Institution: University of Oxford

Unit of Assessment: 9 - Physics

a. Overview

The mission of the Physics Department is to pursue the foremost scientific problems on which the transformational power of physics can be brought to bear. Our major scientific themes are: accelerator physics; astrophysics and planetary physics; biological physics and soft matter; climate physics; particle physics; plasma physics; quantum condensed matter; quantum optics and information; and semiconductor materials, devices and nanostructures. We work closely with cognate disciplines, particularly in the Mathematical, Physical and Life Sciences Division (MPLS) of which we are a part. In the REF period Oxford physicists have published 4364 papers with a collective h-index of 88 (WoS) and been awarded over 20 international prizes including the Shaw Prize for Astronomy, the ICTP Dirac Medal, the IUPAP Boltzman Medal and the Balzan Prize. We employ 138 academic staff, of whom 7 are Fellows of the Royal Society, and 174 PDRAs. We have 310 doctoral students. Our turnover is about £35m and we currently hold research grants worth £89.5m.

Capital letters, e.g. [A], denote the research groups used in REF1 and REF2. Oxford University departments are denoted by capital letter; e.g. 'Chemistry' means Oxford Chemistry Department.

b. Research strategy

Our mission is to pursue the foremost scientific problems on which the transformational power of physics can be brought to bear. The principal elements of our strategy to achieve this are to

- Identify those areas where we can make the most scientific impact, tensioning existing activities against new opportunities
- Recruit and retain the best physicists worldwide to achieve our scientific aims
- Foster a supportive environment that encourages individual initiative, the sharing of ideas and resources, and the reinforcement of each other's plans and aspirations
- Ensure, where appropriate by working closely with the wider UK community, that we have access to scientific facilities that meet our research needs
- Work in collaboration with other departments in Oxford and other universities globally to deliver research programmes that none could accomplish alone
- Build much stronger research links with industry to deploy our expertise on their challenges
- Develop and maintain strong relationships with national laboratories, through use and development of their facilities; shared projects; joint appointments; and visitor programmes
- Use our unique capabilities and expertise to leverage access to those overseas national facilities that are not available to us through RCUK programmes
- 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

Responsibility for our research environment lies with the Head of Department (HoD), John Wheater. He chairs and is advised by the Physics Management Committee (PMC), which consists of: an Associate Head for finance, Susan Cooper; six members with management responsibility for the science areas indicated, James Binney [B,D,E,M,R], Roger Davies [P,Q,R], Paul Ewart [I,J,L], Neville Harnew [A,N], Paolo Radaelli [C,H,K] (also Associate Head for shared facilities), Peter Read [F,G,O]; and two elected members, Laura Herz and Niranjan Thatte. Since RAE2008 we have established the Research Forum, consisting of all permanent academics and chaired by the HoD, to enable regular informal discussion of strategy issues and the scientific challenges we face.

The major themes discussed below focus on our vision of the most important research for the next decade. The balance of the department's science has shifted since RAE2008, with Accelerator Physics now well established, the expansion of Climate Physics, and the growing role of Plasma Physics. For each major theme we give examples of achievements in the light of our RAE2008 plans, developments in staffing, and our vision for their future direction.

b.1 Accelerator Physics [N]: The success of the John Adams Institute (JAI), launched in 2006 by the University and Royal Holloway as a focus for accelerator science, is demonstrated by Imperial College's decision to join us in 2012. We recruited Andrei Seryi from SLAC in 2010, to succeed founding JAI director Ken Peach, and a lecturer in novel radiation generation methods (Ivan

Konoplev). Since 2008 we have maintained our comprehensive leadership (§e.1) in the design of linear e^+e^- colliders (ILC and CLIC), particularly the development of beam delivery systems, and continued development of laser-driven plasma accelerators for which we originated ionization induced injection. We work closely with ISIS and Diamond on their upgrade programmes, and with industry ranging from Siemens on novel robust accelerator technology for industrial and medical applications to TMD (an SME) on high-power radio frequency systems. Our priorities are to work in partnership with RAL, ASTeC, and other UK and international institutions, such as CERN and DESY, in research and development for major facilities; develop compact X-ray sources driven by laser plasma accelerators (§b.6); maintain our leadership role in whichever international e^+e^- collider project proceeds to maturity; and extend our research and technology links with industry.

b.2 Astrophysics and Planetary Physics [O,P,Q,R]: The standard model of cosmology has been established by the analysis, in which we played a major role, of CMB data from the WMAP and Planck satellites. Our analysis of recent observations of Saturn made by the CIRS instrument, carried on the Cassini spacecraft, has shown that the North Polar Hexagon structure extends from the cloud tops into the stratosphere. CIRS was partly designed and built in the department in the 1990s. Our strategy to maintain this capacity to conceive and construct major instruments has again been vindicated by selection of the HARMONI integral field spectrometer (IFS) for first light on E-ELT and the DREAMS wind sensors for ExoMars.

To generate a new synthesis of existing strengths in observation and modelling with the theory of fundamental astrophysical processes we have appointed theorist Steven Balbus to the Savilian Chair of Astronomy. As intended at RAE2008 we have combined our expertise in solar planets with new lectureships in exoplanet observation (Suzanne Aigrain) and the theory of planetary formation (Caroline Terquem) to create an exoplanets group. We have reinforced our position in IFS with new lectureships in galaxy evolution (Michele Cappellari) and high red-shift galaxies (Andy Bunker). Following the death of Steve Rawlings in 2012 we have regrouped by appointing lecturers specifically to work on the SKA and its precursor programmes (Matt Jarvis and Rob Fender).

Our strategy is to be at the centre of the major developments, both observational and theoretical, that we foresee over the next two decades: understanding dark matter (see also §b.5) and dark energy; the precise determination of parameters of the cosmological model; accretion, the formation of stars and galaxies, and the role they play in the evolution of the Universe; and comparative planetology. We will continue to use the current generation of facilities while working towards the exploitation of data from new ones such as the Gaia survey of the Milky Way. For the longer term we are involved in hardware development for the SKA and instrumentation for E-ELT, and in science working groups for SKA, E-ELT and Euclid. We have recently decided to join LSST.

b.3 Biological Physics & Soft Matter [E,H]: Since RAE2008 we have developed new techniques for direct observation and manipulation of molecular machinery, devices for nanomedicine, and new theoretical understanding of self-assembly and active colloids. Interdisciplinary work is ubiquitous in this area: e.g. recent research with Biochemistry used single-molecule fluorescence to observe DNA repair in living cells and our theorists collaborate with experimentalists in Chemistry on colloids, active systems and complex fluids (§e.2). We have created a new lectureship in the theory of living/active matter (Ramin Golestanian), and over the next decade will focus strongly on the emerging fields of active matter research and synthetic biology. We will continue to play a major role in interdisciplinary projects: e.g. Andrew Turberfield is currently leading a pan-institutional bid to BBSRC for a Synthetic Biology Centre. Tomorrow's research problems demand a wide range of disciplinary capabilities; together with several other departments we are planning an Interdisciplinary Bio-sciences Centre to provide greatly enhanced access to equipment and services. We plan new appointments to take full advantage of these developments.

