioritising quality of teaching *"to educate the next generation of physicists*";
3. Encouraging participation in PER "*to promote public engagement with physics"*.

2.2 Academic and Research Staff

2.2.1 Development

New lecturer appointments are for a probationary five-year term, with reviews after two years (an important early checkpoint to catch and address difficulties) and in the fifth year. The PMC oversees this process. Each new academic has an experienced (academic) mentor who is key in ensuring they receive necessary support (all staff can request a mentor). Teaching and administration loads are adjusted to ensure new academic staff gain experience, whilst having time to establish their research in Oxford: all new lecturers receive a departmental teaching waiver in their first year and a 50% load in their second and third years; many also have reduced college-assigned (tutorial) teaching during this period.

New academics receive £20k start-up allowance and supervise at least one fully-funded 3.5-year PhD student. The Research Facilitation team (§3.3) supports applications for research funding, especially important for those unfamiliar with the UK funding landscape. If, by the two-year review, someone has produced excellent proposals and publications but not been awarded a grant with PDRA funding, we fund a three-year PDRA. We make substantial investments to equip labs and/or provide dedicated compute clusters; and contribute additional funds to many grant applications. Bench fees for visitors of new appointees are waived in their probationary period. Staff new to graduate supervision receive training and are assigned an experienced academic to act as co-supervisor. New academics are prioritised in funding applications to University seed funds (awards typically £50k-£150k), usually for critical items of equipment. We offer help with loans for visa costs and NHS surcharges.

Academics are supported to develop their careers via annual one-to-one Professional Development Reviews with a senior academic (chosen in consultation with HoD), and with HoD every five years. This provides support for work objectives, achievements and difficulties, career development and training needs. Promotion opportunities (via the University's Recognition of Distinction exercise) and external recognition are discussed.

Postdoc probation is a formal year-long process, with clear goals and tasks. Subsequent annual performance reviews are conducted by supervisors, who receive training from the University. Postdocs are offered Professional Development Reviews.

Support for research staff – mostly postdocs plus nine Junior Research Fellows (college career-development posts) – is crucial. The *Concordat to Support the Career Development of*

Researchers is implemented. The entitlement to a minimum ten days p.a. for career/professional development is well publicised. All staff have access to widely advertised University training opportunities in transferable skills, including teaching, IT and languages, leadership, and management.

A Committee of Postdocs organises annual events including a Researcher Conference. Departmental financial support to attend conferences is available. Postdocs are encouraged to teach, contributing to professional development including helping to secure permanent academic posts.

Our Research Facilitators (§3.3) assist with the preparation and review of all grant proposals and advise on appropriate funding schemes. We encourage and support early-career fellowship applications, of which half are from external candidates; all are mentored by an Oxford academic to ensure high-quality proposals, well matched to strategic priorities.

Our research depends crucially on the expertise of research-support staff (e.g. engineers and technicians). Many have enormous experience and vital skills that are secured by the award of permanent contracts where the potential for long-term grant support exists. These colleagues access similar development opportunities to academics, including opportunities to teach and, where appropriate, take sabbaticals (§2.2.3). Some develop into independent researchers and may earn Associate Professor title (equivalent to lecturer) e.g. Karastergiou.

We have a strong record of successfully developing the careers of our staff: ECRs progressing to faculty posts elsewhere during the period include Jennings (lecturer, Leeds, 2018), Johnson (lecturer, UCL, 2019), and Vacheret (lecturer, Imperial, 2016). Taking a longer view, of the 71 postdoctoral fellows of the Beecroft Institute for Particle Astrophysics and Cosmology since 2001, 57 are now in permanent academic or research positions.

2.2.2 Recruitment and Demographics

We seek to hire world-class academics via our dynamic intellectual environment, our world-class facilities, the strength-in-depth of our large faculty, an increasingly diverse and inclusive culture, availability of outstanding graduate students and postdocs, and interdisciplinary work often catalysed by the intellectual breadth of the college environment.

Academic and research posts are recruited by open competition, advertised globally, attracting large pools of well-qualified applicants. To ensure the fairest possible competition, all Oxford academic search committees have a diverse membership (including at least two females, and external members); all members must undertake unconscious bias training. We have appointed 27 new permanent academic staff during REF2021: six professors and 21 lecturers (25 left, mostly retiring). Five of the last eight lecturer appointments were women, with one BAME. The proportion of female PDRAs is increasing, from 18% (2008) to 24% (2013) to 28% (2020).

Of the 21 lecturers recruited in the period, 11 came from overseas institutions, four from other UK institutions, and six were internal hires of prestigious fellowship holders. Our six professorial hires in REF2021 included one woman: Bortoletto (E.M. Purcell Distinguished Professor, Purdue), Davis (A.D. White Distinguished Professor, Cornell), Pierrehumbert (Louis Block Distinguished Service Professor, Chicago), Rose (Imperial College), Salam (Senior Staff, CERN), and Shipsey (Julian Schwinger Distinguished Professor, Purdue).

Among Category A staff, 106 have permanent research and teaching contracts, 24 hold permanent research-only contracts, 44 (32 ECR) hold fixed-term research-only contracts, four (one ECR) hold fixed-term research and teaching contracts, and three hold open-ended externally-funded research-only contracts. Just under 20% of our Category A staff are ECRs, whom we support in applications for open-ended/permanent opportunities.

Of our permanent academics, 17% are female; 56% of women and 41% of men are 50 or under. The number of anticipated retirements over the next seven years is approximately the same as during REF2021, including 50% of Named Professors, which facilitates changes of strategic direction. We do not automatically replace in sub-discipline but determine the sub-discipline of the new hire via strategic planning informed by staff discussions.

Succession planning for Departmental leadership is built into the system. HoSDs and AHoDs, who are *ex-officio* members of PMC, rotate every 3-5 years, thus building a cadre of potential HoDs. Similarly, the unique and almost irreplaceable specialist skills that technical staff possess requires a succession plan for all Technical Services Group (TSG) posts well ahead of retirement, primarily achieved via appointment of apprentices whom we train.

2.2.3 Sabbatical Leave

Academics accrue one term's leave for every six terms worked (excluding terms where other leave, e.g. parental, is taken). In 2019, we extended this provision to cover all staff with academic title, irrespective of underlying contract type. Sixty-four people have collectively benefited from 160 terms of sabbatical leave in REF2021.

2.2.4 Exchanges of Knowledge and Expertise

EPSRC Impact Acceleration Account (IAA) funds support exchanges with industry, e.g. Oxford PV (2014), and Torr Scientific (May 2020); and enabled Reichold to visit Etalon GmbH and PTB (National Institute of Standards, Germany) as visiting professor. The NQIT and QCS Hubs' User Engagement included placing the IBM Q Hub within Oxford. Three students participated in the STFC-POST Fellowship scheme, working in parliament/government. Eleven graduate students spent time at industrial partners, including an STFC CASE project with the accelerator-beamline-component manufacturer FMB Oxford Ltd. Consultancy enables researchers and academics to gain experience of industry, to apply their expertise, and to gain insights into user challenges (§4.3.2). Academics can apply for fixed-term reductions in FTE to spend a more extended period working at their spinout or at an industry partner. We host visiting professors from industry, e.g. Oliver Heid (Siemens).

2.2.5 Recognition and Reward

During REF2021, eight senior researchers were awarded Associate Professor title (equivalent to lecturer); and 32 members of Oxford Physics were awarded 'full Professor' title through the University's annual Recognition of Distinction exercise – demonstrating excellence in research, teaching, and good citizenship, as judged through international peer review. To ensure that everyone eligible is considered, we have created an academic promotions committee. Nine Physics academics also received merit awards (salary supplements).

We aim to provide academics with an equitable balance of research, teaching and administrative responsibilities. A workload allocation model adjusts teaching and administration loads based upon time committed to funded research projects, or for those who take on academic leadership roles in the wider University (e.g. Herz, Jarvis, and Taylor as Associate Heads of MPLS) or outside Oxford. Those holding Professor titles may also apply to transfer permanently to a more research-intensive role: this gives the flexibility to capitalise upon significant funding awards and/or to expand promising research activities, e.g. Chalker (quantum materials) and Fender (astro-transients).

In REF2021, we received 15 University Impact Awards for commercial, societal, and public engagement activities, e.g. KBlundell for inspiring girls in LMICs and Karenowska for cultural heritage preservation.

2.3 Graduate Students

2.3.1 Recruitment and Admission

We offer six distinct, coordinated PhD programmes, reflecting the breadth of our research. Each programme is led academically by a Director of Graduate Studies (DGS). The AHoD-GE implements department-wide policy and represents the interests of graduate students to the University. We run open days, enabling applicants to meet supervisors, current students and PDRAs. We participate in access schemes such as UNIQ+ and we initiated CUWiP (§2.3.1.1).

