Institution: Imperial College London

Unit of Assessment: 9 Physics

a. Overview

The Physics Department supports 122 academic staff, 12 advanced fellows, 11 staff re-employed upon retirement (known as senior research investigators, SRIs), 3 teaching fellows, 12 research fellows, 159 research associates, 368 research students, 139 masters students, 851 undergraduates and 108 technical and operational staff. With average research funding of £24.5M p.a. we pursue a full breadth of physics research at the highest level. We are returning to REF 112 academic staff, 8 SRIs and 9 advanced fellows.

Since RAE2008, the Department has recruited 32 academic staff, diversified the sources of its research funding with 134% increase from UK industry, increased direct spend by 32% and income per academic by 34%. Hosting three Centres for Doctoral Training, research student numbers have increased by 82%, whilst maintaining high 48 month submission rate statistics. Staff have won many prestigious prizes and fellowships, with 6 new FRS, and have been appointed to a range of advisory, editorial and management boards.

The department is structured into nine research groups comprising: Astrophysics (**ASTR**), Condensed Matter Theory (**CMTH**), Experimental Solid State Physics (**EXSS**), High Energy Physics (**HEPH**), Plasma Physics (**PLAS**), Photonics (**PHOT**), Quantum Optics and Laser Science (**QOLS**), Space and Atmospheric Physics (**SPAT**), and Theoretical Physics (**THEO**).

b. Research strategy

Mission

Our mission in research is to work at the highest international level across an exceptionally broad spectrum of physics, from fundamental theory to applications in advanced technologies, in order to advance physics and address societal challenges. We have made major advances in mainstream physics and this will continue to be central to our mission. Our further aim is to enlarge the purview of physics by engaging in multidisciplinary collaborations within Imperial, and with national and international laboratories, other academic institutions and industry. We make it a priority to inform and inspire the public through our extensive public engagement and outreach activities.

Vision

Our vision is to attract outstanding staff and students to fulfil our mission by fostering a supportive and stimulating environment where all individuals can realise their potential and receive the professional recognition they deserve. Recognising that our greatest asset is our staff we are committed to equality of opportunity for all, and to transparent and inclusive management.

Strategy

In line with our plans at the time of the last REF a central plank of our strategy has been to establish new research centres in multidisciplinary areas where we can provide leadership, engaging academics across the College and attracting significant new funding. It was our further intention at the time of the 2008 RAE to maintain our leadership position in key areas of mainstream physics, and this we have achieved. We have also successfully seeded a number of areas where we believe we have the capability to become world leading.

Some evidence of achievements of strategic aims since RAE 2008:

	RAE 2008	REF2013
Direct spend (total over RAE/REF period)	£93M	£123M
In-kind costs (total over RAE/REF period)	£97M	£108M
Income per staff FTE p.a. (snapshot 2007 & 2013)	£149K	£200K
PDRAs (snapshot 2007 & 2013)	125	133
PhD students (snapshot 2007 & 2013)	211	335
PhD awards p.a. (average over RAE/REF period)	44	59

The mission, vision, strategy and professional values of the department are formulated and reviewed by the Head of Department (**HoD**) working with the nine Heads of Group (**HoG**s). To deliver our mission in research our strategy has 5 planks:

1) To enable our staff to thrive in an inclusive and stimulating research environment:

Groups are afforded considerable autonomy in identifying new research opportunities and formulating research strategy through an annual strategic planning exercise with 1 and 5 year horizons. Occasionally opportunities arise through staff turnover or funding initiatives for more radical changes of research direction. Such changes are discussed by the relevant HoG in consultation with the HoD and other HoGs. During the REF period this strategy has led to the appointment of 32 new members of academic staff in core physics and multidisciplinary areas with 20 staff having moved on or retired.

The group structure provides the framework for departmental management, with HoGs meetings constituting the department's senior decision-making body, chaired by the HoD. These meetings take place monthly during term times. The HoD and HoGs roles are all held on 5-year rotating cycles which allow a healthy turnover of research perspectives and leadership.

Since the start of 2008 we have invested £3.3M in laboratory and office refurbishment, mainly to support research areas designed for strategic expansion including high energy density science, plasmonics, biophotonics and astrostatistics (see Groups below and §d).

Stimulation of new ideas, as well as social cohesion and high morale are boosted by seminar series and departmental colloquia (with external speakers) and inaugural lectures followed by informal social events for all staff and postgraduate students.

2) To collaborate in strategic areas and to foster multi-disciplinary research:

Much of our multidisciplinary work is delivered through inter-departmental centres of excellence, working with ten other Imperial departments across the faculties of Engineering, Natural Sciences and Medicine. We have been able, with College investment, to establish the Centre for Plastic Electronics (**CPE**, founded and led by Bradley 2009) involving 4 departments, the Thomas Young Centre (**TYC**) for Theory and Simulation of Materials (founded 2005 by Sutton and 3 from UCL) with 8 departments and 3 other London colleges, and the Centre for Plasmonics and Metamaterials (**CPM**, founded 2010 Pendry and Maier) with 3 departments.

Three new EPSRC Centres for Doctoral Training led by the department were awarded in 2009 in Theory and Simulation of Materials (TSM), Controlled Quantum Dynamics (CQD) and Plastic Electronics (PE). TSM and PE act as hubs for interdisciplinary research across the College and beyond and have strong links to manufacturing industry. CQD engages with experimental and theoretical physicists across the UK to develop and exploit quantum properties of matter. CDTs have brought in 164 PhD studentships of which 12 were industrially or self-funded.

In alignment with national priorities we place an emphasis on the 'Grand Challenges' in Energy, the Environment and Healthcare. Consequently, we have led activities, and developed collaborations within, Imperial institutes: The Climate Knowledge and Innovation Community (**KIC**), The Grantham Institute for Climate Change, (**GICC**), The Energy Futures Lab (**EFL**), The Institute for Global Health Innovation (**IGHI**), The Institute for Security Science and Technology (**ISST**) and The Manufacturing Futures Lab (**MFL**). 9 academic staff now hold positions jointly between Physics and the Institutes as well as with the Departments of Surgery and Cancer, Materials, and Maths.

3) To maintain research funding, diversify sources and expand industrial collaboration:

Over the REF period we have earned research income averaging £24.5M per annum. Our current grant portfolio includes the largest funding by each of EPSRC and STFC to any single UK university Physics Department. We have increased the fraction of our income derived from other sources (see §d). We now have links to more than 160 companies in 50 countries worldwide.

4) To promote translation:

We aim to translate the results of our research effectively to the benefit of the economy, society and culture of the UK and internationally, exploiting the facilities provided by Imperial Innovations to develop spin-outs as well as direct links established with research users. [See REF3a.]

5) To provide a positive working environment:

Over the REF period we have introduced a number of initiatives (see §c) to improve the engagement and sense of belonging of all staff and students, as well as practical support for career development. Staff are encouraged to focus on the quality, rather than quantity, of their publications so that while the average number of journal articles per year per FTE has remained stable at around 7.5, the number of citations, and average impact factor of the journals, has

increased substantially: of our outputs submitted to REF the average impact factor is 7.44 and citation count 46. Other evidence of the success of our approach is in the 57 early career researchers who took personal fellowships in the department. External recognition of our achievements in providing a positive environment is provided by the awards in 2009 of Juno Champion status and Athena Silver SWAN status, both renewed 2012.