b.4 Climate Physics [F,G]: The Physical Climate Science Initiative, planned at RAE2008, has realised synergies across the University and transformed the climate effort in Physics. We succeeded in attracting Tim Palmer to hold his Royal Society 2010 Anniversary Research Professorship in Oxford, appointed Lesley Gray to a senior professorial position, and created new lectureships in atmospheric modelling (Tim Woollings), ocean/climate modelling (Laure Zanna), and the cryosphere (Andrew Wells). As a major node of the Oxford Climate Research Network we work particularly closely with Earth Sciences, e.g. in the jointly run Oceanography Group; with Mathematics on fluids; and on climate risk with Geography, where Allen is now a senior professor while remaining 35% in Physics. Our research now extends from major event response to the resolution of fundamental problems in modelling. We made the first measurements of the optical properties of ash from the recent Icelandic eruptions and our next-generation stochastic representation of sub-grid scale processes is being tested at the ECMWF for use in operational weather prediction. To achieve our strategic aim of understanding the predictability of climate change and climate variability we will continue to investigate the underlying physics issues such as aerosol properties, and turbulence, while, in partnership with the Met Office and ECMWF, integrating that knowledge into climate models. We will address the societal implications of climate change by working with the social sciences and by contributing to IPCC (§e.4) while enlisting the public's enthusiasm and participation through citizen science programmes such as the *weather@home* event attribution project.

b.5 Particle Physics [A,B]: Our strategy to play a leading role in design, technology development, fabrication and data analysis for major experiments with discovery potential has been vindicated as LHC physics has hit the headlines. The ATLAS Semiconductor Tracker Barrel, built and maintained by us, was vital for the discovery of the Higgs Boson at ATLAS. LHCb, for which we led the RICH project and Guy Wilkinson was Physics Coordinator 2009-11, has transformed the precision of hadronic mixing angle measurements and our knowledge of matter-antimatter asymmetry. Groundbreaking results on neutrino mixing angles and mass differences have come from the MINOS and T2K experiments. Our QCD programme for LHC processes, especially W + multi-jet production, plays a crucial role in data analyses. Beyond the Standard Model (BSM) our work encompasses astroparticle physics, dark matter and supersymmetry while the quest for unification of fundamental forces is pursued by our joint string theory group with Mathematics.

To secure the leadership of particle physics in the department, Ian Shipsey, Daniela Bortoletto (collider) and David Wark (non-collider) have been appointed to senior professorships. Lectureships created in anticipation of LHCb's upgrade and analysis requirements and to reinforce ATLAS analysis have been filled by Malcolm John and Claire Gwenlan respectively. To reinforce the theory group we have appointed lecturers in BSM and string-inspired phenomenology (Ulrich Haisch, Joseph Conlon) and gauge/gravity correspondence (Andrei Starinets).

Data analysis, background studies, particle phenomenology, BSM model building, and the search for signals of Planck-scale physics are high priorities for the next decade as we seek to exploit fully the current experiments searching for deviations from the Standard Model, candidates for dark matter, and other new particles. The ATLAS and LHCb upgrades are immediate priorities and we are poised to ramp up our ILC detector programme (see also §b.1). We belong to all the proposed long baseline neutrino collaborations so will play a leading role in any future scenario. Our priorities in deep mine experiments are SNO+, where we lead the neutrino-less double beta decay project, and the LUX-ZEPLIN dark matter search. Ian Shipsey will lead a programme to develop next-generation silicon detectors with integrated sensor and readout functions for particle physics, and colour-sensitive sensors for survey telescopes beyond LSST (§b.2) and other applications.

b.6 Plasma Physics [L,M]: Our strategy centres on creating strong synergistic links with laboratories hosting world-class facilities. Alex Schekochihin, appointed in 2008, has created a powerful plasma theory group working closely with CCFE and drawing on synergies between fusion, astrophysical and space plasma theory. Their theoretical discovery of a transport bifurcation in rotating tokamak plasmas has already led to supporting experimental evidence being obtained by an Oxford research student working on the MAST tokamak. We continue to expand this group with new lectureships in analytic theory (Felix Parra Diaz) and gyrokinetic simulation (Michael Barnes arriving in 2014). The planned growth in inertial fusion and high energy density physics, begun with the appointment of Gianluca Gregori just before RAE2008, has continued with the recruitment of Peter Norreys to a senior professorial position joint with RAL. Our standing in this field is evinced by the allocation to us of two of the eight international experiment slots on the NIF, and six weeks of academic time on AWE's ORION laser in its first year of operation.

Over the next decade our priorities span magnetically confined and inertial fusion, astrophysical plasmas, high energy density science, materials in extreme conditions, and plasma accelerators (§b.1). We expect a renaissance in plasma astrophysics: reinforced by the arrival of Steve Balbus (§b.2) we are now ideally placed to pursue challenging questions such as the heating mechanism of the hot dilute gas in galaxy clusters, untouchable hitherto but now coming within the realm of computability. We recently established with AWE the Oxford Centre for High Energy Density Science to enhance our continuing collaboration on issues relevant to national security (§d.3, §e.1) and will continue to work closely with CCFE on magnetically confined plasmas.

b.7 Quantum Condensed Matter [C,D]: Our decision to concentrate experimental effort on quantum materials has been rewarded with the demonstration of magnetic monopole excitations, originally predicted by Oxford theorists, in spin-ice $Dy_2Ti_2O_7$ crystals grown by us (§d.1); and of excitations with E8 symmetry near a quantum critical point in the Ising-chain system $CoNb_2O_6$. Significant theoretical progress has been made in understanding the emergence of non-thermal distributions after quantum quenches and their relationship to generalized Gibbs ensembles.

In 2008 we appointed Paolo Radaelli, an expert in multi-ferroics, as Dr Lee's Professor to lead the development of experimental research in quantum multifunctional materials. We have created lectureships in quantum magnetism and phase transitions (Radu Coldea), ARPES spectrometry (Yulin Chen), thin film device fabrication (Thorsten Hesjedal), and the theory of strongly interacting quantum systems (Steve Simon) where we intend to create a further post soon. In addition, seven EPSRC Career Acceleration Fellows in this field have chosen to hold their fellowships here, and we work increasingly closely with the Materials Modelling Laboratory.

Our strategy centres on the theory and experimental realisation of emergent and non-equilibrium phenomena in many-body quantum systems. The experimental programme on quantum materials depends heavily on major facilities: for example we will continue to work closely with ISIS and Diamond (§e.1) in developing and exploiting techniques such as ARPES and resonant X-ray scattering. The ultra-stable environment of the new building (§d.2) is a key enabler of our strategy as it will provide the infrastructure necessary for planned recruitments in STM spectroscopy and in novel quantum electronic devices (§b.8). *[text removed for publication]*.

b.8 Quantum Optics and Information [I,J]: Since 2008 we have demonstrated the operation of a world-leading quantum processor based on integrated ion micro-traps, made new insights into novel quantum correlations such as discord, and demonstrated entanglement between two crystals at room-temperature. We have created new lectureships to work on ion trap devices (David Lucas) and optical quantum technologies (Brian Smith), and appointed Vlatko Vedral to a senior post in theoretical quantum information science (QIS). With these appointments, and by supporting new Fellows in theory (Igor Mekhov, EPSRC) and experiment (Josh Nunn, RS URF, and Peter Leek, EPSRC), we have built on a strong base to pursue a wider range of QIS and strengthened connections to Computer Science, Materials, and Engineering Science. Ian Walmsley has led two major multi-institutional programmes (§d.3, §e.1) and we have a particularly strong collaboration with the Centre for Quantum Technologies in Singapore through Artur Ekert (§e.1). Our strategy is to use our breadth of expertise to undertake research across the gamut of QIS, from foundational questions on the character of quantum correlations to real-world technologies that promise quantum-enhanced performance over classical counterparts. We will address the role of quantum physics in biological systems, and use the very stable laboratory environment of the new building (§d.2) to support initiatives such as building large-scale controllable quantum networks. We plan new posts in the emerging areas of quantum technologies and quantum simulators, and aim to position ourselves as an essential partner for any nascent industry in quantum technology.