Applications increased by 20% during REF2021, with 603 applicants for the 2020 intake of whom 20% were women, 27% BAME, and 9% declared a disability (these proportions are maintained among our admitted students). On average, we admit ~90 students annually, of whom 22% are female, 22% from the EU, and 22% from overseas; during REF2021, we have admitted students from 59 countries.

2.3.1.1 The Conference of Undergraduate Women in Physics

In 2016, we launched the CUWiP initiative, which provides a three-day programme of talks, workshops, lab visits, and social activities to showcase options for women's future in physics and introduce them to inspiring women physicists; 100 students participate each year, selected from across the UK and Eire. We catalysed the nationwide expansion of CUWiP: the 2020 event was in York.

2.3.2 Sources of Funding

Our graduate student population averaged 406 in REF2021. Around 90% of our intake win funding competitively: 55% (about 220 are UKRI funded); 7% (in 2020) hold prestigious individual scholarships, e.g. Rhodes; 8% hold college scholarships; 12% hold other philanthropic and institutional funding, including the Hintze Foundation and partnerships with Kavli-IPMU (Tokyo), Max Planck Society, and US national laboratories. We also have co-funded studentships with RAL, CLF, Diamond, ISIS, and CERN. We receive studentships annually from EPSRC and STFC DTPs, proportionate to our research income; and some of our larger STFC and EPSRC grants fund project students. We participate in CDTs, e.g. the Oxford NERC DTP in Environmental Research (leading the Physical Climate Science stream), BBSRC Oxford Interdisciplinary Bioscience, EPSRC/MRC Oxford-Nottingham Biomedical Imaging, EPSRC/BBSRC Synthetic Biology, EPSRC Life Sciences Interface, EPSRC New and Sustainable Photovoltaics, and four others. A CDT-like experience is provided by teaching co-operatives for first-year graduate students in e.g. accelerator physics (with ICL and RHUL) and plasma science (ICL and Warwick). We plan where appropriate to develop new CDTs with other Oxford departments and partner HEIs. We receive EC funding for students via ERC grants and Marie Curie ITNs; and Royal Society studentships associated with fellowships.

2.3.3 Research Training, Supervision and Monitoring

An intense induction week acquaints students with resources, opportunities, and Oxford. The Department as a whole forms a training unit functionally similar to a CDT. Each of the six PhD programmes has a roughly equal intake, forming a cohort of ~90. Training consists of a mandatory first-year taught component, with 60-80 hours of lectures and transferable skills training. Each programme has a core covering the foundations of its subject as well as general skills such as instrumentation, computing, machine learning, and statistics. These are complemented by many options: we offer ~100 taught graduate courses within Oxford Physics and ~400 within MPLS and the central University. Every student creates a personal programme in consultation with their supervisor and DGS. All students continue participating in relevant seminars and journal clubs beyond Year 1.

Supervisors assess student progress termly and produce online reports. The student's college advisors and our DGSs monitor these proactively to identify potential problems; colleges also provide pastoral support. Where relevant, we appoint external co-supervisors for students who are part of research collaborations external to Oxford Physics.

There are two formal milestone assessments:

(1) By the end of fourth term, for transfer to the status of PhD candidates: two independent examiners assess performance in taught courses, a report, and an oral presentation of the student's research. A follow-up review occurs if necessary.

(2) A similar procedure by the end of the third year assesses progress towards thesis completion. An MSc by Research offers an exit qualification (taken by ~2%). The completion rate for UKRI students with a deadline of 30 Sept 2019 was 91.1% and the five-year average prior to that was 88.9%.

Over 85% of our students publish a paper during their studentship; more than 50% authored at least four. Students have won 12 international awards including e.g. seven from Springer during REF2021.

2.3.4 Student Research Support, Development and Transferable Skills Training

Students access a range of skills development courses, including academic skills (writing papers, conference presentation, etc.). Our "Research Context" course (2020) enhances understanding of funding environments for future grant applications. In 2020 we launched a new Physics Innovation and Entrepreneurship course, developed with the Saïd Business School. Currently 35 physics postgraduate students are engaged in activities at the Oxford Foundry student entrepreneurship centre. A team including our students won the inaugural Oxford Student Entrepreneurs Programme and has formed the start-up company Quantum Dice (§4.3.1).

Financial support is available for conferences, fieldwork, and research visits – from individual conference attendance to 1-2 years at international facilities. Each student is encouraged to present at one conference/summer school per year.

A committee of academics and graduate students, chaired by AHoD-GE, is the primary route for feedback from students and reports to PMC. Annual "town meetings", led by programme DGSs, allow students to raise concerns. Committee discussions produced a student-led workshop "Designing a successful PhD", with highly positive feedback, which resulted in improvements to the induction programme. Graduate students are represented on the EDI committee (§2.4.2).

The independent Student Barometer Survey gauges satisfaction with the graduate student experience. In 2019, 97% were 'satisfied or very satisfied' with the expertise of academics; 92% with Department learning technology; 87% with performance feedback from academics; and 88% 'satisfied or very satisfied' across all questions.

Our PhDs are highly prized. Within six months of completion (for leavers 2013-17), 99% of PG respondents were in employment: 63% in academia (mainly PDRAs), 10% in other scientific research in national labs and industry, 8% in IT, 7% in finance, 6% in engineering or manufacturing, and 5% in government, policy, or law. One third had left the UK, including 32% of those in academia.

2.4 Equality, Diversity, and Inclusion (EDI)

We recruit staff irrespective of race, gender, sexuality, socio-economic background, or other protected characteristics. Our highly multinational workforce is enrichingly cosmopolitan (drawn from >48 different nations). We strive to create an environment free from discrimination, where all feel empowered to speak. We have consulted with, and adopted, best practice from our peers. Physics holds mandatory courses against unconscious bias and harassment; and to ingrain the concept of the responsible bystander. Bystander intervention is a vital component in tackling bullying and harassment; everyone has a part to play in creating workplace culture. Eleven members of staff are trained Harassment Advisors. We are developing a bespoke mentoring scheme for all staff (all ECRs already have mentors); from 2021, EDI will be taken into account alongside research and teaching in our recruitment.

Since REF2014, we have been awarded Athena SWAN Silver (2014, previously Bronze) and IoP Juno Champion (2016, previously Supporter) status. Some activities and actions we have carried out in this area, alone or in collaboration with MPLS or national initiatives, are discussed below.

2.4.1 Support for Carers

We provide parental leave to all graduate students for 26 weeks, paying the standard UKRI stipend to either partner. We provide funding to PIs to cover for PDRAs on parental leave. For academics, before leave commences, a colleague is appointed to ensure continuity is maintained and important tasks covered. Academics returning after parental leave are given no teaching or administrative duties during the first year. We sponsor five (the maximum permitted) University nursery places. This support has ensured that of 28 people (five males) who took parental leave during the period, all but two returned to work as planned.

Flexible working arrangements are available to all, particularly to support those with child/other caring responsibilities, with medical conditions, and staff returning from any form of leave. Around 95% of staff surveyed are aware of this; 24 academics (5 postdocs) have formal flexible working arrangements, and many more work flexibly informally.

For those attending conferences/meetings in-person, an initiative to assist with replacement care provision or resources where needed has been in place since late 2019.

2.4.2 Career Development and EDI

EDI principles are embedded in all decision making. The AHoD-EDI sits on PMC and chairs the EDI Committee (comprising the HoD, academics, technical and administrative staff, student and PDRA representatives) and the PDRA committee (facilitating communication of PDRA issues at PMC). The AHoD-EDI and other EDI committee members sit on the re-grading committee for technical and support staff and the new academic promotions committee.

2.4.3 Wellbeing and Mental Health

“Physics Thrive” is an informal mentoring network to discuss career development, wellbeing, and ways to cope with problems that arise in academic life. It provides peer support at any career stage, particularly postgraduate, postdocs, and ECRs; and aspires to improve the inclusiveness of the Department, to embed equity in our interactions and structures, and to nurture diversity. The AHoD-GE serves on the University’s Mental Health Task Force and coordinates with AHoD-EDI on student mental health.

2.4.4 Seminars

We organise lectures, seminars, and meetings according to the University’s code of conduct and act to facilitate all voices being heard. The organiser, supported by the Department, is responsible for ensuring that everyone in an event behaves respectfully. An increased focus on

EDI has resulted in an improvement in the gender split in speakers to F:M 22:78 (2019/20), (12:88 in REF2014); 52% of seminar speakers are from non-UK institutions.

We created a new “Challenges and Changes” seminar series to discuss issues which affect the careers of researchers and therefore EDI in research. Speakers have track records of improving diversity in science. Seminars are exceptionally well attended, with overwhelmingly positive feedback.