Research group developments since RAE2008 and plans for the next REF period

ASTR: We hold established leadership positions in cosmic microwave background science (Jaffe) and all sky surveys (Warren). In 2010 we identified astrostatistics as an area with significant potential for both research and its translation, and within which we could build on existing strengths. To these ends we established, in collaboration with the Dept. Mathematics, a new Imperial Centre for Inference and Cosmology (**ICIC**), enabled by a College strategic investment in statistics. It is associated with 4 new appointments: 1P (Heavens) and 1L (Pritchard) in Physics, 1P (van Dyck) in Maths and 1 joint L (Mortlock). Initial successes include discovery of the oldest known quasar (Mortlock, this paper identified by *Nature* as one of its 10 research highlights of 2011), and pioneered new approaches to probing primordial non-gaussianity (Heavens). A key goal for the next 3 to 5 years is to establish ICIC as a leading centre for the analysis of astronomical data and to translate the statistical techniques developed to other areas of endeavour. We also intend to extend our activities in the Euclid consortium: Heavens and Warren have senior roles respectively in the gravitational lensing and legacy science aspects of this satellite, designed to quantify dark energy and dark matter and due for launch 2020.*ASTR (9 FTE comprising 3 Professors, 3.8 Senior Lecturers, 2 Lecturers, 0.2 SRI) was awarded 20 grants totalling £6.1M over the REF period*.

CMTH and EXSS: We have established a number of thriving research areas including: theory and simulation of materials (led by Sutton), plasmonics and metamaterials (following ground-breaking work by Pendry), organic and inorganic photovoltaics (Nelson), magnetism (Cohen) and plastic electronics (PE, Bradley). Following the award of a Science and Innovation grant (joint with UCL under the London Centre for Nanotechnology umbrella) we made major investments in the area of plasmonics and metamaterials. The appointments of Maier (R, 2008, then P) in plasmonics, Hess (P, 2010) in computational metamaterials and Oulton (EPSRC CAF, L 2010) in nanoplasmonic lasers have added to our strength in this area and attracted a number of outstanding fellowship holders and further funding, notably Leverhulme Trust Emerging Disciplines (2009 £4.9M) and Active Plasmonics Programme grant (£2M). Despite the departure of Cowburn we have maintained our strength in magnetism through the appointments of Sandeman (URF, L 2009), working on magnetic refrigeration, and Branford (CAF, L 2010) who pioneers the new field of monopole defect physics in artificial spin ices.

The three CMTH/EXSS led College research centres (TYC, CPE and CPM) have spawned new inter-departmental, inter-institutional and industrial links. The TYC, for example, played a pivotal role in winning the BP ICAM node (£2.5M). Our Theory and Simulation of Materials (£6.4M) and Plastic Electronic Materials (£7.3M) Centres for Doctoral Training are embedded within the TYC and CPE.

We aim to develop our work at the interface with life sciences (e.g. IR sensing, Phillips) and in quantum nanophotonics. We will also expand activities in materials for energy, profiting from our strong work in photovoltaic physics. For PE, advances in conformationally-defined photonic structures, the photophysics of novel molecular architectures and the device physics of low temperature metal-oxide (Anthopoulos, ERC Starting Grant 2012) and organic-inorganic hybrids are complemented by a growing engagement in manufacturing-related research (EPSRC Centre for Innovative Manufacturing in Large Area Electronics). In TSM we will focus on rebuilding theoretical and computational metal physics, and on new methods and associated software.

CMTH (8.9: 6.9P, 2SL) and EXSS (15.6: 8P, 2R, 3SL, 2.6L); 109 grants totalling £33.5M.

HEPH: The group has established expertise in theoretical and experimental particle physics, accelerator physics and particle astrophysics. It is internationally recognised for its leadership role at CERN, most notably its role in the discovery of the Higgs-like boson. This follows from the theoretical developments in the 1960s (Salam, Kibble et al) and long-term involvement in experimental work, with Virdee playing a key role in the design of CMS in 1990s and acting as Spokesperson 2007-2010. The work of the group is underpinned by an outstanding grid-computing

group (Colling). The accelerator physics group leads activities in MICE-UK, the high power proton driver at RAL and studies for a neutrino factory (Long, supported by £2.1M grant). Our involvement in the T2K experiment has been maintained after the departure of Wark by the appointment of Wascko (AF and L). Our particle astrophysics activities (Sumner, Araujo) relocated from ASTR to HEPH to develop emerging synergies with studies including the search for Dark Matter with liquid Xenon detectors and gravitational waves with the Lisa space mission, supported by grants from STFC and ESA (£1.6M).

The strategy for the next 5-10 years includes studies of flavour physics with LHCb (with a new L to be appointed 2014 to support these efforts), development of new detectors for LHC and technology development for new accelerators. A new initiative on searching for charged Lepton Flavour violation (COMET, to be based in Japan) received funding on the group's STFC Consolidated Grant and the department has been supporting the development necessary to bridge the activity until the completion of STFC's programmatic review.

HEPH (19.9: 8.5P, 4R, 3SL, 4L and 0.4SRI); 49 grants totalling £32.6M.

PHOT: We have strengthened our broad portfolio of research across laser technology, imaging science and biophotonics, and remote sensing, and enhanced industrial links and interactions at the life science and medical interface. Our high standing in fibre laser research (Taylor) has been further strengthened by industrial financial support (e.g. $480k from fibre laser market leader, IPG Photonics, 2010) allowing new research into applications in remote sensing, optical instrumentation, laser processing and surgery (Popov). To maintain excellence we will appoint, 2014, a new L in Fibre Laser Technology. Current plans include novel ultrafast lasers to realise universal all fibre-integrated femtosecond pulse sources in the visible spectrum. Our laser development programme has also produced the world's highest gain solid-state amplifier, commercialized via spin-out Midaz Lasers Ltd (Damzen), sold to premier laser company Coherent Inc., 2012. We are growing a new area in satellite-based remote sensing, supported by ESA, and have already demonstrated the world's highest power diode-pumped Alexandrite lasers with high efficiency and wavelength flexibility to address this activity.

We have enhanced our internationally-recognised research in biophotonics (French, Dunsby) through a new L appointment (McGinty) and refurbished laboratories. This work, supported by >£5M in current (EPSRC and MRC) funding, involves collaboration with industrial partners, clinicians and scientists across Imperial and internationally. Strategic developments are towards enhancing translation to *in vivo* imaging and clinical diagnosis. We aim to leverage our expertise in photonics technology to create new tools for molecular cell biology and drug discovery, giving life scientists the opportunity to investigate biomolecular processes with unprecedented detail, speed and physiological relevance.

PHOT (11: 6P, 2R, 2SL, 1L); 40 grants/donations totalling £9.9M.

PLAS and ISP: During the REF period we have focused on high energy density science, and have created a unique laboratory for Extreme Physics (Lebedev, Smith). Supported by £1.2M of College and RS Wolfson funding we linked (2013) our pulsed power generator (the most powerful such facility in any university in the world) to the UK's largest university-based laser. Aligned with this the Institute of Shock Physics (**ISP**) was established in 2008 with £5.5M from AWE and 3 new staff (Proud, Bland, Eakins), and renewed in 2013 with a further £2.5M over 5 years to study extreme materials science. We have recently joined the STFC John Adams Institute (with Oxford and RHUL), and a programme grant led by QUB, working on laser acceleration to advance fundamental science, medical hadron therapy and advanced light sources (Najmudin). We plan to expand our work on Inertial Confinement Fusion with links to the US National Ignition Facility (Chittenden, Rose).

PLAS and ISP (11.65: 5.25P, 2R, 1SL, 3L and 0.4SRI); 57 grants totalling £20.7M.