b.9 Semiconductor Materials, Devices and Nanostructures [K]: Our decision to invest in photovoltaics, leading to the appointment of Henry Snaith in 2007 and substantial infrastructure investment in 2008-10 (§d.2), has been rewarded by spectacular progress including a recent world record of 15% efficiency in solution-processed solar cells. We focus on analysing and understanding the fundamental properties of both organic and inorganic candidate electronic materials, using techniques such as THz, time-resolved and excitation spectroscopy, and on fabricating them into functioning devices. Our close collaboration with Chemistry and Materials on advanced microscopy, growth of nanomaterials and fabrication of nanostructures is crucial in pushing the boundaries; e.g. work with Anderson's group in Chemistry is looking for novel physics effects in porphyrin-based molecules. We are developing plans for a new vacuum processing facility for increased sophistication and reproducibility of devices and have created a new lectureship (Moritz Riede) to lead this work. We aim to discover and understand materials and structures with transformative applications: in particular the need for green energy production will continue to drive our search for economically and environmentally viable solar cell technologies.

Synergies and commonalities abound among the themes themselves and the scientists pursuing them: command of both plasma physics and traditional accelerator technology is necessary to build a practical laser plasma accelerator; theoretical particle physicists work with cosmologists in search of the explanation for dark matter and dark energy; terrestrial and (exo-)planetary atmospheres each inform the study of the other; quantum devices are as relevant to astrophysics as to quantum computers. Through connections such as these new research directions emerge.

The science challenges outlined throughout this section are great. Many call for a range of expertise that the Physics Department alone does not possess so we will work increasingly closely with colleagues from other disciplines to establish coherent and powerful programmes. We describe in §d.2 our plans for creating the infrastructure we need to prosper in tomorrow's competitive environment. Scientific leadership requires scientific leaders: the number of senior professorial staff whose main role is to lead research has been increased from 17 in 2007 to 22 today and we are currently filling two further senior posts to ensure that we can maintain scientific leadership across a broad front.

c. People, including:

i. **Staffing strategy and staff development**

Our strategy is (a) to create new academic posts that reflect our evolving research objectives and will attract world-class researchers, (b) to sustain and develop a culture that attracts and retains outstanding academics in an international arena and (c) to offer our staff the highest-quality support in resources and services. To ensure flexibility, vacated academic posts are not simply refilled but instead a full scientific and business case is made to the PMC and the MPLS Division. As a first step we normally discuss potential posts at the Research Forum to consider the fit to our strategy in an international context, and infrastructure and resource implications.

Our support for researchers to pursue promising opportunities is underpinned by a culture of equality and diversity and reinforced by an annual staff development process for all members of the department. Everyone is enabled to discuss concerns in confidence with someone other than any immediate supervisor and, to enhance this, training is offered to those in senior roles. We have taken steps to improve our support for staff across every career stage and personal circumstance and in recognition the Physics Department was awarded an Athena Swan Bronze award in 2012.

c.i.1 Time and resources to develop research programmes

Our aim is to support our staff in the long-term endeavour of developing their research ambitions into successful programmes. We support new initiatives from our staff in several ways:

- Time to explore new opportunities is provided to a large extent by our generous entitlement for academics to take a fully funded **sabbatical** from teaching and administrative duties for one year in every seven. A total of 111 terms of sabbatical leave have been taken.
- We minimise committee work, teaching and examining during the first 5 years of academic appointments. More generally, academics with more than 60% P/Co-I time funded on grants get teaching relief, and a new workload recording system facilitates equitable allocation of duties.
- Researchers in the department have received a total of £3.2m in internal funds to support new research activities (of which 27% was on equipment, 25% for ECRs), and £2.4m in travel funds.
- Our two Research Facilitators (RFs) assist academics, in particular ECRs, to turn good ideas into funded programmes; e.g. an RF successfully supported two EPSRC First Grant proposals and a £93k EPSRC small equipment bid for eight ECRs. Both RFs are physics graduates.

c.i.2 Academic staff development and recognition

Academics at all grades engage in an annual appraisal with a senior colleague. In addition, every **new lecturer** is assigned a mentor for his or her five-year probation programme. A progress review at the end of the 2nd year provides constructive feedback, diagnoses any problems and identifies remedial actions, the implementation of which is reviewed by the Head of Department at the end of the 3rd year. A formal 5th year review confirms the appointment if the probationer meets the required standards for a permanent academic position.

There is no transition point within our Lecturer pay scale, so the development of our **established**

staff can focus on needs and aspirations rather than criteria for particular promotion hurdles. The University's biennial Recognition of Distinction scheme allows academics to apply for the title of Professor and two-thirds of applications from Physics have been successful. Three academics participated in the first Academic Leadership Development Programme in 2012 and three took an induction for academics taking on new managerial responsibilities (2008 and 2011).

c.i.3 Research Fellows

Our policy is to **support all strong candidates** who propose projects that fit our research strategy rather than to commit academic posts to fellowship applicants in advance. Where a funding body operates a quota, an internal pre-application process identifies the strongest applications. We assist the preparation of proposals, for example by discussing with candidates the infrastructure, facilities and other resources that their project would require.

Since 2008 we have hosted new Fellows funded by EPSRC (9), STFC (7), Royal Society (13), FP7 Marie Curie (11) and Leverhulme (2), to a total value of £14m. Holders of advanced Fellowships (e.g. Royal Society, RCUK) are offered equivalent **career support** to other early-career academics, including annual staff development discussions and a mentor. Fellows are involved in most aspects of departmental life that a permanent academic would be, but are not expected to do routine administration or to examine. We support them in applying for research grants and 11 won additional external funding during their Fellowships. Eleven research fellows gained a permanent academic position in Oxford, while others did so elsewhere; overall 88% of all fellows finishing a contract in the department continued in academia including 28% outside the UK.

c.i.4 Implementation of the national Concordat

We are committed to supporting the career development of researchers on fixed-term contracts. All have an annual discussion, normally with a senior academic other than their supervisor, covering publications, conferences, personal development and career planning. All PDRAs moving to a new fixed-term contract participate in a formal review to consider their career plans and whether re-grading or an open-ended contract should be explored. We prompt researchers and supervisors to consider relevant opportunities in a constructive and timely manner as contracts near their end.

The Head of Department chairs a Post-doc Liaison Committee, which was established in January 2013 to succeed a joint committee with graduate students. Reporting to PMC, its responsibilities include tailoring a Physics careers briefing, first held in March 2013, to our researchers' needs. We ensure PDRAs are funded to attend conferences and in the 12 months to July 2013 90% had presented their work outside the Department, including 80% doing so outside the UK. 60% take part in teaching, 21% run a seminar series or journal club and 45% undertake some public engagement. 23 PDRAs have been recognised as Researcher Co-investigators on RCUK grant proposals. 58% of next destinations have been outside public-sector research and 49% overseas.

