Institution: University of Southampton

Unit of Assessment: 9 Physics

a. Overview

We undertake world-leading research at the frontiers of photonics, condensed matter, potentially new physics beyond the Higgs boson, and in determining the fundamental properties of the Universe, topics at the forefront of 21st century physics. This requires exploiting and developing facilities that range from the fastest lasers, to the LHC, to the most powerful telescopes. Our standing is evidenced by high-impact publications, sustained leadership in international collaborations, review invitations and substantial research income. Physics and Astronomy (P&A), a department within the Faculty of Physical Sciences and Engineering (FPSE) comprising 39 academic staff, 32 research/enterprise staff and 108 postgrads; its annual economy is £9.9m. P&A has used strategic appointments to develop a strongly research-led culture, which also underpins our teaching. We play a major role within SEPnet (South-East Physics Network) a consortium of universities working together for the sustainability of physics in the region, through education, outreach, employability and research. P&A consists of three research groups:

Astronomy (**I. McHardy** + 13 Cat A staff, 12 PDRAs, 35 PhD students)
Funding portfolio: STFC consolidated grant, EC (Marie Curie Fellowships, ERC grants) NERC, Royal Society (University Research Fellowships). Research in Astronomy has been built on the high energy astrophysics of accretion on all scales, from white dwarfs, neutron stars and stellar-mass black holes in galactic binary systems, to supermassive black holes in active galactic nuclei, including their effect on galaxy evolution and structure formation. The group have, since 2008, increased their strengths in extragalactic astronomy, leading research into cosmic magnetism and supernova cosmology, becoming key players in next generation radio/X-ray telescopes.

Quantum, Light and Matter (QLM) (**P. Lagoudakis** + 15 Cat A staff, 12 PDRAs, 35 PhD students) *Funding portfolio: EPSRC, dstl, Templeton Foundation, EC, Royal Society.*
QLM explore photonics, condensed matter physics and the interaction of light and matter at the quantum level, emphasising the themes of nanophotonics, novel nanomaterials and the emergence of quantum coherence in the solid state.

Theory (**T. R. Morris** + 12 Cat A staff, 8 PDRAs, 25 PhD students)
Funding portfolio: STFC consolidated grant, EC (Marie Curie Fellowships, ERC grants), Netherlands (NWO/VICI grant), Templeton Foundation (New Frontiers in Astronomy and Cosmology Award). Theory group has a wide range of expertise in theoretical particle physics in both Standard Model and Beyond Standard Model areas, including collider phenomenology, lattice QCD, cosmology, analytic properties of scattering amplitudes, strong coupling, holography, string theory and quantum gravity. It includes two FRS, full and non-Maintenance & Operations paying members of the LHC collaboration CMS, a joint appointment with RAL, and members from Maths.

Strong and long-standing research collaborations exist between P&A and other parts of UoS, particularly for QLM and the Optoelectronics Research Centre (ORC; Director: Professor Sir David Payne; itself a unit within FPSE) as evidenced e.g. by the joint EPSRC Programme Grant on nano-structured photonic metamaterials (de Groot, **Muskens)**. To exploit these synergies, the Zepler Institute (ZI) was established in 2012 to coordinate research in photonics, electronics, nanoscience and quantum technology. ZI is one of the largest research institutes in the UK (~300 research staff) and is unique in covering the whole innovation cycle from basic research, through technology development, to final exploitation. Cross-faculty research includes: a) the *Southampton Theory, Astrophysics and Gravity* (STAG) research centre, a collaboration between Astronomy and Theory (**Sachrajda** is STAG Director) and the Gravity group in Mathematics; b) the Institute for Life Sciences (mainly QLM); c) the Nano and Energy University Research Strategy Group (USRG) (chairman **Lagoudakis)** nurturing interdisciplinary projects as evidenced by the joint Programme Grant on Complex Nano-structures by Supercritical Fluid Electro-deposition with Chemistry (**Smith**) and several interdisciplinary responsive mode EPSRC-funded projects.

b. Research strategy

Following RAE2008, the department's top priority was to significantly strengthen QLM whilst maintaining and developing the already strong research profiles of Astronomy and Theory. (New appointees since 2008 are highlighted in ***italicized bold***, Cat A staff in **bold**.) During the REF period, we have achieved significant growth across a broad spectrum of research indicators among all P&A staff: (a) total number of papers published in *Science* and *Nature* journals 01-07: 9, 08-13: 40, an increase of *344%*; (b) *Phys Rev Letters* published 01-07: 25, 08-13: 82, increase of *228%*; (c) other high impact journals (*JHEP, ApJ, Advanced Materials, Nano Letters*) published in 01-07: 119, 08-13: 243, increase of *119%*; (d) number of papers with >50 citations published in 01-07: 16, 08-13: 91, increase of *468%*; (e) number of papers with >100 citations published in 01-07: 7, 08-13: 37, increase of *428%.* These results demonstrate the commitment to research excellence in P&A.