2.4.5 Protected Characteristics

We support staff and students with protected characteristics, as necessary, when these are disclosed. We hosted a registered blind PhD student 2012-16 for whom e.g. teaching materials in extra-large print were provided. A PhD student with severe congenital hearing loss was hosted 2013-17; we installed hearing loops in the meetings rooms used and provided a personal alarm that linked to the fire-alarm system. For a hearing-impaired professor, we equipped their office with a hearing-loop system and compatible phone system and PC. Our elected HoD is profoundly deaf. A recently-appointed staff member is a wheelchair user; we are now working to improve the accessibility of our older buildings.

2.4.6 Safety and COVID-19

The Oxford Physics Safety Committee is responsible for physical safety and wellbeing. During the pandemic, most staff smoothly switched to working from home, supported by specialised equipment and IT provision (§3.3). The Safety Committee played a key role in this, and in enabling staff who cannot work from home to return to onsite work safely.

2.5 EDI and the REF

Oxford Physics and the female-led team preparing the UoA9 REF submission took EDI very seriously and were careful to ensure fairness at every stage of output selection and attribution.

In accordance with the University’s Code of Practice for REF2021, eligible staff were asked to nominate at least one output and up to ten, which were reviewed by at least two readers. The final selection was made by a team of one female and one male, based purely on quality; except for questions relating to the min/max number of outputs required for an individual, no reference was made to the name or gender of the researcher submitting any selected output.
The average number of outputs by group (size of each group shown in parentheses) is: White Male 2.50 (109), White Female 2.54 (24), BAME 2.47 (15), and ECR 1.7 (33). Within the large uncertainties, our output submission is consistent with the hypothesis that outputs submitted by the first three groups have equal quality; a lower figure for ECRs is consistent with their having had less time during REF2021 to build up their research portfolios.

3 Income, Infrastructure and Facilities

3.1 Income

Our core funding is primarily from the UKRI research councils (£150.9M), particularly **EPSRC** and **STFC**. The European Commission, particularly the **ERC**, continues to be an important funder: our EC portfolio grew to £40.2M. We also receive commercial income (e.g. Google, Microsoft) and charitable funding (e.g. Leverhulme Trust, and Wolfson Foundation). Total research income from all sources was £230.3M.

To **diversify our portfolio,** we actively seek new funding opportunities, and collaboration and partnership opportunities with prestigious organisations in Europe (MPI), Asia (Kavli-IPMU) and the US (Rochester). Our efforts to increase research income are supported by our research facilitators (§3.3).

Philanthropy is a growing source of income. Supported by the University Development Office, we raised £13M in donations towards the Beecroft Building and in 2018/19 secured a gift to endow a professorship in biophysics. In 2020, we appointed a full-time fundraiser.

3.1.1 Funding Portfolio

In REF2021, 58 academics [REF2014: 29] received individual awards, including five ERC Starting, three Consolidator and nine Advanced Grants [REF 2014: 6,0,6]; 17 Royal Society URFs [5], two Royal Society Dorothy Hodgkin Fellowships [1], nine STFC ERFs [8], three EPSRC Early Career Fellowships [2], two NERC IRFs, two UKRI Future Leader Fellowships, one UKRI Stephen Hawking Fellowship, two Royal Society Research Professorships [1], two EPSRC Established Career Fellowships, and one Wellcome Trust Senior Investigator Award.

Examples of our largest awards are provided in Table 3.1.1. The two multi-institution Quantum Technologies Hubs were both led by Oxford: NQIT involved nine universities, focusing on networked quantum-information technology based primarily on ion traps and photonics, and generating seven spinout companies (four from Oxford Physics); the QCS Hub (2019-24) [Director: O'Brien, Oxford Engineering; PI: Lucas] is a 17-university consortium that supports six partnership projects with UK industry and collaborates with ~30 national and international commercial and governmental entities, who contribute £18M of additional resources.

Chalker [PI] received consecutive EPSRC awards in Quantum Condensed Matter Theory across REF2021. An EPSRC Prosperity Partnership supported Snaith and Herz to work with Oxford PV to develop next-generation multi-junction perovskite solar cells, which can deliver even higher efficiencies than “perovskite-on-silicon” tandem cells. This close collaboration has led to improvement of the long-term stability required for these multi-junction cells. An EPSRC Platform Grant for Quantum Materials to Radaelli [PI], with Oxford Chemistry and Materials, supports multi-disciplinary research into an emerging class of materials with potential to impact information technology, energy transport, and storage.

Successive STFC grants support(ed) the design and build of the ELT’s HARMONI first-light spectrograph. Oxford leads the project, which passed Preliminary Design Review in 2017, and has commenced Final Design Review. Our STFC Particle Physics Consolidated Grants supported experimental work across the range of the subject, enabling six collaborations or partnerships to be established, and leading to the award of 18 research prizes.

PI	Topic (number of grants if >1)	Total grant /£M	To Oxford Physics /£M	Co-Is (in Oxford Physics)	Postdoc (technician) years	Publications
EPSRC						
Walmsley	NQIT Hub	38.44	31.12	20 (8)	114 (2)	284
Lucas	QCS Hub	23.96	7.76	8 (3)	75	39
Chalker	2x Quantum Matter Theory	3.77	3.07	5 (0)	23	252
Snaith	Prosperity Partnership	2.71	2.71	1 (0)	13 (0.5)	7
Ardavan	MASCD[1]	3.48	2.34	4 (1)	9	5 & patent application
Parra Diaz	Turbulent Plasmas[2]	2.10	2.10	5 (2)	14	12
Radaelli	Quantum Materials[3]	2.17	1.70	11 (9)	10	174
STFC						
Shipsey	2x Particle Physics CG[4]	16.75	16.75	24	98 (33)	377
Thatte	2x ELT/HARMONI	9.91	9.91	2	52	6 & 24 TR[5]
Balbus	2x Astrophysics CG[4]	7.88	7.88	23	55 (3)	2,850
Jones	3x SKA	9.67	6.85	5	48	88 & 10 TR[5]
Seryi	4x JAI	4.28	4.28	8	21	327
Harnew	LHCb Upgrade	2.12	2.12	2	1.5	2
Bortoletto /Nickerson	4x ATLAS Upgrade	2.43	2.43	6	2 (11.5)	7 & 2 TR[5]

[1] Molecular Assembly of Spintronic Circuits with DNA. [2] Programme Grant. [3] Platform Grant.
[4] Consolidated Grants. [5] Technical Reports.

Table 3.1.1. Examples of large grants awarded in REF2021.

As examples of the success of individual-PI grants, we briefly summarise three from our 17 ERC portfolio and one Royal Society Research Professorship:

- Ferreira's ERC AdG supported research into Large Scale Structure Constraints of General Relativity and has led to a dramatic improvement in our understanding of, and constraints on, cosmological gravity.
- Parameswaran's ERC StG supported theoretical research into Topological Matter and Crystalline Symmetries; outcomes include new results on emergent phenomena in quasicrystals.
- Malde's ERC StG supported research into CP violation with beauty quarks, leading, via measurements at the BESIII experiment, to the world's most precise measurement of the CKM angle gamma.
- A RS Research Professorship enables Salam to provide the foundations for accurate simulations of the fragmentation of quarks and gluons in high-energy particle collisions, central to the interpretation of data from the world's largest particle physics experiments.

3.2 Infrastructure

We have ~20,350 m^2 of operational space across two sites: the Denys Wilkinson Building, and the Clarendon Laboratory complex, which now comprises seven linked or adjacent buildings.

3.2.1 Beecroft Building and Laboratories

In 2018, we opened the new £50M Beecroft building, Oxford's largest investment in experimental physics space since the 1960s, supported by University, philanthropic, EPSRC, and Wolfson Foundation funds. It provides a new home for theoretical physics, with purpose-designed collaboration space for 145 people; and 1,500m^2 of state-of-the-art laboratory space, accommodating experiments in quantum materials, computing, optics, cold atoms, and biological physics. The labs offer some of the best environmental conditions available to any university physics department worldwide: vibration levels in 18 keel-slab laboratories to VC-G (velocity limit of 0.8μm/s) and performance better than VC-M (approx. 10nm/s) above 10Hz with passive air isolators installed (10Hz VC-G is equivalent to a displacement amplitude of 10nm and VC-M is equivalent to 0.2nm.). We achieve precise control of temperature (22 ± 0.1°C), relative humidity (50 +/- 10%), and intrusive noise level (<30dB); a clean dedicated electrical supply to each of the 37 laboratories prevents electrical interference between experiments.

Some of the new laboratories that have recently opened in the Beecroft building and benefit from the ultra-low vibration environment, with equipment investment in REF2021 in parentheses, are:

Ultra-Low Vibration and Ultra-Low Temperature Laboratory [Davis]. Next-generation facilities ~30m underground allow both temperature and mechanical noise reductions by ~10^9. The labs enable unprecedented research on atomic-scale visualisation of electronic and magnetic quantum matter and on gravitationally mediated quantum mechanics (£1.8M ERC, £1.4M Oxford).