Sessions providing an induction to the Department are held regularly for new employees and an optional University-wide scheme provides a wider context. PDRAs have taken up development opportunities in the MPLS Division and wider university: there are courses on career planning, job search and interview skills, teaching, and a wide range of personal development programmes. For example 15 research staff and students attended a Springboard course for women. The University has gained the EC's HR Excellence in Research award for its systems and practices.

c.i.5 Support for equality and diversity

As we set out in our Athena Swan application, our strategy is to create a culture that attracts and retains outstanding academics of both genders: our female academics are very clear in their opposition to special treatment. All categories of staff and students are represented on our Equality and Diversity committee, which reports directly to the PMC. Our policy is to accommodate requests for flexible working wherever practicable: e.g. one academic, who has family commitments and lives some distance from Oxford, is supported to work from home at least one day per week. The absence of regular promotion hurdles means that academics who take family leave of any kind can continue to progress in seniority without disadvantage. Actions to improve our provision included:

- Consulting staff on the best times for key seminars and business meetings to allow for family or other responsibilities, and improving scheduling as a result.
- Sponsoring six prioritised university nursery places since 2011 and providing a factsheet on

flexibility and provision for parents. All 30 women taking maternity leave returned as planned.

- Underwriting any shortfalls in costs of maternity leave of PDRAs employed on research council grants, to ensure there can be no perceived disincentive to employing female researchers.
- Improvements to graduate admissions, including clearer advice on the interview process.

Seven members of staff are Harassment Advisors trained in accordance with the University's policy. We follow the University's Integrated Equality Policy which includes a code of practice to remove discrimination at all points in the recruitment process, implemented through regular training of interview panel chairs. The success of our approach is shown by an increase in the proportion of female PDRAs from 18% in 2008 to 24% in 2013. 25% of all new academic staff, and two of the eight new senior appointees, are women.

c.i.6 Members of an international research community

We participate in, and recruit from, an international field (also §e.1). We advertise academic and research vacancies globally, on our own website and via *academics.com*, AAS, APS, CERN Courier etc. Where it fits our research strategy, we are able to be agile and flexible in directly recruiting leading individuals. *[text removed for publication]*. 47% of advertised academic posts attracted successful candidates from positions outside the UK. By nationality, half of our PDRAs are from the UK, 26% from other EU countries, and 24% from the rest of the world.

Our intellectual community is enriched by international **visiting scientists**, on both sabbaticals and short-term visits, including Joss Bland-Hawthorn (Sydney), Savas Dimopoulos (Stanford), Luca Guidoni (CNRS MPQ), Alexei Tsvelik (Brookhaven), and Carl Wunsch (MIT) as George Eastman Visiting Professor 2012-13. We have subsequently published at least 26 joint papers with these five visitors alone. Funding for visitors has included £152k in Leverhulme Visiting Professorships and £80k from EPSRC plus shorter-term support from STFC and the Royal Society. Our own academics visit other institutions extensively (§e.4).

Eleven highly distinguished individuals were made new Visiting Professors, to bring our complement to 31 of whom half are based outside the UK. These include William Dorland (Maryland), Bernie Fanaroff (Project Director, South Africa SKA), Gerard Milburn (Queensland), John Singleton (LANL) and Keiichi Torimitsu (Chief Research Scientist, NTT); these individuals are co-authors on over 40 of our papers. Nobel laureates David Gross and Bob Laughlin were amongst the speakers in our four annual named lectures. The 65 speakers at our regular Physics Colloquium included Nobel laureate Frank Wilczek, 24 from outside the UK, and 10 from outside academia. We have a rich set of 17 seminar series, in which we have hosted more than 750 speakers from abroad.

ii. Research students

Our doctoral students are an integral part of our research environment. From the exceptional applicants we attract from the UK, EU and overseas, we seek to admit those with the highest academic ability. We provide them with comprehensive supervision and training in both discipline-specific and transferable skills, support their development through structured monitoring and feedback, and give them experience on leading research facilities (§d.1,5). Our aim is to produce highly-capable, independent scientists who can solve problems in whatever domain they choose.

Our students' achievements have been significant. For example, Sam Vinko, Sam Stranks and Tom Ouldridge won thesis prizes from the IoP (2012); Paolo Gandini and Caterina Doglioni both had their theses accepted for Springer's 'Outstanding PhD Research' series; Kevin Schawinski won an RAS thesis prize (2008) and all six continued to research positions. We place great importance on students' global competitiveness with their peers, exemplified by publication record: over 85% of students submitting in 2012-13 already had a paper published and over half had more than three accepted. Over the REF period, two-thirds submitted a thesis within 4.5 years.

There are six Directors of Graduate Studies (DGS) covering the science areas of the department and together forming the Graduate Committee (GC). The Chair of the GC has a substantial role in the department, carrying responsibility for all aspects of the research student experience and reporting regularly to the PMC. He or she also chairs the Graduate Liaison Committee (GLC) at which student representatives can raise concerns for the GC's and PMC's attention. Actions from the GLC included improvements to specific graduate courses and plans for new careers events.

c.ii.1 Recruitment and admission

Since 2008, the **number of applications has increased by 65%** and we now receive, from students in 75 countries, over six times more applications than we have funding or capacity to admit. Alongside interviews we run themed open days (e.g. astrophysics), enabling applicants to meet potential supervisors and talk to current students and PDRAs to understand the experience that graduate study with us would provide. Overnight accommodation can be provided, as can interviews over Skype, where these will make participation more practicable.

We make offers to students **according to academic merit**, and then work to match them to available funding. Over 2008-12, we made offers to students from 60 countries and 60% of these were accepted. 20% of students admitted are female, 20% from the EU and 23% from overseas. Approximately 90% of our students win funding competitively, for example through our rigorous allocation of research council DTA quotas, and ten Rhodes Scholarships won in their own names.

c.ii.2 Research training, supervision and monitoring

On arrival, an intense week of **induction** acquaints students with resources, opportunities and processes in the Department, research group and wider university. All students receive **structured training** through the Graduate Academic Programme (GAP) of the MPLS Graduate School, which offers over 60 graduate courses in Physics and approximately 300 in other departments. Each student chooses a set in close consultation with their supervisor: typically core courses for their research area are complemented by specialist topics, including skills such as applying for telescope time and using our technical facilities. Our breadth of expertise enables us to provide courses on advanced topics, such as AdS/CFT and astroparticle physics. We expect students to participate in relevant seminar series and journal clubs from the outset. The University's IT Service offers over 100 different courses, from programming to data management and security.

Supervisors typically meet weekly with their students and encourage them to take full advantage of the size and depth of our community by working closely with their peers, researchers and academics. Where applicable, co-supervisors from other departments or national laboratories ensure that students are properly integrated into collaborating groups. In the Student Barometer surveys 2010-12 (administered independently by *i-graduate*), 98% of our graduate students were 'satisfied or very satisfied' by the subject expertise of academics, 88% by the timeliness of academic support from supervisors and 86% across all questions on their learning. The University provides supervisors and students with online resources including examples of good practice, policy documents, tools and links to external resources. New supervisors are supported by their mentor (§c.i.2) and by training from the Oxford Learning Institute. Our Athena Swan programme (§c.i.5) led us to create a leaflet offering advice on the sometimes daunting process of undertaking a PhD, e.g. reassurance that some difficulties are normal and suggested tactics to overcome them.

Supervisors are required to **assess progress** for each student termly using the University's online Graduate Supervision System (GSS) to report on progress, frequency of meetings, formal training and any difficulties encountered; typically 90% of reports are provided on time. We encourage students to submit their own reports, and the proportion that do so has increased steadily from 10% in 2008 to over 40% in 2013. The Graduate Committee monitors both reports to check that student-supervisor relationships are functioning well. Every student is also a member of a college, where each receives practical, social and pastoral support from a college Advisor under the leadership of a Graduate Tutor. The college receives the termly GSS reports, enabling a genuinely independent check on progress and welfare and a complementary route to resolving problems.