- **Astronomy**

The Astronomy Group consists of 14 academic staff (***Altamirano***, **Bird**, ***Breton***, **Charles, Coe**, ***Croston***, ***Ho***, ***Jackman***, **Knigge, Lanchester, McHardy**, ***Scaife, Shankar, Sullivan***). Over many years, the group has developed a strong reputation in high energy astrophysics, particularly in time domain studies in X- and γ-ray astronomy, aiming to understand accretion processes onto compact objects, the resulting production of radiation and ejection of matter in the form of winds and jets, the relationship between variability in X-ray and other wavebands, and the scaling relationships across the full range of compact object masses. Historically this work has concentrated on stellar-mass compact objects, i.e. white dwarfs (WDs) neutron stars (NSs) black holes (BHs). While important results have been shown for active galactic nuclei (AGN) whose emission is powered by accretion onto supermassive BHs, the extragalactic side of the group, in 2008, was less strong.

The strategic development of Astro over the last 5 years, has therefore been to: (a) expand into extragalactic/cosmological areas, (b) extend the application of our expertise regarding galactic compact objects to the wider Universe, (c) become a well-balanced multi-frequency group, and (d) strengthen our research in magnetospheric physics. This has been accomplished through 8 new appointments, two of whom, ***Scaife*** and ***Sullivan***, were awarded very prestigious ERC grants (Starter and Consolidator respectively, each of €2m). SEPnet support allowed the appointment of ***Croston*** who, together with ***Scaife*** and Fender (who held a €3m ERC Advanced grant) established Southampton as a centre for radio astronomy. ***Croston*** and ***Scaife*** both have major roles in key science projects for LOFAR, SKA and SKA pathfinders, MeerKAT and ASKAP.

***Extragalactic astronomy/ observational cosmology*:**
(i) We aim to understand how **clusters of galaxies**, the largest gravitationally bound structures, are affected by the interaction of jets from AGN and how the jet particles are accelerated**.** ***Croston*** leads the jets science case for the recently approved Athena+ X-ray observatory**.** ***Scaife*** is tackling the fundamental question of the origin of cosmic magnetic fields (which underlies her ERC award).
(ii) Extensive theoretical modelling of **AGN and the large-scale evolution of galaxies** (***Shankar***) probes evolutionary links between super-massive black holes, their host galaxies and Dark Matter haloes leading to predicted AGN no. counts at z>5 (used in Athena+ science case and EUCLID).
(iii) **Supernova physics** is central to modern cosmology in measuring the geometry of the Universe and the Dark Energy equation-of-state parameter, which underlies the ERC award to ***Sullivan*** (a RS URF and proleptic Reader) who plays a leading role in the Palomar Transient Factory and ESO PESSTO surveys. The nature of SN Ia progenitors links with **Knigge's** expertise in the evolution of accreting white dwarfs.
(iv) **Strong Gravity** effects in AGN have been revealed by negative reverberation time-lags between X-ray energy bands (i.e. higher energies lead) as first noted by **McHardy**, and now a major topic in X-ray astronomy (as well as a key science driver for the Athena+ and LOFT missions). The time-lags are now being modelled using full GR ray-tracing to probe the inner geometry of the disc around BHs, providing a strong link with STAG.

***Galactic high energy astrophysics*:**
(i) The importance of **accretion disc winds** in affecting the spectra of almost all compact objects from white dwarfs to quasars, has led to **Knigge** adapting his disc wind code to model quasars.
(ii) In **Galactic X-ray binaries, Charles** has undertaken the first decades-long studies of both X-ray and optical variability. ***Altamirano***, another proleptic RS URF appointment, uses quasi-periodic

oscillations (QPOs) to search for signatures of GR effects around compact objects, and ***Breton*** has discovered one of the heaviest known neutron stars, providing strong constraints on the fundamental problem of the NS equation of state (a key science driver for Athena+/LOFT) and again links strongly to STAG, through the theoretical work of ***Ho***.

In γ-**ray astronomy, Bird** produces the definitive INTEGRAL catalogues, and we are the UK science archive centre. **Coe** has established that γ-ray binaries are a significant new class, and has produced an X-ray survey of SMC high-mass binaries. We are also involved in feasibility studies for constraining quantum gravity from TeV energy-dependent time lags with CTA.

In *Space Environment Physics* (SEP) we have appointed ***Jackman*** and Fear (a proleptic Rutherford appointment from Oct 2014). They study the Earth, Saturn, Jupiter and Mercury magnetospheres and the fundamental physical process of magnetic reconnection, applicable in both planetary and stellar systems. Collaborative work with ***Scaife*** is increasing the synergy of Astro and SEP by using radio instrumentation to probe terrestrial and planetary magnetospheres, as well as to improve the calibration of low frequency radio arrays, e.g. LOFAR and SKA, for ionospheric effects.