QOLS: We have focussed on attaining and maintaining leadership in three key areas: (1) We invested in staff and laboratories such that we host the only UK university group that can perform attosecond measurements, achieving a world record for the shortest, fully-characterised high power few-cycle laser pulse (Frasinski). Averbukh (EPSRC CAF) has been appointed L to maintain the theoretical component of this activity, and we have won EPSRC Translation and Programme Grants as well as an ERC Advanced Investigator Award (Marangos). Our future plans include attosecond measurements of electron dynamics on surfaces and in nanoplasmonic structures, and

applications of attosecond spectroscopy in a condensed phase environment. (2) In 2010 our Centre for Cold Matter was awarded a flagship EPSRC Programme grant (£6M) with Durham on Cold Atoms and Quantum Information. We recently achieved a world record measurement for the maximum value of the electron Electric Dipole Moment (EDM, Hudson 2012). Hinds won (2013) an ERC grant to further study the EDM. Our research interests are now shifting from cold atoms toward cold, and ultracold, molecules and waveguide QED using molecules. (3) Quantum optics/theory is central to our research portfolio and, following the departure of Plenio (who retains 10% FTE) and Scheel, we have made new appointments Kim (P), Mintert (SL and ERC Fellow) and welcomed a new URF (Jennings). Our focus is increasingly turning towards applications in quantum enhanced technology. We have significantly expanded our PGR provision within the CDT in Controlled Quantum Dynamics with an EU Innovative Doctoral Programme in Frontiers of Quantum Technology (Kim, €3.8M Mari-Curie ITN).

QOLS (13.41: 8.21P, 1R, 2SL, 2L and 0.2SRI); 49 grants totalling £31.3M.

SPAT: Space Physics: We are leaders in experimental space magnetometry and theoretical heliospheric physics. Dougherty led the Jupiter Icy Moons Experiment (JUICE) proposal which was selected (2012) as ESA's next L-class mission and she is now PI on the magnetometer: JUICE's only UK-led instrument. Science from JUICE will be a major focus of our planetary research, and this will be supported through a new L appointment (2013). The College is supporting our translation of space science to engineering practice through a new Imperial Space Lab (Schwartz, Director), which will link space-related activities across Imperial with external users in government and industry. A new initiative is in Space Weather where we have developed miniaturised sensors capable of rapid deployment on cubesats (patented and licensed to a commercial company, Carr, see Impact Case Study P8) while Eastwood (L 2012) leads our participation in Sunjammer. **Atmospheric Physics:** Aligned with college strategy in environmental research, and partially funded by GICC, we are linking our Earth Observation and Climate Physics research to Life Sciences and appointed two new Ls (Voulgarakis 2012, chemistry-climate interactions, and Graven 2013, carbon budget). KAUST is funding work using EO data with regional models to investigate dust effects over Saudi Arabia (Brindley, Toumi); we plan to expand this area. A NERC consortium (PI Haigh) advanced understanding of solar influences on climate; future work will develop links with solar physics (ASTR and external). Czaja runs the GICC ocean initiative and is developing projects with Earth Sciences and Maths Depts.

SPAT (14.9: 5.6P, 3.75R, 1.85SL, 3.3L and 0.4SRI); 72 grants totalling £18.9M.

THEO: We have maintained a leading position in string theory and have won two ERC Advanced Grants in this area (Tseytlin, Gauntlett). We made the first realisation of holographic superconductors in M-theory (Gauntlett, Wiseman, 2009) and pioneered new connections between black holes and quantum information (Duff 2010). Strong links have been established with Donaldson's Geometry Group in the Maths Department. A highlight in cosmology was Contaldi's contribution (2009) to the data analysis of the high impact ACBAR results that comprised, at the time, the most detailed CMB anisotropy measurements. Our plans are to maintain our strong position in string theory, quantum field theory and quantum gravity and to expand in cosmology, capitalising on new data streams and extending links with ASTR, and in particle phenomenology, strengthening links with the new HEPH L in Flavour Physics.

THEO (14: 12P, 1R and 1SL); 19 grants totalling £9.0M.

Plans for multidisciplinary activities

We plan to place increased emphasis on research with applications in medicine and healthcare. Applications of our biophotonics research are being developed through the CDT in Chemical Biology. With the Department of Surgery and Cancer (DSC) our technique for IR imaging of tumours (Phillips) will shortly undergo clinical trials. With funding from a cancer charity and the Cockcroft Institute we have appointed, jointly with DSC, a new L (Posocco) to develop technology for hadron beam therapy. ISP staff (Proud, Eakins) are integral to a new Centre for Blast Injury Studies at Imperial, funded by the Royal British Legion, where civilian engineers and scientists work alongside military doctors. We will exploit super-resolved microscopy to develop predictive microbiological tools and a unique Physics of Food Science Lab is being established (Török, Paterson) with the Institute of Food Research and with commitments from commercial partners for the provision of equipment valued at €65k. Increased collaboration with biomedical scientists and

clinicians will be further facilitated through the new Francis Crick Institute (with MRC, UCL, KCL).

The Centre for Inference and Cosmology (ICIC) aims to translate statistical techniques to other areas including finance and medicine.

ISP is part of a new £4.9M Programme Grant, led by Materials Dept with strong industrial links, set to improve understanding, performance and application of hexagonal material systems used by the aero, energy and defence sectors. PHOT is part of a new EPSRC CDT which will research the physics of diamond.

Our research in climate and environmental physics will be enhanced by PhD studentships awarded through the new NERC-funded Doctoral Training Programme at Imperial and the new EPSRC CDT in Mathematics of Planet Earth (led by Maths, with U. Reading), both in collaboration with GICC.

c. People, including:

i. Staffing strategy and staff development

The quality, motivation and well-being of the department's staff are essential for successful research activity. We prefer to appoint at a junior level, and to give new staff time and support to enable them to initiate and develop their own activities, while recognising that senior appointments provide leadership and enable us to open up new areas. Our 32 new academic appointees consisted of 5P, 1R, 1 SL, 22 L, 3 fixed-term L. In line with our strategy of expanding multi-disciplinary research three of the lectureships were joint with the Departments of Surgery and Cancer, and Maths and with the Grantham Institute. Over the REF period 50 academic staff were promoted, including 18 to personal chairs. Promotion to professor requires the support of international referees and significant achievements to be demonstrated to a senior College panel. That over one half of our academic staff are at this level is testament both to the high calibre of the staff and the excellent opportunities for promotion in the College. We are returning to REF 92% of our academic staff.

Our staff age profile has remained fairly constant with quartiles at 41, 46, 55 in 2007 and 41, 48, 54 in 2013. We retain the skills and contributions of many of our experienced staff following retirement by appointing them Senior Research Investigators (with a part-time salary and returned to REF) or Distinguished Research Fellows. All our retirees during the census period have one of these roles and are active in research or teaching, primarily through UG or PGT research projects.

Interdisciplinary research, at which Imperial excels, enables departments to share space (e.g. the cross-departmental Complexity and Networks group). Future reconfiguration of the Blackett Lab, as well as the new Imperial West campus (see §d), will expand our capability and maintain flexibility in our staffing strategy.