A key milestone in our **monitoring and feedback** is the required transfer of status from probationer to PhD candidate by the end of the student's fourth term. A discussion with two members of staff, neither being the supervisor, assesses performance in taught courses, a report and presentation of the student's research, and his or her concerns, if any. Actions to resolve any difficulties are set out in written feedback to the supervisor, student and the relevant DGS and a follow-up review is conducted if necessary. A similar process is required before the end of the 3rd year to assess progress towards thesis preparation. An MSc by Research offers an exit qualification where further progress is found not to be possible (taken by only 2% of students).

c.ii.3 Personal development and transferable skills training

Our students can draw on a wide range of opportunities for skills development. Courses in GAP include academic skills such as writing of papers and conference presentation. There are over 20 more skills development courses tailored for scientists available from the MPLS Graduate School, such as academic English and research integrity: over a three-year period, 137 of our students attended one or more MPLS training events. The Department encourages each student to present a poster or talk at one conference or summer school per year by providing funding for travel and posters and also help with preparation. Over the year to July 2013, 68% gave a talk on their research outside the Department, 49% did so abroad and 59% went to a summer school. We have awarded 69 months' support after thesis submission from EPSRC's Doctoral Prize (PhD Plus).

We encouraged greater uptake of business and entrepreneurship training from the Saïd Business School: e.g., our active promotion of 'Building a Business' doubled the number of physics graduate students and PDRAs taking that programme from 2011 to 2012. The Careers Service offers one-to-one assistance and training events, including career planning workshops and talks by alumni from a range of career paths. Six months after completion, in surveys 2009-12, 90% of graduate student respondents from Physics reported being in employment. 58% of the employment reported was in academia, 14% in other scientific research, 8% in finance and 8% in government, policy or law. 30% went outside the UK including 32% of those continuing in academic research.

d. Income, infrastructure and facilities

d.1 Specialist infrastructure and facilities

Ultimate responsibility for provision of specialist infrastructure and facilities, and related strategic investment, lies with the HoD and the PMC who are advised by a committee of academics and consider annual reports and accounts from each facility. A senior technical manager supervises the day-to-day operations of the facilities which are staffed by 32 FTE skilled technicians. The facilities are formally structured as separate Small Research Facilities (SRF) to ensure that they work to a viable and sustainable financial model. We counter the inevitable fluctuations in the physics-driven workload by actively seeking business from outside the Department to maintain skill levels and generate income, and the facilities are advertised on our website and at Open Days and other events. Since 2008 we have completed the reorganization of our facilities into SRFs: in 2008/9 turnover was £1.33m whereas in 2012/13 turnover was £2.38m and recovery of direct costs from grants has improved from 65% to 73%. Details of **individual facilities** are given below.

To fulfil our mission of playing a leading role in major international projects we maintain an extensive design and manufacturing capability. The **Design Office** and the **Workshop** provide the principal mechanical fabrication facility in the University. The **Electronics Group** develops and assembles customised electronics systems, and **Photo-fabrication** manufactures etched components. **Thin Films** designs and produces high performance anti-reflection and high reflectance coatings. **Space Instruments** is an integrated facility for the design, build, test, calibration and qualification of space instruments and their components. The KMOS spectrographs for ESO's VLT and the Compact Modular Sounder for UK TechDemoSat-1 are just two examples of instruments completed in these facilities since 2008. The availability of the HIRDLS cryogenic test chamber was crucial in bringing a major part of the HARMONI project to Oxford.

Cryomagnetics operates a liquefier that processes helium gas returned from many parts of the Science Area in a pipe system; 55,000 litres of LHe is delivered annually to university departments. This system is crucial to the sustainability of the many research areas that require LHe, as the market supply is unreliable and on occasions suppliers are unable to make deliveries.

To support our research strategy in quantum condensed matter and semiconductors (§b.7,9) we maintain a number of specialist facilities for material and device preparation. **Crystal Growth** has an extensive range of furnaces and other equipment for the preparation of high quality single crystals, and provides samples for research in Oxford and elsewhere. **Material Properties** has four X-ray diffractometers, a SQUID magnetometer for measurement of magnetic properties, and a physical properties measurement system capable of operating over a wide range of temperatures and magnetic fields. **Nanofabrication** is based in an ISO class 5 clean room suite and provides fabrication and analysis using systems including e-beam lithography, focussed ion beams, and SEMs; its management committee includes representatives from Materials and Biochemistry.

The Magnet Laboratory provides the highest magnetic field capability in the UK, currently 55 Tesla pulsed; it is also used by Materials, Chemistry, and groups from Siemens Magnet Technology, Cambridge University, and Los Alamos National Laboratory. We use microscopy facilities run by Materials, and share the Centre for Advanced Electron Spin Resonance (CAESR) with Chemistry. The Centre for Materials Design, a joint initiative with Diamond directed by Thorsten Hesjedal and located at the Research Complex at Harwell, uses molecular beam epitaxy and sputtering to produce thin film samples of quantum materials for synchrotron and neutron studies.

In addition to the formal facilities discussed above we share equipment through an online database holding information on about 1200 available items of equipment with capital value over £10k.

Our research generates substantial numerical modelling and data analysis requirements so we maintain extensive **high performance computing** resources. Physics itself has about 4400 cores and 1.8 Pb of storage. These systems and their users are supported by 4 FTE staff. The Oxford Supercomputer Centre provides a further 2500 cores and a 16 GPU system; we used over 3m cpu-hours in 2008-13, including 1m for climate physics. The University is a partner in the e-infrastructure South consortium which provides high-end supercomputing with 12000 cores and a system of 372 GPUs. Users of HPC generally are supported by the Oxford e-Research Centre.

Every staff member and student is provided with a personal workstation; 8 FTE staff manage both the network, and about 1100 desktops and 300 laptops for **general purpose computing.** We have comprehensive subscriptions to **electronic journals** and the Oxford Research Archive provides robust digital storage with open access for theses and other research outputs.

d.2 Investments in infrastructure and facilities

Buildings and laboratories: We have invested £3.52m over the assessment period in renewing over 900m^2 (5%) of our existing laboratory and office space. This includes eight laser laboratories with temperature controlled to 22 ± 1°C for quantum optics (§b.8) and plasma physics (§b.6); six wet laboratories for biological physics including a cell growth facility (§b.3); an ISO class 7 clean room for preparation of photovoltaic and semiconductor materials (§b.9); a new computer server room; and an interactive working environment for theoretical particle physics (§b.5).

We have been allocated a further 800m^2 of space with completion of the £2.2m refurbishment expected in July 2014. This includes 200m^2 of ISO classes 6 and 7 clean rooms for a new silicon detector development and fabrication facility for Ian Shipsey and Daniela Bortoletto (§b.5); accommodation for Yulin Chen's ARPES spectrometer (§b.7); more laboratories for photovoltaics (Henry Snaith, Moritz Riede, §b.9); and more offices for Climate Physics (§b.4).

Following a thorough review of the Department's future needs a major infrastructure renewal programme has been initiated. The first new building will provide 1500m^2 of state-of-the-art laboratory space with vibration levels to VC-G or better; temperature control to 22 ± 0.5°C with capability to go to ±0.1°C; relative humidity <45% in laser table zones; and intrusive noise level <30dB in quiet labs. These facilities, competitive with those available to any university physics department, will underpin an enhanced nanofabrication suite for the whole MPLS Division, and enable experimental work in quantum materials, biological physics, and quantum optics requiring the most demanding environment standards. The building will provide a flexible collaborative office environment for 145 people into which most of our theorists will move from their present isolated quarters. To date £1.2m has been invested in feasibility studies and detailed design up to RIBA Stage D. We have obtained Planning Consent and the total project budget is expected to be £35m.