- **Theory**

The Theory group contains 14 academics (***Accomando*****, Belyaev, *Di Bari*, *Drummond,* Evans, Flynn, *Juettner*, King, Moretti, Morris,** Ross**, Sachrajda, *Skenderis* and *Taylor***) although Taylor is being returned in the Maths UoA and Ross is now retired, but continues in the group as a Leverhulme Emeritus Fellow. The wide range of expertise in theoretical particle physics makes it well equipped to meet the exciting challenges expected from ongoing LHC research and other developments. Since 2008 the group aimed to: (i) *continue to position itself so as to exploit the awaited discoveries of the LHC, neutrino experiments, and in cosmology*. The group hired ***Di Bari*** (2009) an expert on neutrinos and cosmology, and the collider phenomenologist ***Accomando*** on a joint post (for the first 5 years) with RAL; (ii) *Strengthen and secure the lattices area for the future.* The group appointed ***Juettner*** (2011); (iii) *Extend and strengthen the group, forging closer links with Maths and Astronomy.* This has been facilitated by the STAG research centre, and through it the appointments of ***Drummond*** (2013) a world-leader in properties of scattering amplitudes, and (in Maths) of ***Skenderis*** (2012) an expert in String Theory and holography in particular, and ***Taylor*** (2012) an expert in String Theory and black holes. *Near-term goals are to strengthen the group still further in areas of overlap with Astronomy e.g. cosmology, dark energy and dark matter.*

Although there is considerable overlap, Theory can be split into four areas (each supported by a postdoc through STFC in the new Consolidated Grant) as described below:

(i) Collider phenomenology within and beyond the standard model (***Accomando*****, Belyaev, King, Moretti)** plays a unique role in LHC data exploitation, contributing to resolving the nature of the Higgs boson and the wider theory in which it is embedded. These staff have wide theoretical expertise on both SM and BSM physics, and in the tools for sophisticated phenomenological investigations (CalcHEP, HERWIG, HEPMDB). This is done within the framework of the NExT (New directions in Experiment and Theory) Institute (in which we play a leading role, see section e) and with participation in LHC real data analyses (through full signing author (**Belyaev)** and non-M&O paying (**Moretti)** CMS membership). Future strategy includes: working further with CMS; testing non-minimal fundamental Higgs models with and without SUSY; continuing exploration of composite Higgs models; establishing benchmarks for the most promising BSM theories above; further development of HEPMDB and CalcHEP.

(ii) Beyond the Standard Models of Particle Physics and Cosmology (**Belyaev, *Di Bari,* King, Moretti)** played a leading role in interpreting both the major 2012 discoveries of the Higgs boson and the leptonic reactor angle θ_{13}, through NMSSM and discrete family symmetries respectively, and discovered new effects in leptogenesis linking the sign of the asymmetry to CP violation in neutrino oscillations. They form a node of the ERC ITN "INVISIBLES" network. Their future strategy keeps the direct link to experiment and observation via model predictions and interpretations of new discoveries, including addressing the SM flavour puzzle via innovative new discrete family symmetries; exploring the origin of Matter-Antimatter asymmetry, Dark Matter, Inflation and Dark Energy within well motivated BSM models; sub-halo search strategies for Dark

Matter; and finally new SUSY models with a higher scale but which allow for lower fine-tuning.

(iii) Lattice QCD (**Flynn, *Juettner*, Sachrajda**) is a leading group in lattice phenomenology, and works as part of the RBC-UKQCD Collaboration with Edinburgh, Columbia and Brookhaven. This is widening to the Japanese JLQCD/KEK groups for heavy quark physics. They have Large Project access to the DiRAC BG/Q supercomputer until 11/ 2015, and ***Juettner*** holds an ERC grant. Their calculation of ΔI=3/2 K to ππ decay amplitudes won the 2012 Ken Wilson Lattice Award. Their future strategy includes calculating the CP-violating parameter $\varepsilon'/\varepsilon_K$ and ΔI= ½ K to ππ decays; further improving the B_K and K_{l3} results, including isospin-breaking effects; applying new ideas for calculating long-distance effects to rare kaon decays; studying hadronic contributions to the muon g-2; and developing a D physics programme using domain-wall charm quarks, followed by extrapolation to heavier quarks for application to B physics.

(iv) Strong Coupling, Holography and Quantum Gravity (***Drummond*, Evans, Morris, *Skenderis, Taylor***) has been significantly strengthened by the addition of ***Skenderis*** and ***Taylor*** (from Maths), and most recently ***Drummond*.** Research highlights include the discovery of `dual' superconformal and Yangian symmetries in scattering amplitudes of maximally supersymmetric Yang-Mills, advances in asymptotic safety in quantum gravity, and development of holography for inflating cosmologies, Ricci flat spacetimes, and a wide range of other phenomena. Future strategy includes extending the class of space-times that admit a quantitative holographic description, holographic and non-holographic approaches to the conformal window and walking technicolour, explicit formulae for planar scattering amplitudes beyond one loop and more generally the link between algebraic and geometric structures and loop integrals.