Staff with personal research fellowships: Vibrancy is maintained within the department through encouragement and support of fellowship applicants. In the REF period 22 new staff with fellowships (including 12 of the new academic staff) joined us and 46 staff won (or renewed) personal research fellowships: 1 RS Professorship (Hinds), 1 EPSRC Senior Fellowship (Gauntlett), 1 RS Industry (Nelson), 1 NERC Knowledge Exchange (Toumi), 3 Leverhulme (Jaffe, Rudolph, Warren), 5 RS URF, 1 RAEng, 2 RS Newton, 1 RCUK, 8 EPSRC CAF/ECF, 2 1851 Fellowships, 12 Imperial JRFs, 1 Daphne Jackson, 1 Sir Henry Wellcome, 5 Marie Curie, 4 STFC Advanced, 10 EPSRC/STFC PDF. The Imperial JRF scheme, initiated in 2009, is an annual competition set up to attract young scientists of exceptional international quality. The 12 awardees (of a total of ~90) in Physics contribute to the high calibre of ECRs in the department.

During the assessment period, of those not already associated with an academic post, 7 Fellows have been appointed to lectureships. Of our departing Fellows 24 gained academic posts: 16 in UK universities and 2 in each of EU, USA, Far East, and Central Asia.

International staff appointments: We attract high quality applications from overseas and only one half of our 32 new academic staff are from UK, with 8 from EU, 4 from N. America, 1 from each of Russia, India, Korea, Australia. In addition, 32 appointments have been made to formal Visiting Academic positions. Of these 18 are from UK with others from around the globe including Germany, Poland, Mexico, Russia, USA.

Of our 8 academic staff leavers 5 took positions overseas: Director of the Max Planck Institute for Extraterrestrial Physics in Garching, Director of Institute for Theoretical Physics at Ulm, Chair at U. Potsdam, Chair & Head of HEP at U. Ioannina and Lectureship at U. Rostok.

Support for career development: To ensure that we are aware of any staff concerns, and to assist in the design of support mechanisms, we ran departmental surveys in 2008 and 2013 of all staff (The Athena National Asset survey in 2010, in recognition of our good practice, used many of our 2008 questions). The results of these surveys, and those of a College-wide survey in 2011, led us to introduce activities, courses and committees to provide support, guidance and advice. For all new staff we have created a welcoming Induction Site filled with information and links to all key activities in the department.

Research Assistants: One striking outcome of our surveys was the need to engage our post-doctoral community. To address this we set up in 2009 a Physics RA committee with representation across all research groups, with aims to (1) provide discussion forum covering all aspects of the working lives of RAs, (2) act as an informed body to disseminate information to the RA community and (3) help define training needs for HR Staff Development. It has had a very positive impact on RA morale, captured by the later 2010 National Asset survey.

The importance of our researchers' personal and career development (and lifelong learning) is recognised and supported at all levels by Imperial College. It has implemented fully the Concordat to Support the Career Development of Researchers and has achieved an HR Excellence in Research Badge from the European Commission.

The College's Postdoc Development Centre (PDC) offers a tailored programme of support providing at least 10 days per year on professional development. Physics RAs in have made full use of the opportunities provided with 110 attending its courses (2008-2013), 70 receiving 1:1 coaching sessions (2009-2013) and 21 taking mock interviews (2010-2013). The RA committee ran a survey to identify the courses that would be useful and, as a result, the PDC has produced tailored programmes, including bespoke courses for women.

On completion of their post-doctoral positions staff destinations were: HEI or research institution – 24% UK, 36% OS; 8% industry, 11% other, 21% not known/unemployed.

Early Career Researchers and new academic staff: We have a thriving community of fellowship holders who are listed on a dedicated web page. This celebrates their success and identifies them for networking purposes. As one of the main entry routes into academic posts is through fellowships, we have provided guidance concerning the departmental selection of ECRs for fellowship applications, in part to encourage strong applications from poorly represented gender and ethnic minority groups.

In the REF period 13 ECRs were appointed to lectureships at Imperial and a further 45 were given academic posts at other universities across the world.

Probationary lecturers in the department are given reduced teaching/admin allocations (50% in first year, 75% in second), start-up funds (totalling £160k) and have preferential access to PG studentships. A 2011 College scheme to provide ECRs with small items of equipment has awarded 8 grants, totalling £71K. Each new lecturer is appointed an academic advisor, who regularly reviews academic progress (teaching, supervision, research grant applications, visibility and training needs), and a teaching buddy who provides constructive feedback on teaching performance. We have established a scheme of Departmental Champions who are available to share expertise while further one-to-one mentoring is available both within and outside the department.

One measure of the effectiveness of our support mechanisms is the success of our newly-appointed staff and fellows in winning research funding: 20 have been awarded grants exceeding £10M in the REF period of which over £4M was earned by ECRs.

Established staff: The College's Learning and Development Centre (LDC) provides management and leadership programmes to all staff. This includes the Female Academic Development Centre (support for women in academic positions), and the Senior Academic Leadership Programme (equipping senior academic staff with the practical skills and awareness required for organisational leadership).

To enhance staff engagement we consider it crucial to make departmental processes transparent. HoGs meet monthly to discuss strategic issues. The minutes of these meetings are made available and termly meetings of all staff allow open discussion on any departmental issue. We have set up webpages which include information on promotion (including the very early stages) and the mechanism by which teaching load is allocated.

Each year every member of staff is required to undertake a Personal Review and Development Plan (PRDP), a two-way discussion between staff member and line-manager aimed at recognising achievement, providing constructive feedback, and assisting with career development.

To provide an element of independence an allocation of funds totalling about £300K p.a. is distributed to groups, based on factors including size, grant income and teaching loads, to spend as they see fit; this is often used to support conference travel costs of junior staff.

The success of our staffing strategy (for research) is evidenced by 90% of all academic staff having been a PI or Co-I on a grant awarded during the REF period, 77% were line manager to an RA, 94% supervised at least one PhD student and 86% started a new PhD student.

Equalities and diversity: The College is committed to supporting equality-related activities. These comprise a dedicated Equalities Unit and support networks, including Imperial as One (race), Imperial 600 (LGBT), and Disability Staff and Student Forums. The Elsie Widdowson Fellowship Scheme provides 50% of the salary costs for 12 months to allow female academics to concentrate fully on their research work upon returning from maternity / adoption leave. 11 of the 112 academic staff submitted to REF are employed at <1 FTE.

A departmental "Juno" committee was formed in 2007 to address equality and transparency in education and employment practice. The Department was awarded IoP Juno Champion status and an Athena Silver SWAN Award in 2009 in recognition of exemplary efforts in the area of diversity and equality, being one of only two departments in the UK to hold both awards at that time. Each was renewed in 2012 for a further three years with Imperial College as a whole achieving Silver SWAN status in 2013. The department's Juno website summarizes our activities.

ii. Research students

Recruitment: Post graduate studentships are widely advertised. Candidates are interviewed by at least two academics, offered a tour of the Department and meet current students.

Our PGR student numbers (including those on MRes courses) have increased steadily from 213 (4) in 2008 to 357 (7) in 2012 full (part) time, with an average application to admission ratio of 5.2:1. The increase has been enhanced by the 3 CDTs hosted since 2009. Increased staff numbers means that PGR (excluding MRes) student to staff ratio (SSR) has moved only gradually from 2.1 to 2.9.

The current funding profile for our PhD students is: 21% EPSRC DTG, 32% EPSRC CDT, 21% STFC and NERC, 15% self-funded or scholarships, 11% industry (up from 5% in 2008). Students may apply for Imperial College PhD Scholarships (6 were awarded to Physics applicants in the scheme's first year of operation 2013).

In order to attract further high quality overseas applicants we established (2012) a scheme of Academic Ambassadors who travel regularly to particular countries and talk to prospective students. An early result is the establishment of a UG research exchange with MIT.