Ultracold Atom Laboratory [RSmith]. This ultra-low vibration, temperature-stabilised laboratory provides the environment needed for our dual-species erbium/potassium ultracold-atom experiment, which creates a highly-controllable setting for studying quantum many-body phenomena (£0.4M EPSRC, £0.4M Oxford).

Quantum Information Network and Optics Laboratories [Lvovsky]. These house research on all-optical implementation and training of artificial neural networks, and linear-optical super-resolution microscopy in the far field (£0.2M EPSRC, £0.4M Oxford).

The **Beecroft Instrument Assembly Laboratory** [Thatte] provides state-of-the-art ISO 7 facilities for assembly, integration, alignment, and testing of optical instruments. It hosts a large Coordinate Measuring Machine, and 1.1m-diameter multiport cold-testing chamber, to be used for sensitive alignment and testing of the HARMONI optics to 2 microns accuracy at temperatures down to 77 K (£110k Oxford).

AFM Biophysics Laboratory [Contera]. Four individual laboratories housing four Atomic Force Microscopes (AFM), including an Asylum Research Cypher AFM with atomic-resolution capabilities in fluid environments, facilitate interdisciplinary collaborations on physical aspects of biological and biomedical problems. Low-noise capabilities make it possible for the first time to investigate fundamental-physics questions at the interface of quantum information, quantum biology and "classical" biological, and soft-matter physics (£221k Oxford).

3.2.2 Technical Services and Small Research Facilities (SRFs)

Owing to its scale, the Department can offer a wide range of in-house technical services to support research through provision of specialised state-of-the-art equipment and expertise that is either too difficult or expensive to source from industry. Many such services have recently been brought together under a common management framework to form the Technical Services Group (TSG). Several other facilities managed by individual research groups operate as Small Research Facilities (SRFs) to support financial sustainability and promote sharing of equipment and infrastructure.

The TSG comprises ten SRFs with 49 highly-skilled technical staff, managed by the Head of Technical Services [Preece], an internationally-known project engineer, who provides strategic vision and direction. The TSG Committee, chaired by the AHoD-RI, provides oversight and steers strategic development in accordance with researcher needs. Proximity of researchers to technical staff makes the design-prototype-test cycle rapid and responsive; and recently-introduced Siemens Solid Edge software makes the CAD-to-manufacture process more integrated and efficient. The TSG is vital to allow us to take leading roles in large projects, e.g. telescopes, space instrumentation, particle-physics experiments, and for design and construction of state-of-the-art probes and in-house experiments.

The SRFs and other shared facilities are listed below, *with investments during REF2021 in italics*:

1. The **Mechanical Workshop** (MechWS) and **Design Office** together provide the principal University mechanical fabrication facility. Extensive facilities (over 770 m^2) include Computer Numerical Control (CNC) mills, lathes, wire eroding machines, and in-house expertise in 3D-design software, including finite-element analysis (fluid dynamic, non-linear and transient, and static analysis). Rapid prototyping can be achieved via 3D-printing. *Two new 5-axis CNC milling machines and a wire eroder were purchased* (*£776k Oxford)*;

2. The **Electronics Group** develops and assembles customised electronics systems. *It has been strengthened with a new RF engineer and large-area laser-engraving machine (£30k STFC)*;

3. **Nanofabrication and Electron Microscopy** in ISO 5 and 6 clean-room suites provide advanced capabilities for sample preparation and lithography (electron-beam, focused-ion-beam, and UV photolithography, including resist-processing, thin-film deposition and etching). There are two state-of-the-art FEI scanning electron microscopes for high-resolution imaging, structural characterisation and elemental analysis using EDX. *We have upgraded the Raith electron-beam lithography system, EDX detector, FIB, and spin coater (£73k Oxford)*;

4. **Photofabrication** manufactures etched components to large areas, including flexible copper circuits and multi-layer PCBs;

5. **Thin Films** designs and produces high-performance anti-reflection and high-reflectance coatings on metals, plastics, semiconductors, ceramics, and glass, from 1 to 254 mm in diameter. Metallic coatings can be deposited as either single layers or with other metals to thicknesses from 3 to 500 nm;

6. **Space Instruments** is an integrated facility for the design, build, test, calibration, and qualification of space instruments and their components. KMOS spectrographs for ESO's VLT and the Compact Modular Sounder for UK TechDemoSat-1 were completed in these facilities. Availability of the HIRDLS cryogenic test chamber was crucial in bringing a major part of the HARMONI project to Oxford;

7. ***Infrared Multilayer Laboratory (IML)****. In 2019, we realised the strategic benefits of rehoming the* ***IML*** *and its equipment, which Reading University had decided to close. It is one of only two global suppliers of optical filters for space instruments, designing and manufacturing customised multilayer optics for infrared applications in atmospheric and planetary science, e.g. coatings for astronomical instruments, including for NASA and ESA missions. Consequently, our infrared-filter capabilities have been transformed and this crucial resource remains available to the global scientific community*;

8. The **Nicholas Kurti Magnetic Field Laboratory (NKMFL)** provides the highest magnetic field capability in the UK. It runs a pulsed-field facility, and develops and maintains superconducting magnets for steady fields up to 21T. Users include researchers in Oxford Physics and Materials, and groups from Warwick University and LANL. *Following a major upgrade, the NKMFL now produces pulsed magnetic fields up to 70T (£363k EPSRC, £50k Oxford)*;

9. The **Cryomagnetics Group** supports the NKMFL; and supplies and recovers helium across the University Science Area (55,000 litres of LHe annually). This system is crucial to the sustainability of the many research areas that require LHe. *We replaced the helium liquefier and ancillary equipment (£1.3M EPRSC), ensuring continued supply across multiple Oxford departments*;

10. The **Physical Property Measurement System**, *new in 2016 (£489k Centre for Applied Superconductivity), is a highly versatile dual cryostat and a 16T magnet system which measures electrical and thermal transport, magnetisation, torque, specific heat, etc., allowing characterisation of a range of physical phenomena in novel quantum materials*;

11. The **X-Ray Diffraction** laboratory comprises five state-of-the-art X-ray diffractometers, *two of which are new (£751k EPSRC)*. Users: Quantum Materials and Photovoltaics in Physics, other MPLS departments, and groups external to Oxford;

12. **Materials Characterisation** comprises a SQUID magnetometer and other equipment together capable of measuring materials properties (including magnetisation, heat capacity, and magneto-transport) as a function of temperature and magnetic field. Users: Quantum Materials in Physics, and other Oxford departments;

13. The **Crystal Growth Unit** supports bulk sample preparation. The unit has two optical floating-zone furnaces, eight resistive-chamber and tube furnaces, and specialised equipment for crystal growth by the Czochralski and Bridgman methods. *During REF2021, the equipment was augmented with three new resistive-chamber furnaces, a refurbished multi-zone chemical-vapour transport system, and an optical floating-zone furnace for high pressure and temperature crystal growth. The latter (£1.2M EPSRC, £300k Oxford) is the first of its type in the UK, and one of the first worldwide.*

In addition to the SRFs and other shared facilities, there are many dedicated research labs that are part of research groups. Those that are new or significantly upgraded during REF2021 are:

- The **NQIT and QCS Hubs** received £23.2M (EPSRC) for capital equipment, providing a unique high-power laser system to perform high-fidelity quantum-logic operations.
- **Oxford Physics Microstructure Detector Lab** is configured for design and assembly of detectors for particle physics and applications, including 160m^2 ISO-7 and 20m^2 ISO-5 clean rooms equipped with a 12-inch silicon probe-station, three wire-bonders, robotic assembly gantry, and non-contact metrology station (£1.5M Oxford, £0.7M STFC).
- **Large-Scale Instrumentation Assembly Lab**: Previously used for assembly and test of the barrel Semiconductor Tracker (SCT) for ATLAS at LHC, with a 24m^2 cold room and separate 60m^2 grey area. Now refurbished and enlarged to 260m^2 (£1M Oxford); used for: the RICH and VELO upgrade projects for CERN's LHCb experiment; astrophysics projects; and R&D using composite technologies for ATLAS and future linear-collider trackers. It hosts the **Centre for Thermo-Mechanical Composites** and R&D activities within the ERC AIDA2020/AIDAinnova networks; and houses the Departmental Coordinate-Measuring machine and other precision survey equipment.
- **CMB Instrumentation Lab:** In 2016, the lab was enlarged from 25 to 35 m^2 and refurbished (£32k Oxford) for development of SKA Band-5 receivers. New equipment includes a 20 GHz 4-channel vector network analyser, and facilities for testing cryogenic RF components (£150k STFC, £50k Oxford). The lab also builds, and hosts training in the development of, new radio-astronomy receivers for ODA projects (§4.4.2), and

develops digital and RF hardware for joint research/commercial projects in deep-space and satellite communications.