- **QLM**

The QLM group comprises 16 academics (**Apostolopoulos, *de Liberato*, Freegarde, Goremychkin, *Himsworth*, Kaczmarek, Kanaras, Kavokin, Lagoudakis, *Muskens*, *Newton*, *Politi, Sapienza*, Smith, Tropper, *Ulbricht***) who explore light-matter interactions at the nanoscale, novel nanomaterials and the emergence of quantum coherence in the solid state. QLM has a strong applied component evidenced by industrial collaborations, such as Fianium, Merck, TeraView, IBM Zurich, Hitachi, Toshiba, UniLite, Luxtaltek. Internationally QLM collaborate with >50 research groups around the world through >20 funded national and international projects. The group occupies ~500m^2 of modern, highly-serviced laboratories, with a broad range of laser sources and characterisation tools. QLM operates the Nanomaterials Rapid Prototyping Facility, ULTRASPEC (the university's ultra-fast advanced spectroscopic facility) and is a partner in the newly established ZI exploiting the £120M clean-room complex.

Achievements of the QLM strategic aims as articulated in RAE2008:
(i) *Polariton physics*: the group is internationally leading in the physics of strong light-matter coupling in semiconductor nano-structures through a combined experimental (**Lagoudakis -** IUPAP award on Quantum Electronics), and theoretical (**Kavokin -** EPSRC Fellow**)** effort, that, since 2008, has been supported by 5 EPSRC grants, 4 EU projects that led to high impact journal publications (8 Nature, 2 Science, 23 Phys Rev Lett) and >50 invited talks. Beyond the fundamental aspects of light-matter coupling there is major activity in the development of semiconductor lasers (VCSELs group) and THz sources, where the group holds the shortest pulse world record (**Tropper** 1 EPSRC grant, 1 Nat Phot, Wilcox EPSRC fellowship, **Apostolopoulos** 2 EPSRC and 2 dstl grants). Wilcox, one of Tropper's postgrads, has now moved to Dundee. In 2013 the activity in quantum cascade lasers (**Apostolopoulos**) and polaritonics was complemented by a new appointment (***Sapienza*** from NIST) with an excellent track record in strong coupling with intersub-band transitions, chip-based cavities and single quantum dot cavity QED.

(ii) *Strengthening theoretical activity*: This was accomplished by the appointment of ***de Liberato*** (2012) a pioneer in *ultra-strong coupling*. Within 4 months, ***de Liberato*** was awarded an EU Marie Curie international fellowship, and then (in Sep 2013) a Royal Society URF starting in 2014. His research in ultra-strong coupling bridges the activity in polaritonics (**Lagoudakis, Kavokin)** and THz emitters (**Apostolopoulos**).

(iii) *Atomic/molecular cooling in nanostructured traps*: the research in cold atoms (**Freegarde**) was extended to nanostructured traps with the award of a RAEng fellowship to ***Himsworth*** in 2010,

who is utilising the clean room facility to fabricate atom chips and is supported by 2 dstl grants.

(iv) *Quantum coherence*: In 2008, ***Ulbricht*** joined QLM (from Univ of Vienna) bringing to the UK the first experimental activity on matter-wave interferometry with heavy molecules and nanoparticles. This program explores non-classical properties such as superposition and entanglement of massive particles at meso-scopic scales, and is supported by EPSRC and the largest ever awarded grant from Templeton Foundation (£500k) to test the limits of quantum theory (2 Nature, 1 Phys Rev Lett, 1 Rev Mod Phys).

(v) *Nano-bio research*: QLM invested in multi-disciplinary research developing in-house synthesis and functionalization of inorganic colloidal nanoparticles (**Kanaras,** a chemist) building synergies within Chemistry and the Institute for Life Sciences that led to high impact work on the self-assembly and functionalization of nanoparticles, and was strengthened by the appointment of ***Muskens*** (2008) in plasmonics. Strong collaborations were built with Biology and Medicine to investigate biomedical application of functionalised metallic nanoparticles and in particular in imaging and manipulation of angiogenesis and laser-induced damage of nanoparticle-targeted human endothelial cells (1 Nano Lett, 1 ACS Nano, 1 Small).

(vi) *Nanomaterials/nanofabrication*: ZI provides a world-leading suite of instrumentation for nanofabrication and characterisation that QLM fully exploits through strategic new appointments (***Muskens, Newton, Politi, Sapienza, Ulbricht***). Since 2008 ***Muskens*** (2 EPSRC grants, EPSRC fellowship) has pushed to the limit the capabilities of our e-beam and He ion lithography, and is pioneering in the field of switchable plasmonic nano-antennas (1 Nat Phot, 2 Phys Rev Lett, 5 Nano Lett). Our nanomaterials activity is supported by two EPSRC Programme grants: a) ***Nano-structured Photonic Metamaterials,*** (with ORC, Zheludev) developing a new generation of revolutionary switchable and active nano-structured photonic media (de Groot, now retired, ***Muskens***); b) ***Complex Nanostructures by Supercritical Fluid Electrodeposition*** (**Smith**) (with Chemistry, Bartlett) aiming at new and industrially viable deposition technologies that exploit the unique pore-penetrating ability of supercritical fluids. QLM also work on new types of liquid crystals (**Kaczmarek**) and their hybridisation with colloidal nano-particles (**Kanaras**) and novel materials using X-ray diffraction techniques at RAL and Diamond (**Goremychkin, 2 Nature, 3 Phys Rev Lett**). In 2013, ***Newton*** joined the group from Japan to work on coherent X-ray diffraction, utilising the nearby facilities and our in-house attosecond laser systems (with ORC, Brocklesby).