Training and support mechanisms: The Imperial Graduate School provides an award-winning professional development programme that supports PG students with specific emphasis on their future careers. The College is the only university to have won the Times Higher Education Award for Outstanding Support for Early Career Researchers twice; in 2012 the TSM-CDT was shortlisted for the same award for its ground-breaking course on team-building, collaboration and self-awareness. All our CDTs have created exemplary postgraduate training packages that are offered elsewhere within College and nationally. The CQD-CDT training was recognised by the award of Innovative Doctoral Training programme (€3.8million) under the EU Marie-Curie ITN. Its annual summer schools are attended by all UK-based students whose research is related to quantum technology. In 2011 the PE-CDT received the Technology Leadership in Education Award from the US-based FlexTech.

All research groups provide discipline-specific training, including a minimum of 30 hours taught courses, workshops and/or summer/winter schools. All students also participate in regular seminar events, research-focused presentations and journal clubs.

PG reps sit on the department's PGR and Teaching Committees. We have also established a PG student committee, on which each research group is represented and into which the department makes an annual investment (about £1500) to facilitate networking and social activities. In response to a request from this committee we set up an Industry Club to enhance engagement

with companies who are interested in research and/or offer potential career opportunities. In 2011 we initiated an annual post graduate research symposium, enabling PG students to interact with Club members. About 40 industrialists per year have attended. Very positive reports from both PGs and industrialists suggest these events are of benefit to both groups.

To recognize the achievements of PhD students we have increased the number of internal prizes awarded for theses, presentations and posters from 3 in 2008 to 15 in 2013. Some of these are funded by members of our Industry Club.

In response to a PG focus group suggestion we held (2011) a refresher workshop for PhD supervisors, supported by the College's Educational Development Unit. Over 70% of supervisors attended and it proved extremely valuable in the sharing of best practice. It has now been adopted more widely across College.

Personal support for PGR students is available through the group Academic Mentors, the department PG Welfare Officer as well as College Tutors, the Counselling Service, the Health Centre and the Student Union Welfare Office.

Progress monitoring: We follow the formal monitoring of PhD progress advised by the Graduate School: students produce a written report at 3months, 9-12mo and 18-24mo and give an oral presentation to an independent academic alongside the supervisor(s). If progress is identified as less than satisfactory the DPS follows up and, if necessary, alerts the PG Welfare Officer. The department has also instigated further formal monitoring at 36mo and 42mo. This strategy has been successful in achieving a four year average (2008-2011) 48-month PhD submission rate of 86.7%, with 244 theses submitted and examined in this time period resulting in a total of only 4 referrals (to MPhil).

After completing their degrees 50-60% of the graduates stay in HE as post-docs, 15-20% enter the finance/business sector and about 10% go into IT/Communications.

d. Income, infrastructure and facilities

The success of our research strategy is partially evidenced by our ability to attract funding.

Grants awarded: Over the REF period the department was awarded research grants totalling £162M made up of 402 grants from 55 funders. The funding sources were: 72.8% UK RCs, 12.9% CEC and other EU, 8.0% UK government, 5.0% UK industry and charities, and 1.3% overseas.

These included 31 large (>£1M) grants, total value of £78.6M, of which 4 were EPSRC Programme Grants (Hinds, Hull, Marangos, Najmudin (with QUB)) and 4 ERC Awards (Anthopolous, Hinds, Marangos, Tseytlin). 2 more ERC Awards (Gauntlett, Mintert) are in the pipeline.

Annual spend: We have maintained our total annual research spend at ~£24.5M but the proportions from different funding sources have not remained static. During the period 2008/9 to 2012/13 the RC contribution declined, mainly due to changes at STFC, but the EU component has seen a steady growth. The UK industry component has also increased, partly reflecting significant new grants from BP (Sutton) and Unilever (Bradley). We are building relationships with large companies and SMEs and anticipate that industrial funding will be an area of continued growth; we are also working to develop further our interactions with US government and defence establishments. We anticipate that our strategy (outlined in §b) to expand our portfolio of research, especially into areas related to medicine, will provide access to new funding streams.

Investments in infrastructure and facilities: In line with its strategic priorities the College has awarded since 2008 funding totalling £2.1M to the department to support the following activities: Thomas Young Centre, 08/09-12/13, £225K; Centre for Plasmonics and Metamaterials, 2008/9-2013-14, £175K; Plastic Electronics Institute I, 2008/9-2013-14, £322K; Plastic Electronics Institute II (Manufacturing and scale-up facility), 2011/12-2015/16, £888K; Centre for Nanoplasmonics, £250K; Imaging Across the Scales, 2008-2012, £200K. EPSRC-related work has received additional College strategic investment of £68K for work in cold matter (Hwang) and quantum information (Rudolph), while Faculty provided start-up funding of £150K for Imaging Science and £50K for Astrostatistics in 2010.

The department occupies 14,585m^2 on the College's South Kensington campus, primarily within the Blackett Laboratory, of which research accounts for 10,500m^2. Space usage is regularly reviewed and a programme of refurbishment of existing and new space is implemented to address requirement associated with strategic developments in research activities and staffing. During the

REF period Imperial College funded refurbishments in Physics to a total value of £3.3M:

- A complete corridor (397 m^2) was developed to provide a suite of new laboratories to accommodate our expanding activities in biomedical imaging, experimental plasmonics and a new programme of work on new quantum states of light (initiated via the award of an EPSRC Early Career Fellowship to Nyman).
- Refurbishment of 242m^2 lab space included linking the MAGPIE Z-pinch and Cerberus laser laboratories for extreme physics (with beam pipe connections). A donation of laser hardware (worth £10M) by AWE has been part integrated into the new labs giving us a facility which is matched only by the Sandia National Laboratory in the US. It also includes new high quality laser bays and a radiation shielded target area built to support work with the John Adams Institute.
- 341 m^2 of office space was refurbished for the new Centre for Inference and Cosmology and an additional 406 m^2 for the ISP and QOLS staff.

Spending by the College/Department on equipment (in addition to that funded directly by grants) amounted to ~£756K on items above £10K and ~£1.08M on items above £50K. This includes strategic purchases in the Centres for Plastic Electronics (£425K) and Plasmonics (£246K).

Faculty Strategic Funding under the Kick-Start and Institutional Support schemes has contributed a total of £144K to department activities. Examples of spend under this category included the build of a short pulse mid-IR laser source (Marangos, QOLS), the purchase of a heated stage for a vibrating sample magnetometer (Sandeman, EXSS), a Vertical Machining Centre in the main workshop and contributions towards visitor programmes.

Further external support, unrelated to research grants, was received from AWE in the commissioning of the gas gun. This amounted to an initial investment of £2M.

To ensure a continued ability to grow research activity, Imperial College is currently progressing a master plan for its estate. Within this plan a priority item is the refurbishment of facilities for the Physics department commencing, over the next three years, with an ~£8M investment in upgrade of infrastructure in the Blackett Laboratory. The department will also benefit from participation in the new Research and Translation Hub at Imperial West – a 42,000m^2 high-specification, multi-disciplinary research and incubator space for 1,000 engineers and scientists who will collaborate with global industrial business and higher education partners in an environment that fosters translation and commercialisation. Construction will commence in Q2 2014.

Consultancies and professional services: The establishment and management of external consultancies are facilitated by **Imperial Consultants** (ICON) which, since 2007/8, has brokered 55 commercial consulting projects between Physics staff and 42 external clients with a total value of £3.6M. Examples include advice to Aqua21 Ltd. on plasma ozone generation by Bland, to Johnson Matthey on Raman spectroscopy by Cohen, to DSTL on explosives by Proud and to BP on resilience to regional climate change by Toumi. A further 32 formal consultancies, with 27 clients, and 10 company directorships have been established by staff independently of ICON. In several cases consultancies have led to more formal research partnerships (§ e outlines some examples).