Equipment: In collaboration with Materials we have acquired a JEOL 5500FS e-beam lithography machine and the associated ancillary equipment at a cost of £930k, of which £460k came from an EPSRC grant held by Materials. The X-ray and Crystal Growth facilities have been substantially enhanced and modernised with investment of £500k in upgrading the existing diffractometers, and the acquisition of a new single-crystal diffractometer with low-temperature capability, and a mirror furnace. The Mechanical Workshop has been upgraded to maintain our capability for major projects by the investment of £695k in milling machines, wire eroders and an autoclave. Space Instruments has been upgraded at a cost of £185k with a 1.2 metre thermal vacuum chamber, new electronics for the shaker system, and enhanced instrumentation. Since 2008 we have spent £4.7m, of which grants provided £2m, on computer hardware, software licences, and services.

The Magnet Laboratory is currently being upgraded to provide fields of 70 Tesla and to increase the available pulse duration. The total cost of the project is £453k, of which £80k is a University contribution and the remainder is from the EPSRC strategic equipment fund. In collaboration with Chemistry we have been awarded an EPSRC strategic equipment grant of £1.2m towards the £1.5m cost of upgrading the CAESR facility with an X/Q band spectrometer.

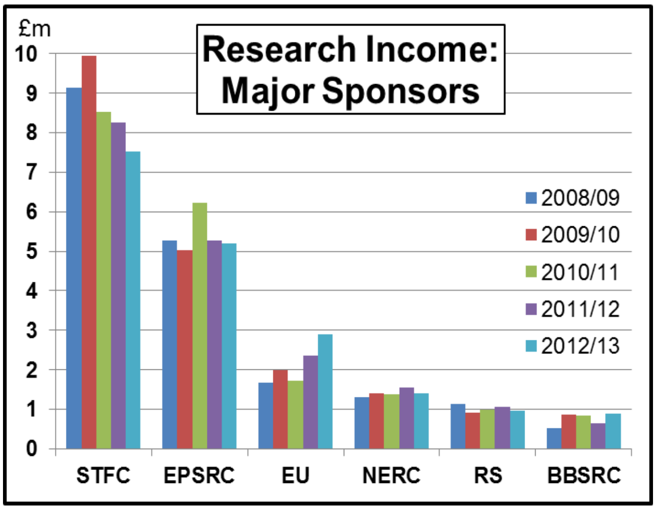
We will continue our policy of investing significant internal resources to enhance our facilities and, where the opportunity arises, to leverage major infrastructure investment from external funding agencies. For example we have committed £625k to equip the new silicon detector facility and we plan to replace the helium liquefier, now over 20 years old, in 2015/16 at a cost of about £1m.

d.3 Research funding portfolio

In 2010, the new Head of Department decided to appoint two Research Facilitators in order to underpin the sustainability of our funding portfolio by enhancing the support we provide to academics who are applying for grants. The facilitators seek out new opportunities for funding and provide advice on all aspects of the application process. Our Knowledge Exchange Officer, appointed in 2012, supports the growth of industry income, and we draw on the MPLS Business Development Team to build strategic relationships with major companies such as *[text removed for publication]*.

We have sustained our annual research income and received total funding of £105m during the period (REF4b). Grants worth £130m have been awarded and 235 grants are currently active.

Our core funding remains that from the UK Research Councils, in particular STFC (£43.4m) and EPSRC (£27m). We have maintained steady income from all Research Councils except STFC where the decline in income has been offset by the growth in ERC funding. The larger drop in STFC income in 2012/13 is caused by the spending profile of three specific grants and we expect it to revert to above £8m in 2013/14. Notable recent awards include an EPSRC Programme Grant of £3.5m (Walmsley) and a BBSRC grant of £1.7m (Turberfield). Charitable income includes £951k from Leverhulme, £362k from the Templeton Foundation and £194k from the British Heart Foundation.



To **diversify our portfolio,** and maintain the stability of our research income, we have actively pursued new funding sources. The European Commission, particularly the **ERC**, is becoming an increasingly important funder: our ERC portfolio grew from one award starting in 2009/10 to five starting in 2011/12. We have been awarded 15 ERC grants worth £22.6m including a €10m Synergy grant to Dieter Jaksch, Andrea Cavalleri and two EU collaborators in 2012; this was one of only 11 awarded in the first round. Our largest **industrial funders** have been NTT (£841k), AWE (£720k), Pfizer (£277k) and BP Amoco (£145k). We have some small-scale **philanthropic funding** for research, e.g. *[text removed for publication]*.

We plan to continue to diversify and grow our funding portfolio, using the support we have now put in place. We aim to increase the number of very large grants we hold, especially in the EPSRC science remit; take full advantage of new opportunities in Horizon 2020; and develop new industrial funding streams. Our endeavours to identify new industrial projects are already delivering results: in 2013 we signed agreements for £773k funding from AWE including for a collaborative research centre that will significantly augment our future industrial research portfolio. We are currently pursuing further new opportunities, e.g. *[text removed for publication]*.

d.4 Consultancies and professional services

We encourage academic staff to take advantage of their entitlement of 30 days per annum paid consultancy without loss of salary. This incentivises individuals to provide their expertise to external organisations and helps to frame and diversify our research outlook. Twenty-two members of staff held a total of 34 personal consultancies, of which 27 (worth £301k) were negotiated by the University's technology transfer company, Isis Innovation. We also undertake departmental consultancies for technical services, which has brought £115k income from five companies.

d.5 Usage of major non-RCUK facilities

£97m RCUK income in kind (REF4c) has been supplemented by over £10m from other facilities:

1/2008–7/2013	Time awarded	Value £k		Time awarded	Value £k
Accelerators			**Telescopes (optical / IR)**		
DAFNE BTF	2 weeks	24	IRTF	8 nights	60
FACET (SLAC)	176 hours	* 320	Keck	18 nights	558
Neutron and muon sources			McMath-Pierce	7 nights	10
LLB	5 days	28	MMT	2 nights	* 40
SINQ	72 days	615	Palomar	14 nights	113
SμS	163 days	1,392	SAAO	70 nights	* 35
Synchrotrons			Subaru	11 nights	423
ALS	111 shifts	176	WIYN 3.5m	8 nights	55
DORIS-III	9 shifts	20	**Telescopes (mm / radio)**		
Elettra	30 shifts	92	Arecibo	12 hours	31
Spring8	18 shifts	58	ATCA	59 hours	35
SSRL	34 shifts	44	CARMA	377 hours	* 117
Lasers			VLA / EVLA	57 hours	* 71
LCLS	80 shifts	* 3,200	GMRT	78 hours	unknown
FLASH	42 shifts	* 350	Green Bank	28 hours	* 35
JANUS	15 weeks	391	IRAM 30m/PdBI	398 hours	335
PHELIX (GSI)	3 weeks	128	Parkes	90 hours	53
TITAN	6 weeks	156	**Computing**		
LULI2000	11 weeks	525	ECMWF	17 M-SBU	60
Lund LC	4 weeks	17	JUROPA	12 k-node-hr	8
High Magnetic Fields			** denotes an estimated value (e.g. based on operating costs) but not ratified by the facility.*		
HFML	450 hours	346			
LCMI-G	12 weeks	* 323			
LNCMP	90 pulses	31	*We include only access awarded competitively and where the PI for the award was in this UoA.*		
NHMFL	60 days	* 279			

In addition to these peer-reviewed awards, through collaboration we have benefited from access to the Hubble Space Telescope, Kitt Peak, MegaCurie, OMEGA and NIF, among others (§e.1).

e. Collaboration or contribution to the discipline or research base

e.1 Research collaborations

The extent of our collaborations is well illustrated by publication metrics. Of the 4,364 papers published in the REF period (collective h-index 88), 75% have at least one co-author outside the UK and Éire. Even excluding astro- and particle physics, where large collaborations are normal, this decreases by only 5% to 70%. The set includes over 100 papers co-authored with each of 110 institutions worldwide. 18% of our 235 active grants are joint with another department or institution.