Future strategic directions: In 2012 QLM identified Quantum Technologies as the unifying theme linking engineers, physicists, chemists and mathematicians, leading to the formation of the Quantum Technology Centre (QTC) to drive research ranging from fundamental quantum physics to novel quantum technologies. This led to the appointment of ***Politi*** (2013) from UCSD, with expertise on quantum information technologies of silicon waveguides, and QLM are filling a senior post to build on this strategic initiative (recognised in "Encouraging a British Invention Revolution": Sir Andrew Witty's Review of Universities and Growth, Oct 2013).

Collaborative research and networks

Key to P&A strategy has been UoS participation as a core founding member of SEPnet, a collaboration with 6 other regional Physics departments. With £12.5m HEFCE funding (2008-13) SEPnet has promoted innovative research, a collaborative graduate school, lectures using video conferencing, regional employer engagement and a schools outreach program. It has had a major impact on P&A. Southampton is the host for SEPnet-2, recently approved by HEFCE with a further £2.75m, plus £10m from the (now) 9 partner Universities so as to further develop the graduate school, and with an additional focus on widening participation, impact, diversity and outreach.

QLM is part of ESF-POLATOM (**Lagoudakis, Kavokin**) investigating the physics of Bose-Einstein condensation in atoms and the solid state and represents the UK node on Nanophotonics for Energy Efficiency, the EU network of excellence (**Lagoudakis**) that contributed to the EU nanophotonics roadmap informing the relevant research strategy for Horizon 2020.

Within UoS, Astro and Theory have recently formed the cross-faculty STAG research centre together with the Gravity group in Maths. STAG was officially opened in 2013 by the Astronomer Royal, Lord Rees of Ludlow, and has been strongly supported (with postdocs and PhD students) by UoS. P&A staff play key roles in a number of other cross-faculty Strategic Research Groups including *Computationally Intensive Imaging, Energy* and *Nanoscience.*

c. People:

i. Staffing strategy and staff development

Permanent academic appointments are approved through FPSE's annual strategic plans, with internationally competitive research being the driving factor for all staff. To maintain vitality, we normally recruit early-career, highly-driven staff who are already excelling on the international stage, and take advantage of external fellowship schemes (since 2008 almost 40% of our Cat-A staff have held fellowships).

New appointments: In RAE2008, Theory was singled out as particularly strong, and their subsequent aim has been to identify suitable opportunities for strengthening, particularly given the staffing changes described in section b. Since 2008 P&A have made 20 new appointments; 8 in Astro, 5 in Theory and 7 in QLM. Chairs have been awarded to **Kaczmarek, Knigge, Lagoudakis, Moretti, Smith** and Readership/Senior Lectureships to **Apostolopoulos, *di Bar*i, Belyaev, Kanaras, *Muskens*** and ***Scaife***.

Personal Research Fellowships: Included here are 6 Royal Society, ERC and EPSRC-funded independent research fellows (***Sullivan, Altamirano, Scaife, Muskens,*** **Kavokin, *Juettner***). One other (**Fender**) won his ERC Advanced award here during the REF period, and has just moved to an SKA-related post at Oxford. Newly appointed fellows are treated similarly to other academic staff, included in all activities, fully integrated into research groupings, and are able to co-supervise PhD, Masters and UG project students, and hence fully develop their academic careers.

Early Career Researchers: UoS aims to sustain and improve research performance by attracting, developing and retaining high-achieving staff and continuing to nurture and grow their early careers. UoS supports initiatives that enable progression of researchers' careers, particularly through the assignment of senior staff as mentors. In 2005 UoS was a founder signatory to the Athena SWAN charter, receiving a University-level Bronze award (successfully renewed in 2009 and 2012), and is fully committed to the SEPnet-2 targets established from 2013 for enhanced diversity at all levels. In 2009, UoS signed up to the *Concordat to Support the Career Development of Researchers* (hereafter referred to as The Concordat) while 2012 saw the European Commission present UoS with the HR **Excellence in Research Award** in recognition of its commitment to supporting the personal, professional and career development of its researchers. This acknowledges alignment with the principles of the European Charter for Researchers and Code of Conduct for their Recruitment and incorporates both the QAA Code of Practice for Research Degree Programmes and the Concordat. Southampton was among just 12 institutions to achieve the award initially, and FPSE is fully aligned with these objectives, as evidenced by the establishment in 2012 of the ***Dean's Awards for Early Career Researchers*** (ECRs) to recognise exceptional contributions in scientific publications, knowledge transfer, enterprise, public engagement, etc. (with P&A winning two of these in 2013). ECRs are of course fully integrated into our implementation of the Concordat, including induction, appraisals and training specifically tailored for them.