Commercialisation of our research is advanced through **Imperial Innovations**, a publically-listed company combining the activities of technology transfer and company incubation with investment. Since 2008 Innovations has registered 74 Invention Disclosures, filed 56 Patents and 19 Families and brokered 8 IP deals from Physics research. Innovations has raised significant funds for the companies spun-out of Physics research including £1.9M for Duvas in 2013 and £0.9M for Quantasol in 2010. Successful spin-outs contribute to 9 of our 13 REF Impact Case Studies.

Specialist infrastructure and facilities: The department's experimental research is supported by 4 well-equipped workshops and 4 clean rooms (either IS06 or IS07) with total area 1,063m^2 for semiconductor, polymer and nanofabrication as well as spaceflight hardware development. The main Mechanical Instrumentation Workshop, which was extensively refurbished in 2007, has benefited from £130K of new equipment during the REF period. It holds precision engineering machines and a Computer Aided Design facility. It underpins research in HEPH, CCM, ISP, PLAS, SPAT and is also contracted out for Biosciences and Medical research. Our Electronics Instrumentation Workshop hosts a range of equipment and facilities for design, measurement, manufacture, repair and fault diagnosis and works to enable full integration with projects serviced in the Mechanical Workshop and other research service facilities. More specialist facilities are

operated in the HEPH and PHOT workshops.

The workshops are staff by 31 technicians (up by 3 since 2008) with open-ended contracts, one of whom was awarded the Royal Society Hauksbee Medal 2010. We are active participants in the College's new technician apprenticeship scheme with two trainees currently in the department.

Specialist equipment: Imperial College coordinates centrally a directory of research facilities, a searchable list designed to enable collaboration and to improve efficiency and utilisation of existing equipment and facilities. It currently lists 864 items from across the college, including 77 in the Physics Department. We host two facilities that charge out:

- The Raith e_Line electron-beam lithography facility in EXSS which provides sample nano-fabrication, and inspection by Scanning Electron Microscopy.
- The Gas Gun in the ISP. This 100 mm bore, single stage helium-driven Gas Gun, the largest of its kind in the UK, is capable of studying impact-conditions on a wide variety of materials. Together with a state-of-the-art suite of diagnostics this is accessed by industrial associates (e.g. AWE, QinetiQ, Thales TME) and collaborators worldwide (including US National Labs; Russian Academy of Sciences; Military Technical Academy, Romania; U. Pardubice, Czech Republic).

Four EPSRC grants, totalling £118K, have been awarded through the College's "Efficiency and Effectiveness: Promoting sharing of research equipment" to make specific items (including the e-beam) more widely accessible.

Usage of major and international facilities not supported by the Research Councils: Through extensive international collaborations (see §e) staff are involved actively in experiments in labs across the world. Specific examples include:

- Sandia National Laboratory SATURN facility for a period of approximately 2 weeks (estimated value ~$200k) and a total of 5 "Z" facility shots (~$1M).
- Cornell University where PhD students and RAs have spent periods of up to 6 weeks undertaking experiments using the COBRA pulsed-power facility and the Nanofacility.
- Usage of the PALS laser Facility in the Czech Republic for approximately 2-3 weeks per year for the last 3 years.
- Lawrence Livermore National Laboratory Jupiter Laser Facility (~ £280K)
- Los Alamos National Laboratory LANSCE Facility (~ £550K).
- Advanced Light Source, Berkley, USA (~ £150K)
- AWE Orion laser access awarded under competitive peer review (~£500K)
- The ASTRO group has won observing time on non-UK facilities, leading programmes on telescopes including Chandra, Spitzer, the Submillimetre Array, the Jansky VLA, Hale 5m, Subaru 8m and Keck 10m.

ICT: The College provides an extensive range of ICT infrastructure to support research including a very high bandwidth (4x10 GBits) connection to the Janet network – the capacity being driven by the intensive requirements of our HEPH Group. This allows high rate data transfers to and from UK, European and international research establishments.

During the REF period, the College has invested £5.05M in HPC, recognising its importance for research. This service provides research groups with access to large shared memory and massively parallel systems. In 2012 all Physics research groups made use of the HPC provision running 346,998 jobs over 18,840,770 processing hours.

In addition the HEPH group has a dedicated HPC facility in support of the GRID activity. This includes a small cluster providing 336 job slots, and a large cluster of 3208 job slots. The larger cluster is part of the UK TIER 2 and comparable with similar international tier 2 provisions in Caltech and Wisconsin. Our large cluster provides the engines for the main analysis of the data from, amongst others, the Higgs Group, and the SUSY Group.

e. Collaboration or contribution to the discipline or research base

Research Collaborations

We are an outward-facing department and view interactions with other establishments as fundamental to maintaining the quality and reach of our research. We collaborate with over 120 UK national labs, academic institutions and charities and hold more than 700 established collaborations with overseas institutions, and ~160 commercial organisations, in over 50 countries.

Within the international arena staff hold/have held numerous formal leadership roles: In

particle/accelerator physics these include Spokespersons for CMS (Virdee), LHCb (Golutvin), MICE (Long), ZEPLINIII (Sumner, Araujo), SciBoone (Wascko) and in astro/space missions Principal Investigators for Cassini (Dougherty), JUICE (Dougherty), Solar Orbiter (Horbury), with other senior roles in LUX (Araujo), LISAPF/eLISA (Sumner), Euclid (Heavens, Warren).

At least 21 staff hold visiting professorial status at universities across the globe. These include CalTech (Hull), U. Chiba (Damzen), Chinese Academy of Sciences (Hoskins), U. Helsinki (Rajantie), KAIST (JS Kim, M Kim), OU (Hinds), U. Rochester (Knight), U. Parma (Barnham).

International research collaborations are enabled by a range of funding sources including £0.9M from EPSRC for Collaborative Research With China (Energy) on photovoltaics (Nelson); the Korean World Class Universities scheme (with UKTI/British Embassy support) has funded collaborative studies with KAIST (JS Kim); KAUST, Saudi Arabia is funding joint work on satellite monitoring of dust storms (Brindley). Other international collaborations have been supported by College funding (totalling £77K since 2012 when the fund was established) for projects including exchange with Australian universities of PhD students working on metamaterials (Hess) and joint training courses on plastic electronics with S. Korean HEIs (Stavrinou).

Within Europe research collaborations have been developed through FP7 with the initiation of 32 new projects involving 313 research institutions and 60 industrial partners across 47 countries. These include SSEEC/DRREAM on magnetic cooling (led by Sandeman) and CORINF - a Marie Curie Network on laser-matter interaction (led by Ivanov, Averbukh).

UK collaborations have also provided strong platforms for the development of research. We have formal (funded) research partnerships with 35 other UK universities while enhanced interactions with accelerator physicists at the STFC Rutherford Laboratory have been enabled by a number of joint appointments (Long, Pasternak, Pozimski and Wark, subsequently left). Particle astrophysics and plasma physics have also benefitted from joint appointments with RAL (Araujo, Najmudin).

Collaborations with Industry: We engage with 160 external companies in over 50 countries through collaborative research, consultancy, knowledge transfer and patenting/licencing of our intellectual property. In addition to our Industry Club (see § c) we engage with companies through: ICON, Innovations (see above) and Imperial Corporate Partnerships who support the formation and development of strategic alliances and through partnerships on grants. Our Industry Champion (Toumi) advises staff on how best to exploit opportunities through the various College schemes.