- **High-Energy-Density Science Lab**: A new high-power laser facility and radiation-shielded target areas (£1.4M Oxford), housing an upgraded 15 TW Ti:Sapphire laser (£640k STFC), provides new capabilities for laboratory astrophysics and laser-plasma accelerators.
- **Oxford Planetary Spectroscopy Facility** was upgraded to test Oxford-built sensors in conditions replicating those found in real missions (£105k Oxford).
- The **Wolfson Clean Room Facility** contains sample-preparation stations and associated characterisation equipment for photovoltaics research**.** The air-handling system essential for reproducibility of solar-cell materials and device development has been upgraded, and two new nitrogen glove boxes installed. A new solar simulator and solar**-**cell test station have been purchased (£400k EPSRC, ERC, industry, and Oxford).
- **CAESR Electron-Spin-Resonance Facility**. With Oxford Chemistry, we upgraded the facility through the addition of an X/Q ESR Spectrometer (£1.2M EPSRC, £200k Oxford).

We will continue to invest significant internal resources to enhance facilities and to leverage major infrastructure investment from external funders. For example:

- **National Thin-Film Cluster Tool (NTFCT):** We invested £2.67M (Wolfson Foundation, Oxford) to build the facility to host the NTFCT (£3.1M EPSRC) – a bespoke multi-chamber vacuum-deposition system that will support investigation of a broad portfolio of new materials and composites, their development, and integration into devices, complementing research in solution-processed advanced functional materials. Samples can be transferred under vacuum between five chambers: two organic thermal, one perovskite thermal, one sputter, and one atomic-layer deposition. The facility will produce organic and hybrid organic-inorganic structures with performance exceeding those of conventional semiconductors in many applications. Originally due to open in 2020, following COVID-19-related delays, the facility will now open in 2021.

3.3 Support Staff and Services

Oxford Physics employs dedicated teams for Human Resources, Finance, Buildings, Safety, and Technical Services (§3.2.2), which work with the corresponding University services.

Our **Research Facilitators** (3.8 FTE [2FTE, REF2014]), all with science PhDs, support applications for research funding by members of Oxford Physics and external fellowship applicants. They cost projects, critically read applications (and arrange internal peer-review and/or mock interviews where appropriate) and ensure applications meet funder criteria and deadlines. Our Innovation & Enterprise (I&E) Manager supports the growth of industrial collaboration. All staff are proactively offered Research Facilitator support via regular emails.

Our **IT Support** provides stable and secure long-term infrastructure that enables effective research, including High Performance Computing clusters (~6,750 cores, all new in REF2021, up 50% from REF2014) and high-performance storage (5.3PB, all replaced in REF2021, a three-fold increase since REF2014), which is supplemented by the University's Advanced Research Computing facility (8,000 cores, 2PB). Networking for these clusters at 10Gbit connects via a new firewall (enabling network segregation and improving security) to the University network. We have 12 GPU systems used to develop codes prior to submitting to HPC facilities. We invested over £1.5M in our IT infrastructure during REF2021.

IT Support manages multiple internal research databases and ensures appropriate data backup. We run a high-availability gitlab server to ensure version control of code can be handled in a modern industry-standard manner. We have comprehensive subscriptions to electronic journals.

3.4 Facilities supporting Impact

Departmental facilities and services provide access to many innovative and bespoke processes not readily available in the private sector. For example, interactions between our MechWS, RAL, and Fermilab over the pressure loading of Beryllium Windows for the Muon Ionisation Cooling Experiment (MICE); fabrication of submillimetre fibre guides for the SLOAN Digital Sky Survey telescope; and with IML, the spectral design and fabrication of the mid- and long-wavelength infrared entrance window and dichroic beam-splitter filters for ESA's Land Surface Temperature Monitoring Copernicus mission. For NASA/JPL's PREFIRE Earth Observation mission, IML-manufactured filters, integrated into MechWS-manufactured specialist frames, are space-qualified in the Space Instruments SRF. For both missions the data returned will feed data analysis companies across the world, including those at Harwell.

Collectively the MechWS, IML, Space Instruments SRF, our expertise, and connections initiated by our 2018 Space Industry Day, provide capability to support space-led data applications for next generation missions. This is an Oxfordshire strategic technology priority, with the Satellite Applications Catapult (SAC), RAL Space, ESA's ECSAT, ESA-BIC, the UK National Satellite Test Facility, and a growing cluster of space-related businesses at Harwell.

5% of MechWS time is allocated to groups external to Oxford (2017-19); and 85% of IML time. Our Wetton Telescope hosts ~10 visits/year from local schools and community groups (~200 visitors), enabling the public to engage with our research.

3.5 Major National and International Facility Usage

UKRI income-in-kind has been supplemented by over £43M from other facilities:

	Time awarded	Value/£k
Lasers		
ALS Berkeley	50 days	*1,500
FERMI	10 days	*150
FLASH(DESY)	30 days	*500
LaserNetUS	4 weeks	*328
LCLS	~500 hours	8,000
LMJ	1 week	5,000
NIF(LLNL)	18 shots/days	13,000
OMEGA	9+ days	1,986
PSI	~58 days	*550
Synchrotrons		
ALBA	18 shifts	*126
BESSY-II	74 days	*860
Elettra	70 days	*672
PETRA-III	21 days	*315
SOLEIL	50 days	*350
SSRL	70 days	*672
High Magnetic Fields		
EMFL	14 weeks	*700
NHMFL	5 weeks	*100
Accelerators		
SMS PSI	14 weeks	*2,000
Miscellaneous		
FRMII	25 days	*250
TURLAB	6 weeks	*5

	Time awarded	Value/£k
Supercomputers		
AWS	100 TB	*73
Climate SPHINX/Reloaded	30.9M hours	*616
ECMWF	200M SBUs	124
HELIOS	17.8M hours	*890
Marconi 100	18.4M hours	*920
TACC	234k hours	*207
Telescopes		
Arecibo	27 hours	*37
ATCA	200 hours	*137
CARMA	112 hours	*37
GMWRT	40 hours	*4.5
Hubble ST	26 hours	*78
IRTF	6 nights	*72
Jansky VLA	42.5 hours	*306
Magellan	3 nights	*39
MMT	23 nights	*480
Murchison	104 hours	*35.5
NICER	30 ks	*27
NuSTAR	240 ks	*300
Onsala	80 hours	*9
Parkes RT	50 hours	*11.5
Subaru/FASTSOUND	40 nights	1,500
*denotes estimated value e.g. based on operating costs, not ratified by the facility		

In addition to these peer-reviewed awards, we benefit from access to e.g. the MAST tokamak, SDSS IV, Parkes, JET, DESY, PRACE, Chandra X, CHESS, HETDEX and Compute Canada.

4 Collaboration and Contribution to the Research Base, Economy, and Society

4.1 Collaboration and Contribution to the Research Base

We lead and/or participate in over 60 large, multi-institution research consortia, often with associated large grants (§3.1.1). We work closely with colleagues outside Oxford to establish powerful new programmes, e.g. the UKRI Strategic Priorities Fund QTFP programme, proposed by Shipsey, involves physicists working in quantum information, cold atoms, astrophysics, and particle physics. Seven experiments will be conducted, bringing together many HEIs, RAL, NPL, and three National Quantum Technologies Programme Quantum Hubs. Highly interdisciplinary activities include our QCS Hub, bringing together engineers, materials scientists, and physicists from 17 HEIs and 28 industrial partners; and our COVID-19 research, involving collaboration between biophysicists and Oxford's Medical Sciences Division.

The extent of our productivity, impact and collaborations is illustrated by publication metrics. According to Scopus and SciVal, of the ~7K papers published in the current REF period [~5.5K REF2014], which have a collective h5-index of 130, ~76% involve an international collaborator [75% REF2014]; 41% of our 245 grants live in FY2020/21 are joint with another department or institution [18% of 235 grants in REF2014, FY2013/14].

A central research contracts team oversaw collaboration agreements or MoUs signed with 57 universities and laboratories [44, REF2014], 22 other research organisations, 27 companies [12, REF2014], and 14 government agencies [9, REF2014]. Other formal collaborations exist through FP7 and Horizon 2020 funding; we participated in 53 new collaborative projects (including ITNs, FET, and research projects) [19, REF2014]. Contracts for 108 [40, REF2014] collaborative graduate studentships were agreed.

We support collaborations via:

(i) **Opportunities for joint appointments, and our sabbatical policy (§2.2.3), liberate time to form new collaborations and enable existing ones to flourish**: e.g. joint appointments at Hamburg/DESY [Cavalleri, Foster], Diamond [Bartolini], MPI-Göttingen [Golestanian], UC-Cork [Davis], and seven others with Harwell. External visiting positions e.g. Perimeter, Stanford, and UC Berkeley [March-Russell]; Singapore [Ekert, Taylor, Vedral]; and CERN [Burrows] play a similar role.