Career Development: The FPSE "Adventures in Research" fund provides an opportunity for extra research support that is made available to new staff members, and their development is reviewed through annual appraisals. This ensures that priorities and future objectives are set that are in line with the expectations of the post and the needs of P&A, as well as to recognise and record areas of good performance, consider prospects for promotion and to agree their individual needs.
The development needs of all staff, including ECRs, are met through a combination of central and local provision. UoS is generous in its support for regular sabbaticals, which are critical for taking stock and adjusting research directions where appropriate. UoS offers courses, resources and advice to all researchers and graduate students, in line with the Vitae initiative. Through the mentoring scheme, we identify and support outstanding junior academics and post-doctoral researchers in their bids to secure prestigious RCUK funded fellowships, ERC fellowships, as well as permanent academic posts. This strategy has been very successful: 13 ECRs have received prestigious fellowships (e.g. 2 ERC Starter grants of value in >€1m each) or have been promoted against external competition to permanent academic posts. The Researcher Mobility Programme and the Career Destinations service are available to ECRs as well as other staff and students.

Equality and Diversity: FPSE, through its Diversity Committee, is fully committed to Equality and Diversity (E&D), and widening participation is a key activity within P&A that is being funded as part

of SEPnet-2, with the aim to make our own Athena SWAN submission in 2014. Examples of this include the provision of diversity training, so as to increase the cultural awareness, knowledge, and skills of staff. Other examples of our commitment to E&D include: ECS Women (founded 2008); Theano (founded 1999) a networking group bringing women together that is open to all female students and academic staff across UoS; WiSET (founded 2002) a group for women in SET subjects. Recently an individual in FPSE has been supported through contracts being paused and then re-enabled for her to return part-time.

ii. Research students

Organisational Structure and Strategy: The Faculty-wide Graduate School was established in 2011, replacing separate schools that had previously run in each unit. The Graduate School has overarching responsibility for monitoring progression, training, supervision, registration status, and receiving/acting upon student feedback. It also oversees all PGR support and training. P&A has joint PhDs with partners in SEPnet, while Theory have joint programs through NExT (e.g. with Bristol) and STAG brings Maths into joint PhDs with both Astro & Theory. QLM is a partner to the EPSRC Centre for Doctoral Training in New and Sustainable PVs due to start in Oct 2014. On the international stage, QLM have currently established PhD programs with Nanyang Tech University (NTU, Singapore) that coincides with the establishment of a dual UoS/ NTU photonics research centre that supports an Erasmus Mundus Joint Doctorate programme in EUV and X-Ray Science and Technology (with 8 EU/UK partners). UoS has been a strong supporter of the activities of the SEPnet regional graduate school (GRADnet) and intends to use the enhancements proposed in SEPnet2 to expand the training experience of our PhD students across all research groups.

Admissions: Across the Faculty, PGR recruitment and admissions is led by the individual research groups, with student funding provided through many routes including: EPSRC doctoral training account (DTA) STFC, NERC, ERC, industrial funding, direct Faculty/UoS funding, SEPnet and self-funding (mostly international students). The Graduate School can enable funding for a student to be made up from a number of sources so as to broaden access. The Graduate School aims to attract the best students using funded scholarships for international and EU students, and enhanced stipends (DTA funded) for UK students. UoS-funded scholarships are allocated on the basis of academic quality, the strategic importance of the research, and availability of matching funding. The Graduate School ensures that all PGR students receive a full induction programme on arrival, covering all aspects of PhD progression, including essential health & safety training, as well as the transferable skills courses and subject-specific training available. Throughout the induction period there are also a number of Faculty, department, and research group social meetings at which the students get to know each other, their co-workers, and members of staff.

Progress Monitoring, Training and Support: The Graduate School has pioneered a web-based system, *PGR Tracker*, which supports progression monitoring, with reports and details of key progression stage tasks and vivas, together with formal recording of all student training activities. This provides a permanent, personalised and easily accessible record of every student's progress, and PGR Tracker is being implemented across UoS. The Graduate School provides a broad range of courses to enhance research-based learning and transferable skills training. FPSE provides each student with a Research Training Support Grant (RTSG) of £1,200 per annum, conditional on progression, to support participation in, and presentation of papers at, national and international conferences/summer schools. An extensive set of graduate lectures already constitutes a key part of student training in Theory, and this is being extended into Astro through SEPnet.

Career Development: Engagement with employers is an essential part of PGR career development. Students frequently attend conferences which incorporate large industrial shows, while industry-based researchers are regularly invited to give PGR seminars. PGRs are also encouraged and trained to assist in teaching, such as laboratory demonstrating and undergraduate problem classes. We also have a special 4-year PhD programme (the Mayflower Scholarships, typically 12 in place at any one time, funded by the Faculty) in which students spend 25% of their time on education activities. This gives the students a good background in the teaching skills necessary if they were to pursue a more education-based career, as well as providing funding for more extended research projects. SEPnet again provides additional regional support for career development, offering opportunities that go beyond the capabilities of individual institutions, as well as interaction with employers across the much wider geographic area represented in SEPnet-2.