The Research Centres and the larger (programme) grants have all established External Advisory Boards where industry are represented specifically to inform research strategy and engage with research students, in some cases as industrial co-supervisors.

At the individual level 3 staff (Nelson, Popov, Toumi) were awarded Royal Society Industrial Fellowships to work with SolarPress, IPG Photonics and BP respectively. Another industrial collaboration (Hall) with IBM, using facilities installed at Imperial, has produced integrated circuits for the CMS experiment at CERN attaining unprecedented radiation hardness requirements.

Centres for Doctoral Training: The three EPSRC CDTs led by Physics staff, initiated in 2009, have enabled us to dramatically increase our reach through collaborations with industrial centres and government as well as other academics. Industrial partners are involved in research supervision, industrial visits, master classes, manufacturing practice as well as representation on the advisory boards. All 3 CDTs have financial commitments into the future, from a total of 59 project partners, comprising £4.31M in cash contributions and £4.0M in in-kind contributions. The CQD and TSM CDTs have been renewed by EPSRC while the decision on PE is deferred. We plan that in the event of PE not being in receipt of EPSRC funding it will continue with the >30 half-studentships promised by industry enabling us to secure co-funding. Further collaborations are being initiated through the new Imperial-led CDTs in Maths of Planet Earth (EPSRC) and Environmental Science (NERC) as well as led by U. Warwick in Diamond Science (EPSRC).

Academic Visitors: from academia, industry and government, UK and overseas, provide continual refreshment of ideas and scope for new collaborative projects, with the list of formal visitors refreshed annually. 54 new Visiting Professors/Lecturers were registered during the REF period. We also encourage outgoing academic visits, in part by making decisions on the allocation of sabbatical leave dependent on the existence of a secondment. Examples of such funded visits include Dowker to the Perimeter Institute, Ontario, Czaja to Kyoto and Hull to Stony Brook, New York. Over the REF period 16 staff-years in total have been allocated for sabbatical refreshment.

Interdisciplinary research: A key strength of Imperial College is its ability to bring together ad hoc multi-disciplinary teams in science, engineering, medicine and business to respond to research challenges. To encourage interdepartmental collaborations the Faculty has run bi-annual competitions for grants since 2010. These take the form of expenses for multidisciplinary "Creativity Labs", kick-start funding for new collaborations and funding linked to external applications for large grants. One example was kick-start funding for collaboration between Physics and Materials on high temperature thermomagnets for power generation (Sandeman, Cohen) which led to collaborations with BASF and Evonik.

A successful multi-disciplinary collaboration has been developed by our biophotonics team with industries including GSK and AstraZeneca, to build a fluorescence lifetime imaging (FLIM) multiwell plate reader. Its TSB Technology Award (£500K, 2006) was enhanced by an additional £154K in 2009 and the partnership of GE Healthcare. The reader has since been used in many projects, e.g. with Pfizer, to explore its capability to assay protein-protein interactions. This was enabled by a laboratory refurbishment programme and from strategic investment in staff (Dunsby, McGinty). In another medical collaboration the Complexity Science group (Christensen, Evans) has established work on atrial fibrillation with the National Heart and Lung Institute.

Interdisciplinary research has been stimulated by the research centres and institutes with whom we are associated. For example Nelson and Ekins-Daukes lead the photovoltaics network in EFL, while Czaja leads the ocean science theme in GICC. Contributions to salary from the institutes give staff more time for research. Research collaborations with other Imperial departments are increasing with a total of 55 Physics staff having established links and 15% of our REF outputs published in 2013 include a co-author from another Imperial department, up from 10% for those published in 2008.

Much of the CDT success stems from their inclusive, collaborative approach to education, training and research supervision, e.g. the CQD-CDT works closely with Bristol and Oxford universities to capitalise on the complementary interdisciplinary strengths they have in controlled quantum dynamics. The PE-CDT involves 45 supervisors including academic staff from Chemistry, Materials and QMUL, the TSM-CDT involves 84 academic staff across 8 departments and the CQD-CDT offers 60 projects including academics from across the UK.

Research collaborations have informed our strategy: New research activities frequently follow from collaborative projects, enabled by the department's flexible and supportive approach. Examples include**:**

- Sutton was invited to carry out a review of the potential for physically based modelling of materials to make an impact in Rolls-Royce. He met most of the senior engineers in the aerospace and nuclear sectors of the company and his report showed that modern theoretical and computational metal physics can aid alloy design and in understanding and predicting component failures. He became aware that theoretical and computational metal physics has declined almost to extinction, in the UK and worldwide, but that with metals-based industries in the EU worth €1.3 trillion a year the industrial need has not. As a result metal physics is a central pillar of the renewed TSM-CDT, with very strong support from Rolls-Royce and other companies.
- A visit to the A-Star Institute for Infocomm Research in Singapore (Taylor) has kick-started an active collaboration, with one of our PhD students currently working in that laboratory and one of the A-Star researchers spending a year here as a Visiting Researcher.
- Collaborations with Sandia (Lebedev, Chittenden) led to their use of new wire array targets for the world-leading Z-pinch facility, greatly increasing the efficiency of X-ray sources for driving inertial fusion, work supported by our world-leading 3D modelling. New Magnetized Linear Fusion concepts proposed by Sandia were enabled by our uniquely relevant quantitative data.
- During her RS Industry Fellowship with SME Solar Press UK Ltd, Nelson started a new research area analysing the influence of materials, manufacturing process and applications on the potential to mitigate cost and emissions of emerging PV technologies. She identified key priorities for basic research, such as low embedded energy electrode materials, low energy manufacturing protocols, efficient energy storage technologies, and analysis of technologies in the context of particular applications. Subsequent research efforts and funding applications have exploited her research.
- Evans has been working with Symplectic Ltd, a start-up formed by ex-THEO PhD students, developing his studies of complex networks and the analysis of bibliometric data. An originally

loose collaboration led first to funding of a summer student and subsequently to a joint proposal to EPSRC. The Physics department supports such entrepreneurship from its students and staff by providing the necessary resources to enable them to build successful startups seeded by departmental resources and expertise.

- Toumi's RS Industry Fellowship at BP plc developed new tools for climate change adaptation, including for internal BP processes. It also informed the research strategy in the department for developing high resolution regional climate models.

The department has further responded to the needs of research users by initiating 20 EPSRC PhD CASE conversions with industrial funding totalling £443K. Companies that support this mechanism include AWE, Astrium, Aurox, Baker Hughes, Cambridge Display Technology, De Beers UK, IQE, Materials Design, Merck, Pfizer, Plastic Logic Ltd., Rolls-Royce, Toshiba and UKAEA. Other companies such as the National Physical Laboratory contribute one-off contributions to student costs (e.g. contribution to travel costs).

Academic Leadership

Staff at all levels, and across all research areas, have been active in the national and international physics community and have been acknowledged by a wide range of awards and honours.

Research Councils: Within STFC Knight was Chair of Science Board and Pendry Chair of the Cockcroft Institute Board, 8 members of staff were Committee Chairs including: PPAN (Nash), PLSC (Rose), NUAP (Dougherty), ground-based facilities review (Rowan-Robinson), panel on space science and exploration (Schwartz). Heavens and Rose are members of Science Board and 26 other members of staff were members of committees and review panels.

For EPSRC Smith leads the new EPSRC UK-IFE network, Hinds chairs the NanoPhotonics Portfolio Partnership and 28 members of staff sat on EPSRC advisory boards or peer review committees. Other RC involvement included membership of 2 BBSRC advisory panels (French) and membership of NERC National Centre for Earth Observation Advisory Board (Southwood).