We provide **support for collaborations:** for instance our sabbatical policy (§c.i.1) liberates time to enable new and existing collaborations to flourish, e.g. Roger Davies joined the SAMI galaxy survey collaboration (Australia) during his sabbatical. Internal funds are available to support early-stage collaborations, e.g. four grants have been awarded from a joint Oxford-CNRS scheme. Our Research Facilitators and Knowledge Exchange Officer help find partners and funding opportunities for collaborative bids. A central Research Contracts team ensures that collaboration agreements support and protect our scope to do the widest research. Where **formal research agreements** were necessary, collaboration agreements or MoUs were signed with 44 universities and laboratories, 12 companies, and 9 government agencies. Other formal collaborations exist through FP7 funding where we have participated in 11 new *Infrastructures* projects and eight other networks. We have agreed 40 contracts for collaborative graduate studentships.

Our collaborations with **national laboratories** enable us to contribute to the development of new initiatives and facilities, and directly enhance our research projects; e.g. by working with laboratory scientists we optimise planning and implementation of our experiments. We have built up strategic joint appointments and secondments with RAL, in plasmas (Norreys), particle physics (D.Wark and Weber) and astrophysics (Dalton and Rigopoulou), and with Diamond (Bartolini, Hesjedal and Chen). We have six co-funded students with Diamond and three with ISIS. Our new research centre with AWE builds on collaborative projects using AWE's ORION laser: Peter Norreys has become an AWE William Penney Fellow while Basil Crowley is already a Visiting Professor in the department. Justin Wark leads the consortium of 10 **UK universities** working for full re-engagement with the European X-FEL. Ian Walmsley leads an EPSRC Programme Grant involving Imperial College and Southampton University. We maintain strong links with **international laboratories** such as the National Ignition Facility (NIF) in the US, where we collaborated in the design and first experimental demonstration of a new instrument (using two laser shots of estimated value $1m each). We have been allocated a further 10 shots on NIF by peer review. We work with the NASA Goddard Space Flight Centre, e.g. on operation and observation strategies for the CIRS instrument in orbit about Saturn. Collaboration with national laboratories and facilities gains us access in addition to that awarded through peer review (§d.5); e.g. in part-payment for building spectrographs for KMOS, Roger Davies secured 36 nights of observing time on the VLT.

Our staff hold 56 leadership and 4 international spokesperson positions in **international collaborative projects**. Neville Harnew led the LHCb-RICH project, Guy Wilkinson was LHCb Physics Coordinator 2010-11, and both have senior roles in the LHCb upgrade; others have convened both UK and collaboration-wide groups (Barr, Gwenlan, Hays and Issever in ATLAS). In neutrino physics, our staff are the UK spokesperson for the SNO+ (Biller), T2K (D. Wark) and MINOS (Weber) experiments. In astrophysics, Niranjan Thatte is PI for the HARMONI instrument for ESO-ELT and Roger Davies chaired the group that produced the science case. Ian Walmsley led a 35-partner €9.9m EU consortium on quantum information processing and Henry Snaith leads a €5m FP7 solar cell network. We play key roles in proposals for **future collaborative projects**: Brian Foster is European Director for the ILC global design effort (§b.1); the late Steve Rawlings was Scientific Coordinator of PrepSKA and we remain heavily involved in the SKA programme.

Our academic staff hold **joint appointments with other universities** including Hamburg (Foster, Cavalleri), Rome (Hook), Singapore (Ekert), UC Berkeley (March Russell) and Western Cape (to 2013, Jarvis). Others sustain collaborations through visiting positions (inward §c.i.6, outward §e.4).

e.2 Interdisciplinary research

Collaborations with research groups beyond physics have led to new science that we could not achieve alone. Web of Science classifies over 50 of our papers as primarily in each of chemistry, materials science, engineering, nuclear science & technology and biosciences. Over 25% of our papers have a co-author from a university department of another discipline.

Networks within Oxford play a key role in providing **support for interdisciplinary research**. The Oxford Martin School (OMS) supports interdisciplinary collaborations in global challenges; five programmes currently have co-Directors from Physics and 21 of our academics are members of its funded research programmes (£584k income). The Oxford Centre for Soft and Biological Matter enables collaborations between our theoretical physicists and experimentalists in Chemistry through projects and shared research staff. The Oxford Photonics Network, which received funding from the EPSRC Pathways to Impact allocation in 2012, brings together researchers from across the University, as does the Oxford Climate Research Network. As part of the Physical Climate Science Initiative (§b.4), interdisciplinary collaborations are supported by a dedicated climate science Research Facilitator. We joined the Met Office Academic Partnership in 2013 both to support our work with them and to explore new interdisciplinary links with the partner universities (Reading, Leeds and Exeter) through research projects and secondments.

Interdisciplinary research projects, combining our skills with expertise from other disciplines, are required to tackle many scientific problems. Many have already been highlighted in §b and here we list more exemplars. In Biological Physics, Richard Berry collaborates with **Biochemistry** on flagellar motors in live bacteria; Sonia Contera developed new AFM techniques for mapping nanomechanical properties of live cells in collaboration with **Mechanical Engineering** at Purdue; and Achillefs Kapanidis has combined his knowledge of single molecule fluorescence with expertise on the rotavirus at the London School of **Hygiene and Tropical Medicine**. Laura Herz collaborated with **Chemistry** to create bio-mimetic light-harvesting molecules. Henry Snaith works with **Materials** through an EPSRC grant on the design and fabrication of solar cells. Collaboration initiated through the Oxford Photonics Network between Ian Walmsley, Brian Smith and **Engineering Science** led to a successful EPSRC Programme Grant. OMS funding has supported collaborative programmes such as in climate modelling with **Mathematics**, ocean/carbon-cycle interaction with **Earth Sciences**, and particle beam therapy with the Gray Institute for **Radiation Oncology and Biology**. Led by Vlatko Vedral and Dieter Jaksch, a newly established quantum biology research programme, also funded by the OMS, includes collaboration with **Philosophy** as well as several MPLS departments.

e.3 Research informed by needs of users

Both specific projects and research strategy have evolved in direct response to the needs of end users. The demands on the Met Office and ECMWF to deliver accurate weather forecasting have driven new research projects in atmospheric modelling. Our growing collaboration with AWE in extreme conditions science has informed our decision in 2013 to take a more strategic approach by establishing a joint research centre. Requirements from NASA for the design of their Diviner instrument on the Lunar Reconnaissance Orbiter led to Neil Bowles developing a new laboratory facility that has since underpinned a number of new projects on space weathering. Jaguar Land Rover's collaborative project with Paul Ewart has led to research on non-invasive monitoring of combustion processes in engines. Licensee APE GmbH has informed Ian Walmsley's research as he seeks to improve their laser pulse characterisation devices. John Gregg's collaboration with *[text removed for publication]* has informed his research and led to patents in non-destructive testing and position measurement. The real-world requirements of long-term stability and increased efficiency in solar cells has been a driver for Henry Snaith's research.

e.4 Academic leadership and service

From setting the direction of strategic multi-national initiatives to winning prestigious awards, our members are recognised for their international leadership and excellence. The career achievements of Brian Foster (2008), Ian Walmsley (2012) and Julia Yeomans (2013) have been recognised by election to Fellowships of the Royal Society, while early-career academics such as Jo Dunkley are already being acknowledged in international arenas.