(ii) **Funding support for collaborations**: (a) early-stage collaborations e.g. via internal seed funding, and (b) collaborations with industry via EPSRC/STFC IAAs. Our Research Facilitators and I&E committee help to identify partners and opportunities for collaborative bids.

(iii) **Active emeritus community, visiting scientist and industrialist programme**: In Oxford, emeriti (such as Prof Dame Jocelyn Bell-Burnell, FRS) and long- and short-term visiting scientists enrich our community with their long experience and stimulating perspectives. We have hosted >2,000 visitors including (* indicates long-term Visiting Professors): Stephen Belcher* (Met Office), Richard Ellis FRS (UCL), Patrick Gill* FRS (NPL), Chennupati Jagadish* (ANU), Mehran Kardar, US National Academy of Science (NAS) (MIT), Ralph Keeling (Scripps), Lisa Randall NAS (Harvard), John Singleton* (Los Alamos), Richard Walker* (Diamond), Nobel laureate Rainer Weiss (MIT), John Womersley* (ESS). We have published 69 collaborative papers with these 11 visitors alone. Funding for visitors has included £71k Leverhulme Visiting Professorships, £164k Royal Society International Exchanges, four University-funded Astor Lectureships (Leroy, Milchberg, Ryutov, and Sasselar) and responsive support from STFC and EPSRC.

(iv) **Seminar and Colloquia series**: Seminars and workshops stimulate new ideas; bring distinguished speakers, often for longer stays; and are essential to a healthy research environment. We provide financial support for 12 specialised seminars each week during term and three colloquia series. We have invested in new Department-wide seminar series in rapidly developing areas e.g. machine learning. We have instituted workshops and meetings which connect with scientists at national facilities (e.g. annual quantum materials meeting with ISIS and Diamond, quarterly Oxford-Met Office advisory panels, etc.).

4.1.1 Collaborations with Physicists outside Oxford

Our staff have held 56 leadership and 5 international spokesperson positions in **international collaborative projects**:

Accelerators: Burrows (Spokesperson, CLIC collaboration), Foster (European Director, Linear Collider Collaboration), both major international efforts towards a future linear electron-positron collider; Foster (Spokesperson, FLASHForward International Partnership for Science), a leading electron-beam-driven plasma-wakefield accelerator;

Particle Physics: Biller (Spokesperson, SNO+ UK), Bortoletto (Deputy Scientific Coordinator, AIDA2020), Harnew (PI, LHCb-RICH and -TORCH), Nickerson (PI, ATLAS-UK ITk), Shipsey (Chair, CMS Collaboration Board), Weber (Spokesperson, DUNE UK & member, DUNE Executive and Finance Boards), Wilkinson (Spokesperson, LHCb);

Astrophysics: Thatte and Dalton (PIs, HARMONI (ELT) and WEAVE (WHT)), Fender and Jarvis (ThunderKAT and MIGHTEE, Large Survey Projects on MeerKAT), Jones and Karastergiou (high-frequency-receiver and pulsar-instrumentation-development, SKA), Fender (chair, SKA Transients Science Working Group);

Space: Bowles (PI, MIRMIS (ESA Comet Interceptor));

HEDS: JWark secured £10M for DiPOLE (a high-power, high-repetition-rate, diode-pumped nanosecond laser developed at RAL and operating at European-XFEL); the Oxford Centre for High Energy Density Science (OxCHEDS), funded by AWE, has secured more time than any other UK group on the world's most powerful laser system (the NIF in California), and is the lead UK group using the world's first X-ray-free-electron laser, the LCLS at SLAC;

Quantum Condensed Matter: During REF2021, Oxford Physics was the largest user of ISIS and Diamond, and second largest at CLF, in terms of number of PIs and experiments awarded beam time.

We play key roles in proposals for planned **future collaborative projects**: Burrows, Bortoletto, Foster, Shipsey, and Wilkinson have been leaders in the design of a future Higgs factory; JWark played a significant role in developing the science case for a UK-XFEL. We have supported the proposed Vulcan2020 project, as well as the funded EPAC project, along with the European-XFEL Hub for the Physical Sciences. We have led the development of new instrumentation for the Diamond-II upgrade: Bartolini (head), Radaelli (chair, proposed beamline user group), and Chen, Boothroyd (ARPES beamline user group). Oxford Planetary Spectroscopy Facility (OPSF) staff are PIs, planning, designing, and building instruments for future missions to the Moon (e.g. Lunar Trailblazer, NASA) and Comets (Comet Interceptor, ESA).

Oxford Physics academics provide **strategic advice on international facilities** such as the European XFEL [JWark], ILL [Radaelli, vice chair, Scientific Council] and ESS [Radaelli, UK-ESS project board]. Foster and Shipsey are members of the International Advisory Committee for the Chinese Electron-Positron Collider (CEPC); Foster is also a member of the CEPC International Machine Advisory Committee.

In Accelerators, the JAI collaborates with Diamond and the ISIS High Beam Powers group, the Cockcroft Institute, Daresbury, CERN, DESY, KEK, and SLAC; and on global projects, including preparatory work for muon/neutrino factories (e.g. MICE) and plasma-driven accelerators (e.g.

AWAKE). In Space, the OPSF was used to interpret observations made by NASA's Lunar Reconnaissance Orbiter and OSIRIS-REx asteroid sample return mission. In Plasma Physics, we work with UKAEA, York, Warwick, and Strathclyde on Magnetic-Confinement Fusion (MCF) research via a DTP and a £4M EPSRC Programme Grant to develop the national priority, ExCALIBUR. With CIEMAT (Spain), we have revised the foundations of collisional transport theory in non-axisymmetric, 3D magnetic fields (i.e. stellarators). In Quantum Condensed Matter, our connections with facilities at Harwell are expressed by many joint grants, publications, fellowships (e.g. Keeley-Rutherford Fellowship), and joint appointments: Norreys, Bell, and Vinko with CLF; and Hesjedal with Diamond and ISIS. Other joint appointments at Harwell include DWark, Weber (RAL), Dalton (RAL-Space) and Bartolini (Diamond).

4.1.2 Interdisciplinary Research

Web of Science classifies >25% of our papers as primarily in other disciplines, including chemistry, materials science, engineering, and biosciences, although most are carried out by researchers within Oxford Physics. We were awarded £50M jointly with other Oxford departments. Some examples (with Oxford departments unless otherwise indicated) include:

SBlundell collaborated with **Chemistry** to develop new superconductors, as did AColdea to develop high-purity iron-based superconductors used to produce ultra-high magnetic fields to 100T. Herz collaborated with **Materials** to reveal the atomic microstructure of metal-halide perovskites. Ballance (within NQIT) collaborated with **Materials** and **Computer Science** to produce the most detailed analysis of network-based quantum computers. Leek collaborated with MIT **Electrical Engineering** to demonstrate the feasibility of using higher excited states of superconducting qubits to encode quantum information. Christensen collaborated with **Maths** in stochastic parametrisations in climate models, now used by the IPCC. Kapanidis' expertise in single-molecule fluorescence microscopy and collaboration with **Biochemistry** led to breakthrough discoveries about DNA replication and repair and gene expression of bacteria. Turberfield is developing a technology for molecular 3D printing in collaboration with Harvard's **Wyss Institute**. Contera collaborated with UCL Physics and ETHZ **Robotics** to create magnetic microparticles easy to control in fluids that can be used for e.g. drug delivery; and with Osaka SANKEN to create novel graphene sensors for virus and biomolecule detection.

Kapanidis and Robb collaborated with Oxford **Medical Sciences** to demonstrate a novel method for simple, efficient, and instantaneous labelling of enveloped viruses; initially developed using influenza virus, this has been adapted for use on SARS-CoV-2. Combining rapid labelling and deep-learning classification allows detection of SARS-CoV-2 within five minutes – much faster, less invasive, and significantly cheaper than existing diagnostic tests.

We participate in five inter-departmental Oxford networks: the **Space Network** (led by Physics) connects the University with the rapidly growing space sector in Oxfordshire and the UK; the **Climate Network's** fora on e.g. machine learning facilitate research with **Computer Science**, **Statistics**, and **Engineering**; the **Planets Network** has enabled research on tidal heating as a driver of planetary volcanism and on volatile cycling between atmospheres and planetary interiors; in the **Photonics Network**, Hooker adapted techniques for spatio-temporal control of low-energy, ultrafast laser pulses (developed in **Engineering** for applications in microscopy and quantum computation) for use at much higher laser energies in plasma accelerators; the **Oxford Centre for Soft and Biological Matter** fosters collaborations between **Physics** and **Chemistry**, and has led to a joint MSCA-ITN, seminar series, 30 publications, and development of "oxDNA", the leading coarse-grained model of DNA structure and dynamics.