The Career Destination service maintains dedicated PGR and international student web sites, holds careers fairs and events, provides job-related training (for applications and interviews) and helps with work placements. The service also arranges for careers-related advice from relevant alumni and for alumni to volunteer as a Careers Contact (by email) for current students.

d. Income, infrastructure and facilities

Total research income (excluding facilities) at P&A (2008-13) has been £138k/yr/academic staff member, compared with £68k in RAE2008: an increase of *102%*. UoS provides strong support for laboratory-based research through the Nanomaterials Rapid Prototyping Facility, the ZI, the High Voltage Laboratory as well as central facilities. In particular, ZI came from a recent £120m capital investment in state-of-the-art experimental clean room facilities and provides a unique opportunity for attracting substantial UK and EU funding, both in research and in support of industry. The laboratories include optical/electron beam lithography, comprehensive sputtering, evaporation and chemical vapour deposition facilities plus a range of state-of-the-art characterisation instruments. Research in ZI is carried out, mostly collaboratively, by QLM, ORC and the *Nano* group from ECS.
For Astro and Theory, the facilities are more often associated with high performance computing (HPC) and/or large national/international facilities. HPC is strongly supported at Southampton, with local deployment of powerful data analysis clusters for LOFAR and centralised facilities such as UoS IRIDIS cluster (which has a peak >105 TFlops) and SCIAMA at Portsmouth (through SEPnet). The Theory group in particular makes use of IRIDIS and has in addition been very successful in bidding for time from the Distributed European Infrastructure for Supercomputing Applications, under the DEISA Extreme Computing Initiative. This includes a total of 19 million core hours IBM BG/P (JUGENE) and separately, a DiRAC-II Large Project award to exploit Petaflops-scale BG/Q resources awarded in the 2009 HPC grants, of 1,010m BG/Q core hours.

Astronomical facilities of which we are formal partners and invest in their development, include LOFAR (we are a founding, and former lead member of LOFAR-UK, also supported by SEPnet) SALT (founding member) AMI (for which Southampton is funding a new digital correlator via ***Scaife***'s ERC grant) and the ESA INTEGRAL mission (for which we are the UK data centre). We furthermore make extensive use of all front-line research facilities including ground- and space-based observatories across all wavelengths, including these non-RCUK-supported facilities:
X-rays: Chandra (920ks), RXTE (15Ms), Suzaku (320ks) *(approx. total value: $3.3m)*
UV/optical: CFHT, SALT/SAAO *(approx. total value: $0.15m)*
Radio/mm: GMRT (800ks), VLA/VLBA (400ks), SMA (160ks), KAT-7, ATCA, Effelsberg 100m, KAIRA, GBT *(approx. total value: $3m)*

Theory group are frequent visitors to CERN and during the REF period **Belyaev, Moretti, Morris** and Ross have been scientific associates. **Belyaev** is a full member of the CMS consortium and is a signing author on all CMS publications, whilst **Moretti** is a non-M&O paying member. ***Accomando*** is a 50/50 joint appointment with the RAL experimental group until August 2014.

e. Collaboration or contribution to the discipline or research base

P&A have a strong and continuing track record in contribution to their subject disciplines and the overall community, via research leadership and collaborations. Key examples include SEPnet, which has provided key funding for the development of research collaborations such as the NeXT institute, which was created and continues to be led by members of Theory, and LOFAR-UK, which was formed and initially led by Southampton and remains the UK's largest astronomy collaboration.

- National and international advisory board membership

Bird: Member, ESA INTEGRAL Advisory Group; **Sachrajda:** Member, visiting committee, Centre de Physique Theorique, Marseille.; Royal Society Sect. Committee 2; Member, IoP Science Board; **Flynn:** member, HECToR dCSE review panel (2007-2012); member, CERN Computing Resources Scrutiny Group (2007-) and Chair (2012-); **Evans:** Chair, ESF *HoloGrav* Programme; ***Juettner*:** Working Group Leader, Flavour Lattice Averaging Group; **Lagoudakis:** Advisory Member, STFC laser pool; De Groot**, Kanaras, Ulbricht:** members of EU COST actions; ***Skenderis***: External expert, Dept of Physics, Aristotle University of Thessaloniki, Greece; ***Scaife*:** SKA Science Data Processor consortium board; ***Sullivan,*** chair ESO PESSTO public survey.