In addition to project-specific roles described in §e.1, leadership roles have also been held in 88 national and international **committees, reviews and steering groups**, including

- Long-term planning and foresight exercises, e.g. European Committee for Future Accelerators (Burrows, Foster), and ASPERA Advisory Committee on astroparticle physics (Sarkar, Kraus).
- 30 facilities and telescopes outside the UK, by serving on **Scientific Councils** at DESY (Foster), ESO (Roche) and Space Telescope Science Institute (Davies); **Board vice-Chair** at ALMA (Roche); **Scientific Advisory Committees** at LCLS, Fermilab, Australian Astronomical Observatory and the Swiss Neutron Facility; five **User Groups** including Chairs for Herschel (Rigopoulou) and NIF (J.Wark); **Design Reviews** for five instruments on telescopes including ESO's VLT (Thatte) and numerous other management and working groups.
- **Space agencies** through ESA's Astronomy Working Group (Aigrain, Ferreira), UKSA Space Science Advisory Committee (Aigrain) and UK Aurora Science Committee (Bowles);
- **Policy development**, in a sub-committee of the UK Committee on Climate Change (Palmer) and a lead author (Allen) and review editor (Palmer) for the IPCC 5th Assessment.
- **Advisory boards** of NTT's Basic Research Laboratory (Ryan) and the UK Met Office (Palmer).

24 academics have served on **UK research council advisory committees**, for example Stephen Blundell on EPSRC's Physical Sciences Strategic Advisory Team, Philip Burrows as Chair of STFC's Particle Physics Advisory Panel, and three members on STFC's Science Board. 24 have been panel members for EPSRC, STFC, NERC or the Royal Society; 21 have been members of the EPSRC College; and 11 have served on a total of 15 peer review committees outside the UK including four for the ERC. 16 have served on facility access panels or equivalent (ISIS, Diamond, CLF, ESO, HST and 8 others), e.g. Andrew Boothroyd as Chair for ISIS.

Our work is leading international research agendas, evidenced by more than 300 **keynote and plenary lectures** across the full range of our research themes. These include the *EPS Conference* *on Plasma Physics* (J.Wark, 2009), *IAU Symposium 254* (Binney, 2008), *IUCr Congress* (Radaelli, 2008), *SCOSTEP Symposium* (L.Gray, 2010), the *APS Spring Meeting* (Bell, 2008), *Deep Inelastic Scattering* (Foster 2008, Cooper-Sarkar 2011), *Technology & Instrumentation in Particle Physics* (Foster, 2009), *International Conference on Quantum Optics* (Jaksch, 2010), *Foundations of Nanoscience* (Berry, 2011), *European Materials Research Society* (Nicholas, 2009) and *General Conference of the EPS Condensed Matter Division* (Yeomans, 2010). Eight staff have spoken at a Gordon Conference, and Cardy spoke at the 2008 *Landau Centenary Conference.*

Among another 1200 **invited conference talks**, those by early-career researchers have included plenaries by J.Dunkley (*COSMO 2010*), U.Haisch and J.Conlon (*Planck 2012* and *2013* respectively), and invited talks by Y.Chen (*APS March 2010,11*; *MRS Spring 2012*), G.Gregori (*EPS Plasma Physics 2010*); M.John (*Beauty 2009*); I.Konoplev (*ICIMT 2011*), M.Leake (*Biophysical Society 2009*), P.Leek (*Quantum Systems & Technology 2012*), H.Snaith (*MRS Spring 2010 & Fall 2011,12*), B.Smith (*IQEC 2010*) and A.Wells (*AGU Fall 2012*).

Our research has also been presented through **prestigious lectures** at institutions worldwide, including the Spitzer Lecture at Princeton (Balbus, 2012), Victor Starr Memorial Lecture at MIT (Marshall, 2010), and Friday Evening Discourse at the Royal Institution (Walmsley, 2010). Our members have played both scientific and organisational roles in the **convening of over 85 scientific meetings**, including 24 Chairs of Scientific or Programme Committees and 4 session Chairs. Cavalleri was Chair of the Gordon Conference, *Ultrafast Phenomena in Cooperative Systems* (2008); Bureau and Karastergiou chaired *IAU Symposia* (292 & 285).

Prizes have recognised the achievements of individuals at all stages of their careers. 54 individual research prizes were awarded to current and emeritus academics; and more to our PDRAs and students (§c.ii). **Senior academics** have won notable awards including the 2013 Shaw Prize for Astronomy to Steve Balbus; the ICTP Dirac Medal and IUPAP Boltzmann Medal to John Cardy; and the Joseph Keithley award (APS) and Young Medal (IoP) to Ian Walmsley. Tim Palmer won the European Meteorological Society’s Silver Medal and American Meteorological Society’s Rossby Medal, in each case that society’s highest award. Our astrophysicists and cosmologists are members of four teams that won RAS and NASA prizes. James Binney won a Dirac Medal (IoP) and Eddington Medal (RAS) and Robin Devenish received the Max Born Prize (IoP/DPG). Other awards included six from the IoP, two from the APS and one from the Royal Meteorological Society. Prizes for **junior academics** included IoP early-career awards: Maxwell Medals to A.Starinets and J.Dunkley and a Paterson Medal to H.Snaith. J.Dunkley was also part of the WMAP team that won the 2012 Gruber Prize for Cosmology. R.Coldea won the RSC’s B.T.M. Willis Prize; Y.Chen a Chinese ‘Outstanding Young Researcher’ award; and L.Fletcher an RAS Winton Capital Award. Our emeritus academics have inspired their successors with an IoP Dirac Medal to Ross, the Blaise Pascal Medal (European Academy of Sciences) to Sherrington, and the European Materials Research Society’s Jan Czochralski lifetime achievement award to Glazer.

Four new RS Wolfson Merit Awards (Balbus, Rawlings, Turberfield, Simon) recognise particular distinction in research. Subir Sarkar was awarded a Niels Bohr Professorship (2012), Brian Foster an Alexander von Humboldt Professorship (2011), Tim Palmer a Royal Society Anniversary Research Professorship (2010) and Joe Silk the Balzan Prize (2011). Burrows, Cavalleri, Norreys, Schekochihin and Seryi were elected Fellows of the American Physical Society.

Academics and Fellows have been **invited visitors** at over 55 institutions in 17 countries, mostly supported either by their host or a funding agency, including the Simons Visiting Professor at the Kavli Institute (Cardy), the Oort Professor and Lecturer at Leiden (Binney), an ETS Walton Fellow at NUI Maynooth (Simon), the Paczynski Fellow at Princeton (Balbus), and a Visiting Fellowship at ANU (Johnston). John March Russell is a CERN Associate.

Our staff give leadership and service to **international unions, learned societies and journals**. Roger Davies was President of the Royal Astronomical Society (2010-12), Stephen Blundell is President of the International Society of Muon Spectroscopy (2011-14) and Tim Palmer was President of the Royal Meteorological Society (2010-12). Five academics have been members of Council for societies including the European Physical Society and European Astronomical Society. 19 other committees and groups of the IUPAP, IAU, EPS, Royal Society, IoP and RSC have had a member from this department, including four Chairs. Between them, 43 academics are on the editorial boards of 50 journals including *Science*, *Phys Rev Lett*, *Comm Math Phys,* and *MNRAS.*