4.2 Collaboration to Support Impact

Climate Physics: We contributed to the Met Office Unified Model, a core tool for weather and climate prediction. Physics leads the Oxford branch of the Met Office Academic Partnership (MOAP), which facilitates collaboration, e.g. assessing and improving national weather and forecast models. MOAP has steered national research priorities, leading to strategic NERC 'Highlight Topic' calls on climate projections, which funded projects involving Oxford Physics.

Quantum Optics: Collaborative projects involving JLR, BP, and Rolls-Royce – based on development of non-invasive measurements of combusting and non-combusting flows – included research on ultra-efficient engines and fuels, next-generation gas-turbine engines, and a licensing agreement for a laser-based thermometry instrument with Dantec Dynamics.

Quantum Computing: NQIT and QCS include multiple university, government, and business partners including BAE and IBM; and close interactions with NQCC, being built at Harwell.

Quantum Materials/Superconductors: The Oxford Centre for Applied Superconductivity (CfAS, established 2015), engages and supports the critical mass of cryogenic and superconducting technology companies in the region (which began with our spin-out, Oxford Instruments). It is supported by Local Growth Funding (as part of the Oxford Growth Deal), the University, and local industry. CfAS has demonstrated disruptive technological potential; our facilities have been used in collaboration with e.g. Oxford Instruments and Siemens.

Space: ESA_LAB@Oxford (initiated 2019, with ESA) builds links and capability in AI, photonics, quantum computing, and business innovation; and has led to the Digital Twin Precursor project which combines extreme weather forecasting (Oxford Physics) with crop modelling and machine learning.

Accelerators and Particle Physics: In collaboration with VadaTech (UK) and Etalon GmbH (Germany), we have developed Frequency Scanning Interferometry, licensing production of distance-measuring instruments for industry, national labs, and large scientific facilities.

4.3 Contribution to the Economy: Innovation and Enterprise (I&E)

An increasingly important part of our mission "*to apply the transformative power of physics*" is translation from our research to meet societal needs and tackle global challenges (§1.3.1). We encourage our undergraduates to engage with I&E via group projects solving a problem set by a business. Our I&E Manager and OUI find the optimum commercialisation route for each Invention Disclosure. This now involves OSI, to increase options for spinout investment and accelerate company growth.

4.3.1 Spinouts

During REF2021, we have created nine companies (*denotes ICS#4):

Quantum Dice* (2020) https://quantum-dice.com/ is commercialising the first compact, completely embedded, self-certified quantum random-number generator, providing quantum security for encryption: funding package in late-stage negotiation, first employees being recruited. [text removed for publication]

Living Optics (2020) https://livingoptics.co/ is redefining hyperspectral imaging via an algorithmic approach, improving efficiency, resolution and enabling unprecedented miniaturisation: 13 employees, £5.7M raised.

ORCA Computing* (2019) https://www.orcacomputing.com/ is building the first scalable and flexible quantum computer powered by photonics: 9 employees, £3.1M raised.

Machine Discovery (2019) https://machine-discovery.com/ develops and commercialises acceleration and optimisation software for quantum physics. [text removed for publication]

Oxford Ionics* (2019) www.oxionics.com is building high-performance quantum computers based on electronically controlled trapped-ion qubits: 10 employees, £5.1M raised.

Helio Display Materials (2018) https://www.heliodisplaymaterials.com/ (jointly formed with Cambridge) is exploiting novel light-emitting perovskites in optoelectronic devices such as displays and lighting: 7 employees, £1.9M raised.

1715 Labs (2018) https://www.1715labs.com/ explores how businesses can make use of citizen science software tools to classify and label images, text, audio, and video to solve commercial problems: 4 employees, £850k raised, already working with high-profile clients. [text removed for publication]

Oxford Quantum Circuits* (2017) http://oxfordquantumcircuits.com/ is developing a scalable quantum-computing technology based on superconducting circuits: 20 employees. [text removed for publication]

Oxford Nanoimaging (2016) http://www.oxfordni.com/ The Nanoimager is a desktop super-resolution, single-molecule fluorescence microscope for use in biomedical research: ~100 employees (UK/US), raised ~£22M, estimated current annual revenue ~£7.7M/year. Named IoP Startup Award Winner, 2018; founders named BBSRC Innovator of the Year 2019. For more details see ICS#6.

In addition, **Oxford PV (2010)** employs ~130 full-time staff [~15, REF2014] across the UK and Germany, and has raised ~£110M [£4.2M, REF2014]. The company is building a production line in Germany and expects commercial solar cells and modules to be on the market in early 2022. Their technology holds the world-record efficiency, 29.5%, for perovskite-on-silicon tandem cells.

4.3.2 Consultancy

We encourage academics to undertake their contractual entitlement of up to 30 days of consultancy or other outside engagements per year. OUI Consulting negotiates and manages consultancies and provides Professional Indemnity cover. This effective combination has delivered strong growth, resulting in 112 academic consultancy agreements [34, REF2014].

4.4 Contribution to Society

From many examples, we select some highlights below.

4.4.1 Governmental Policy Development

We provide support and communications expertise to engage with policymakers:

- Contera is on the Andalusian Government Research and Innovation Advisory Board;
- Foster advised the Deputy Mayor of the State of Hamburg on a scientific fact-finding visit to the UK and, as Vice President of the Royal Society, participated in many meetings with UK government officials and delegations from other governments. In 2020-21, he reviewed physical sciences in Latvia for the Latvian government;
- Gregg advises GCHQ on cybersecurity and novel computing paradigms;
- Radaelli co-authored the Neutron Review, commissioned by the Italian government, on current neutron facilities (ISIS and ILL);
- Lucas participated in the BEIS roadmapping workshop for UK quantum computing (2020);
- Palmer advised the UK Flood Resilience Committee and was a Drafting Committee member for the RS/NAS document “Climate Change, Evidence and Causes”;
- DWark provided independent oversight and challenge for the Triennial Review of the Advisory Council on the Misuse of Drugs for the Home Office;

- Wheater briefed the Parliamentary Undersecretary of State for Exiting the European Union on the impact of leaving Euratom.

4.4.2 Official Development Assistance (ODA)

Oxford Astrophysics [Cotter, Jarvis, Jones, Taylor] has led both infrastructure and human-capital development linked to HESS/CTA, SKA, and the C-Band All-Sky Survey; working with the Africa-Oxford initiative, AfOx, to promote stronger collaborations throughout Africa. A Newton Fund-supported student exchange programme to visit Oxford resulted in five publications from first-author African students. A Newton-funded initiative, “Development in Africa with Radio Astronomy” (DARA), delivered lectures and projects on radio astronomy to postgraduate students across Africa and funded a DPhil student from Zambia (thesis recently completed). We collaborate with the University of Namibia to use astronomy for capacity-building and sustainable socio-economic growth via educating tour guides and promoting dark-sky tourism. Newton funding also develops technical and human capacity in Mexico by transferring radio-astronomy technology, via conversion of an ex-telecommunications antenna in Hidalgo for research, education, training, and outreach – retaining and creating new jobs. A similar project is underway with partners in Thailand, funded by GCRF and Newton.

4.4.3 Public Engagement with Research

The Access and Engagement Committee Chair [Lintott] supervises 3.5 FTE, who work with the professional public engagement community across the UK (§1.3.2). We are funded through ‘pathways to impact’ on EPSRC, BBSRC and NERC grants; a £95k direct award from STFC; and significant private funding.

Our public engagement programme has been recognised with prizes and awards (§4.6). Approximately half of our staff at all career stages are actively involved in its delivery. We invented, and continue to develop, two citizen science platforms: climateprediction.net (2003) and Zooniverse (2009).

Two examples illustrating our work in expanding participation are:

1. **Space is the Place**: In 2019, STFC funding allowed our researchers to work with local young people and community groups to design and build carnival structures inspired by our space-related research. The 107 people involved were from backgrounds under-represented within STEM careers, facing barriers to participation in science. The carnival procession was seen by over 30,000 spectators (34% identifying as BAME and 10% as disabled). Our carnival stall was visited by >400 people;

2. **Increasing Access: “**Flying Start” supports A-level physics students from less affluent areas to study STEM at university, in partnership with three local schools. It provides after-school physics sessions run by researchers for students and teachers, covering both the A-level curriculum and the researchers’ own work. This enables schools to offer enhanced A-level physics, thereby supporting and retaining their brightest students. These schools’ catchment areas have less than 20% progressing to higher education; half the students in “Flying Start”s inaugural year have now applied for STEM courses at university. From 2021, and planned during REF2021, we will partner with the IoP to offer “Levelling Up”, a new programme for 40 local school students interested in studying physics at university. With philanthropic support, this will provide physics tuition, mentoring by undergraduates, and on-site visits engaging with our research.