- Advisory positions for government, funding or standard setting bodies/other bodies

***Croston*:** member, STFC Astronomy Grant Panels; ***Accomando*:** member, STFC Rutherford

Fellowship panel; **Moretti:** STFC Fellowships panel member (2007,8); **Sachrajda:** member, STFC Scientific Advisory Committee; DiRAC resource allocation panel; Expert advisor, Applied Maths and Physics RAE Subpanels (2008); REF Panel member, assessing framework for Impact of Physics research (2010); Panel Member of subpanel 9 REF2014; Ross**:** Royal Society e-gap panel (2012-) Royal Society Research Appointment Panel A(i) (2013-). **Flynn:** Chair, STFC Gridpp Oversight Committee (2009-); ***Taylor*****:** member, committees for Dutch Research Councils NWO & FOM; ***Skenderis*****:** member, expert panel of Research Foundation Flanders (FWO). De Groot (chairman) **Muskens, Freegarde (chairman) Smith:** members of EPSRC peer review college; De Groot**:** member, Committee for Development of Diamond High-Field Beam Line; **Freegarde:** RS Newton International Fellowships panel (2007-9); IoP Physics Accreditation panel (2012); **Kavokin:** member, NRC evaluation panel (Italy); member, National Institute evaluation panel (France); **Lagoudakis:** Advisory member, national research councils of Finland, Greece; **Kaczmarek:** Evaluator for FNRS (Fonds de la Recherche Scientifique) grant proposals

- Leadership roles in industry, commerce, research councils, charities

King: Leader, UK Neutrino Network (2002 -); **Kaczmarek:** Expert evaluator, vice-chair and reviewer, FP7 EC Grant Evaluations; **Kavokin:** Founding Faculty Fellow, Skolkovo Technical University (Russia); Scientific Director, Mediterranean Institute of Fundamental Physics (2010-); **Morris:** management board member, Winton Programme for The Physics of Sustainability;

- Election to membership or fellowship of learned societies ***Taylor*****:** Election to Young Academy of Dutch Royal Society (2009); **Morris:** Fellow IoP (2009).
- Fellows of the Royal Society: Ross**, Sachrajda**
- Keynote addresses at major conferences or invited lectures

Astro/Theory/QLM: 100+/169+/100+ invited talks; 50+/56+/15 conference committees.

- Journal editorships, editorial board membership

Bird: Editor, IEEE Trans. Nuc. Sci.; **Charles**: Editor, New Astronomy Reviews; **King:** Editorial Board, Rep. Prog. Phys.; ***Ulbricht*****:** Editor, Nature scientific reports for quantum physics (2011-); Guest Editor, New Journal of Physics (2010-12); **Kavokin:** Member, Editorial Board, Superlattices and Microstructures (2011-); **Kaczmarek:** Guest Editor, Journal of Optics A : Pure and Applied Optics, special issue on Nanocomposite Materials (2009).

- Prestigious research fellowships

Sullivan, Altamirano, de Liberato**:** *Royal Society URFs*; Casella, Ponti, Muñoz-Darias, Pretorius, Rushton, Akeroyd, Dos Santos, Merle, ***De Liberato*****:** *EU Marie Curie International Fellowships*; ***Juettner*****:** *CERN Fellowship*; **Kavokin:** *EPSRC Established Career Fellowship*; **Tropper** (2010) **King** (2009) **Kavokin** (2012): Royal Society Leverhulme Senior Fellowships**;** ***Muskens*****,** Wilcox**:** EPSRC Early Career Fellowships 2012; ***Himsworth*****:** RAEng Fellowship 2010; Zwicky(2009), Starinets (2007)**:** STFC Advanced Fellowships.

- Prize-winning publications

Sachrajda: Coordinating author Phys. Rev. Lett. 108 2012 141601 (*Ken Wilson Award*); **Ulbricht:** last and corresponding author of Rev. Mod. Phys. 2013.

- Honours, prizes and awards

Charles: Elected Fellow, South African Institute of Physics (2012); Honorary Professor, University of Cape Town; Visiting Professor, Oxford; **Sachrajda:** University of Sussex 50th Anniversary Fellowship; **Taylor:** Winner of Minerva Prize 2008, Dutch FOM; **Evans:** Durham IPPP associate; **Moretti:** Visiting Professor, Uppsala University (2013-) Universita di Torino (2009-10) CNRS Orsay (2007-8); **Belyaev, Moretti, Morris,** Ross: CERN scientific associates; **Sachrajda:** Senior Visiting Researcher, Yukawa Institute University of Kyoto, Columbia University, and SISSA, Trieste; Visiting Foreign Researcher, KEK Tsukuba; **Sachrajda,** Associate, ***Juettner*****:** Affiliate, of Higgs Centre for Theoretical Physics, Edinburgh; **Kanaras:** Sir Eric Rideal award; **Lagoudakis:** IUPAP Young Scientist Medal on Quantum Electronics, Visiting Professor at EPFL (2013-) Japan Society for the Promotion of Science Research Fellowship (2008); Zwicky**:** Honorary Professorship in Physics, University of Southern Denmark (Syddansk Universitet) (2009-).

- Leadership of consortia (EPSRC Programme Grants, EU)

Scaife**:** (€2m); ***Juettner*****:** (€1m) ERC Starter Grants; **Smith:** Lead Investigator, Basic Technology Grant "Topological Engineering"; **Kavokin:** Coordinator, European Research Training Network (CLERMONT4 2009-13); EPSRC Fellowship (£1m) ***Muskens*****:** (£1.5m); Wilcox**:** (£0.8m).