26 members of staff have held **Offices within Learned Societies and Institutions** including Presidents of the IOP (Knight), the RAS (Rowan-Robinson and Southwood), the RMetS (Haigh) and the OSA (Knight). Other roles include Chairs of 5 Royal Society Committees (Hinds, Knight, Sutton); Chair IOP Council (Knight); Chair of IoP Publishing (Pendry); Chairs IOP committees (Hinds, Mostofi); Board member of European Optical Soc (Paterson) and membership of committees of Royal Society (7), of IOP (6) and organisations including European Geosciences Union, Royal Aeronautical Society, International Union of Pure and Applied Geophysics.

82 members of staff were involved in **Organising** 190 **Conferences**, in the UK and overseas, acting as chair, or main organiser, on over 70 occasions. Examples include a Royal Society discussion meeting (Branford) on magnetic monopoles, an Optics in the Life Sciences Congress (French, at OSA), European Photovoltaic Conference (Ekins-Daukes), First UK-Korea Workshop on Plastic Electronics (JS Kim).

Staff gave 355 **Plenary/Keynote Lectures** and 48 **Named Lectures** including in Johns Hopkins, Princeton and Rice Universities (Pendry), Bonn (Hinds), Toronto (Southwood), Hong Kong (Anthopoulos), Madrid (Duff), Jefferson National Lab and Brookhaven NL (Leader) as well as the RS Bakerian Lecture (Bradley) and RI Discourses (Duff, Haigh).

Membership of **Government Advisory Boards** include Chairs of the Defence Science Advisory Committee (Knight), Committee on Climate Change and the Board of the Met Office (Hoskins), the UKSA Science Programme Advisory Committee (Dougherty), UKSA steering board (Southwood), UK Energetics expert advisory panel (Proud), Deputy Chair of Anglo-Australian telescope board (Warren), Wakeham review of physics (Bradley), UK Fusion Advisory Board (Smith), HPC advisory committee (Heavens). Harries became Chief Scientific Adviser to the Welsh Government while retaining 10% FTE at Imperial.

11 members of staff sit on 15 **Industry Advisory Boards** including Chair UK Leica Scientific Forum (French), Rolls-Royce Environmental Advisory Board (Hoskins), World Scientific Maths/Physics (Evans), Maxeler Technologies (Averbukh), Society for Information Display (Campbell, UK Vice Chair).

42 members of staff sat on 70 **International Committees/Advisory Boards**. Examples include committee membership of International Statistics Institute (Trotta), ERC Consolidator Grants Panel

(Gauntlett), US Dept Energy Panels (Lebedev, Chittenden, Sutton, Virdee), NIF Management Board (Rose, the only non-US national), Photon Sciences Institute (Hinds). Also as advisors to Kurchatov Institute, Moscow (Golutvin), Institute for Quantum Computing, Waterloo, Canada (Dowker), Anglo-Australian Telescope (Unruh), EurBioImaging Steering Committee (French).

Staff were involved in 29 **Reviews of University Depts., Institutes, National Programmes** including a review of ICSU (Knight), RAL Technical Review (Smith), Cambridge U. Astrophys. (Heavens), U. Manchester Programme in Renewable Energy (Nelson), Russian HEP programme (Golutvin), STFC Programmatic Review (Marangos) and reviews of U. Cyprus Physics Dept. (Dauncey), MPI for Steel Research (Sutton), Czech Institute for Plasma Physics (Lebedev).

89 members of staff were involved in 167 **Reviews of International Funding Proposals** for 88 international agencies in over 30 countries, including 28 for national research councils, as well as for ERC, facilities, telescopes, space agencies, government labs and universities.

Staff carried out 313 **External Examinations** for MPhil/PhD/DPhil degrees in 145 different universities across the globe.

Fellowship of Learned Societies: 13 current members of staff and 6 emeritus/visiting professors are Fellows of the Royal Society: 6 (Duff, Dougherty, Haigh, Hull, Virdee, and Cowburn who left 2010) were elected during the REF period. We have 2 Foreign Associates of the US National Academy of Sciences (Hoskins, Pendry), a Fellow of the Academia Europaea (Hoskins) and a Member of the American Academy of Arts and Sciences (Pendry). We also have 1 Fellow of the Royal Society of Edinburgh; 1 of Royal Irish Academy; 32 of Institute of Physics; 6 American Physical Society; 6 Optical Society of America; 12 Royal Astronomical Society; 1 Royal Aeronautical Society; 2 Royal Meteorological Society; 1 Royal Society of Chemistry; 1 Institute of Materials.

12 members of staff are senior **Journal Editors** including Optics Communications (M Kim, Maier), Journal of Physics – String/Field Theory (Tseytlin), Journal of Modern Optics (Knight, Marangos), Journal of the Atmospheric Sciences (Haigh), High Energy Density Physics (Rose); we also host 21 members of editorial boards, and 9 guest editors, of ISI-rated journals. Sandeman has been identified by EPS as a Distinguished Referee.

Staff have been recognised by a range of **Awards and Prizes** including:

International prizes: ICTP Dirac Medal (Kibble); JJ Sakurai Prize for Theoretical Physics (Kibble); Fundamental Physics Prize (Virdee); EPS High Energy Physics Prize (Virdee); UNESCO Niels Bohr Gold Medal (Pendry); James C McGroddy prize of the APS (Pendry); Quinquennial award of the E-MRS (Pendry); W.E. Lamb Medal for Laser Science & Quantum Optics (Pendry); Sackler Prize for Physical Sciences (Maier); Daiwa-Adrian Prize (Rose); Next Einstein Visiting Scholar (Trotta); NASA Distinguished Public Service Medal (Southwood, Harries); Russian Academy of Sciences Zeldovich Medal (Eastwood). In addition the European Physical Society has formally recognised the Blackett Laboratory as a Historic Site in the development of Physics.

Staff were awarded 13 honorary Doctor of Science degrees, by the Universities of Bucharest (Barnham), Glamorgan (Harries), Bristol (Hoskins), Heriot Watt, Royal Holloway, Sussex (Knight), Duke, Hong Kong Baptist, Nurnberg (Pendry), Sussex (Rowan-Robinson), Bern, Plymouth (Southwood), QMUL (Virdee).

Awards from the **Royal Society**: Royal Medal (Kibble, Knight), Hughes (Dougherty), Rumford (Hinds, Taylor), Armourers and Brasiers (Nelson), Bakerian Lecture (Bradley).

Awards from the **IOP**: Honorary Fellowship (Kibble), Isaac Newton Medal (Pendry), Faraday (Bradley, Hinds), Maxwell (Haynes), Thomson (Hinds), Paterson (Maier), Joule (Nelson, French), Rayleigh (Tseytlin), Chadwick (Virdee), Hoyle (Rowan-Robinson), Mott Lecture (Bradley).

National awards: Bradley and Haigh were awarded CBE for services to Science/Physics.

9 RS Wolfson Research Merit Awards were held during the REF period (French, Gauntlett, Hanany, Maier, Nandra, Nelson, Plenio, Sutton, Taylor).

Royal Astronomical Society Group Achievement Award (Mortlock, Warren & UKIDSS team); Royal Meteorological Society Adrian Gill Medal (Haigh); Thales Group Technology Prize (Heavens).

ECRs and PhD students won well in excess of 100 national and international prizes for conference presentations and posters as well as 17 thesis prizes (including from Culham, IOP, EPS), IOP David Bates Prize (Tarbutt, Jones), COSPAR Zeldovitch Medal (Wass).