4.5 Sustainability of the Discipline

Oxford Physics provides the critical mass and leadership required to attract high-quality individuals, maintain significant networks of collaborators, lead national and international research initiatives, and secure long-term funding (§1.2). We responded quickly in 2019 to rehome the **Infrared Multilayer Laboratory (IML)** and its equipment, preserving this crucial resource for the global scientific community (§3.2.2).

Almost half our MPhys (4-year course) students proceed to a doctorate, making our undergraduate education an important contributor to the sustainability of the discipline. The course has a growing research component: an additional 3rd year research project was introduced in 2018. Summer research placements are provided. Our graduates are greatly in demand.

CUWiP (§2.3.1.1) also contributes to the sustainability of the discipline by providing an environment in which young women can engage with successful female physicist role models, giving them confidence to pursue careers in physics.

The Department is committed to increasing diversity in STEM by engaging with local pupils (e.g. “Flying Start”, §4.4.3). We engage with around ~2,000 students and 100 teachers annually. We also work with a local community centre and a national charity to provide half-term and out-of-school activities in the most deprived areas. Oxford Physics has increased its offers to students from the most disadvantaged UK backgrounds from 14% in 2018 to 18.3% in 2020, despite concerns that the pandemic would generate difficulties for the most disadvantaged groups.

4.6 Measures of scientific leadership and esteem

During REF2021, seven academics [Balbus, Bell, Ekert, Pierrehumbert, Salam, Snaith, and Wilkinson] were elected to Fellowships of the Royal Society [3, REF2014], and two [Balbus and Palmer] elected to the NAS [0, REF2014], while ECRs such as Nahum have been acknowledged internationally.

Leadership roles in 109 [88, REF2014] **national and international committees, reviews and steering groups** include the following:

- **Long-term planning and foresight** exercises, e.g. ASPERA Advisory Committee on Astroparticle Physics [Sarkar, Kraus], IUPAP-ICFA International Committee for Future Accelerators [Shipsey], US-DOE BRN HEP Detector R&D [Shipsey, chair], ECFA Detector R&D Roadmap [Shipsey, co-coordinator], Canadian Long-term Planning Committee on Particle Physics [Burrows], CERN European Strategy for Particle Physics [Burrows], European Roadmap for IR Space Astronomy [Rigopoulou, chair].
- 41 [30, REF2014] facilities outside the UK, through service on **scientific councils** at CERN [DWark], DESY [Burrows], ESO (President) and ALMA (Chair) [Roche], HMFL Grenoble [AColdea, Nicholas], ILL [Radaelli, vice-chair], Space Telescope Science Institute [Davies]; **scientific advisory committees** at Australian Astronomical Observatory [Davies], DESY Physics Research Committee [Burrows, chair], European Spallation Source [Boothroyd, Roche, Radaelli], Fermilab [Bortoletto, chair], Helmholtz International Beamline [JWark], ISIS [SBlundell], LCLS [Gregori], MEGARA at GTC, La Palma [Dalton], NCAR HAO [Gray], EIC Instrumentation [Shipsey]; **design reviews for instruments** including DUNE [Bortoletto], SKA [Jones], SuperCDMS [Palladino] and numerous other management and working groups.
- **Space agencies** including UKSA Space Exploration Advisory Committee [Bowles], UKSA Solar System Advisory Panel [Calcutt], ESA Herschel User Group Chair [Rigopoulou], NASA Hubble Fellowship Program and ROSES XRP [Birkby], NASA Astrophysics Data System User Group [Lintott, chair].
- **Institute advisory boards**: the UK Met Office [Palmer], the MoD [JWark], Higgs Centre Edinburgh [Salam, Shipsey, March-Russell], Fermilab [DWark], SISSA [Yeomans, chair], multiple MPIs [Foster, Herz, Radaelli, Salam, Simon], the Perimeter Institute [March-Russell] and 51 more.

21 [24, REF2014] academics have served on **UK research-council advisory committees**, e.g. UKRI Infrastructure Advisory Committee [Foster]; 37 [24, REF2014] have been panel members (two panel chairs) for UKRI, EPSRC, STFC, NERC, or the Royal Society; 27 have been members of the EPSRC, NERC, and STFC Colleges; and 35 [11, REF2014], including three panel chairs, have served on a total of 41 [15, REF2014] peer review committees outside the UK including ERC, Swiss-NSF, US-DOE, US-NRC, NSERC, and DFG. 16 [16, REF2014] have served on facility access panels or equivalent (including ISIS, Diamond, CLF, ATNF, ESO, and HST).

Our work is leading international research agendas, evidenced by more than 440 [300, REF2014] **keynote/plenary talks** and another >2,100 [1,200, REF2014] **invited conference talks**. Our research has also been presented through more than 45 **prestigious, named lectures** at institutions worldwide including *Chern-Simons*, Berkeley [Fendley], *Ehrenfest*, Leiden [Yeomans], *Kieval*, Cornell [Cavalleri], *Micius*, Shanghai [Ekert], *Neils Bohr*, Copenhagen [Davis], *Sackler*, Tel Aviv [Foster], *Sciama*, Trieste [Binney and Ferreira]. Our members have played both scientific and organisational roles in **convening** over 213 [85, REF2014] international scientific meetings. We have hosted 247 conferences/meetings here in Oxford.

Individual research **prizes** were awarded to 78 [54, REF2014] academics, postdocs, and students including: (* now left, but in post at time of award)

Walmsley* - *Rumford Medal* (RS);
Snaith - *Kavli Medal* (RS);
Dunkley* - *Rosalind Franklin Award* (RS);
Gregori - first to receive the *Dawson Prize* (APS) twice, both in REF2021;
Cavalleri - *Isakson Prize* (APS) and *Born Medal* (IoP/DPG);
Sarkar - Homi Bhabha Medal (IUPAP-TIFR);
SBlundell - *Yamazaki Prize* (International Society for Muon Spectroscopy);
Malde - *Women in Science Fellowship* (L'Oréal/UNESCO);
Balbus, Bell - *Eddington Medal* (RAS);
Fender - *Herschel Medal* (RAS);
Foster - *Honorary Fellowship* (IoP);
Chalker - *Dirac Medal* (IoP);
Schekochihin - *Payne-Gaposchkin Medal* (IoP);
Cooper-Sarkar, Shipsey, Wilkinson - *Chadwick Medal* (IoP);
Golestanian *Holweck Medal* (IoP/SFP) and *Pierre-Gilles de Gennes Lecture Prize* (EPJE);
Snaith - *Joule Medal* (IoP);
Johnston - *Massey Medal* (IoP/AIP);
Binney* - *Occhialini Medal* (IoP/SIF);
Nahum - *Maxwell Medal* (IoP).

Oxford Physics' essential contributions to SNO culminated in the 2015 Nobel Prize. In recognition, Biller, DWark and Jelley* accompanied MacDonald (Laureate) to the ceremony. The 2016 Breakthrough Prize was awarded to the SNO Collaboration (Biller, DWark).

Our academics received awards for their work to realise **impact**: KBlundell - OBE; Kapanidis - *BBSRC Innovator of the Year* (Oxford Nanoimaging); Lintott - *Group Achievement Award* (RAS), *Kelvin Medal* (IoP), *Tinsley Prize* (AAS), and *Highly Commended Award 2017* (also Sheehy) (SEPnet).

Our **emeritus academics** inspired their successors: e.g. Bell-Burnell - *Royal Medal* (RS), *President's Medal* (IoP), *Special Breakthrough Prize* (Breakthrough Foundation); Llewellyn-Smith - *Royal Medal* (RS); Silk - *Member, NAS and Gruber Cosmology Prize* (Gruber Foundation). Our **former graduate student** Kosterlitz - *Physics Nobel Prize Laureate (2016)*.

Academics and Fellows have been **invited visitors** at over 60 institutions in 17 countries e.g. KBlundell (Gresham Professorship), Sarkar (Bohr Professorship), Simon (Simons Professorship), and Burrows (Director-General's Professorship, CERN).

Our staff give leadership and service to **international unions, learned societies and journals**:

- Davies - President, European Astronomical Society (2017-22);
- SBlundell - President, International Society of Muon Spectroscopy (to mid-2014);
- Foster - Council member (2015-18) and Vice President, RS (2018);
- Shipsey - Chair, APS Division of Particles and Fields (2012-15);
- Five academics have been Council members for other societies including the Royal Astronomical Society, Royal Meteorological Society, and German Physical Society;
- 36 academics have served on other committees and groups of the APS, IUPAP, IAU, RS, Royal Institution, KVA, and IoP, including five chairs [4, REF2014];
- 39 academics [40, REF2014] are on the editorial boards of 50 **journals** [50, REF2014], including Proc. Roy. Soc., Phys. Rev. Lett., Nucl. Instrum. & Methods A, Nature Scientific Reports and PNAS. Five are Editors-in-Chief [1, REF2014];
- 3 academics [Boothroyd, Chalker, Essler] were named as Outstanding Referees (APS) in REF2021 [7, REF2014].