Institution: University College London

Unit of Assessment: 9

a. Overview

1. Physics research at UCL is focused on the Departments of Physics & Astronomy (PA) and Space & Climate Physics (SCP) and the London Centre for Nanotechnology (LCN). They form a distinctive cluster of expertise with outstanding capabilities in physics, unique and highly inter-disciplinary elements and a presence on multiple sites, rooted in the vibrant academic environment of UCL, a world-leading university in the heart of London.

2. PA, SCP and LCN are distinct entities with independent management and finances but strong interactions in teaching and research. PA and LCN are located in Bloomsbury, central London, while SCP occupies the Mullard Space Science Laboratory in Surrey. All are members of the Mathematical and Physical Sciences faculty (MAPS), which is part of the School of the Built Environment, Engineering and Mathematical and Physical Sciences (BEAMS); the LCN is also a member of the Engineering, Life Sciences and Medical faculties and is a collaborative venture with Imperial.

3. Across these organisations, research is grouped into six broad areas: Astrophysics (AP); Atomic, Molecular, Optical & Positron Physics (AMOPP); Biological Physics (BP); Condensed Matter & Materials Physics (CMMP); High Energy Physics (HEP); and Solar System Physics (SSP). These groupings span PA and SCP and also have members who hold joint appointments with the LCN, and several interdisciplinary centres cut across the subject areas and departments.

4. Our return includes 113 staff, a 10% increase with respect to the RAE 2008 (which included Medical Physics, submitted under a different Unit in this REF), illustrating the strong faculty and institutional commitment to physics. These are split between areas approximately as follows: AP 26, AMOPP 17, BP 13, CMMP 19, HEP 19, SSP 19, though several staff contribute to more than one area. Many CMMP and BP staff are affiliated with both PA and LCN, which also includes academic staff from other departments and faculties. AP and SSP staff are split between PA and SCP. All other staff are members of PA.

b. Research Strategy

5. Physics research at UCL addresses deep questions about the physical Universe, covering its origins, its basic constituents, and complex emergent phenomena. How is it evolving on astrophysical scale? What are its fundamental constituents and how do they interact? What is dark matter? How did the baryon asymmetry in the universe arise and does antimatter behave like matter in gravitational fields? How do galaxies, stars and planets develop? What are planets - in our solar system and beyond - made of and how do they interact with the stars they orbit? What is the origin of solar activity and what role does it play in driving changes in the solar interior? What forms the solar wind and how does it propagate and evolve? What is the origin and distribution of atoms, molecules and dust in the Universe, and what are the most extreme astrophysical phenomena? What is the neutrino mass hierarchy, and is the neutrino its own anti-particle? Are neutrino and anti-neutrino interactions symmetric under charge-parity inversion, and do charged-lepton interactions conserve flavour? Is the recently discovered Higgs boson the fundamental scalar particle of the Standard Model or a more complex entity, and up to what energy does the Standard Model provide a good description of nature? What is the theoretical basis of quantum mechanics? What are the limits to coherent quantum behaviour in matter, and how can such behaviour be exploited? How do strongly correlated electron states give rise to novel forms of quantum matter? Can these states be engineered to produce, for example, room temperature superconductors? What are the organising principles for nanoscale matter, and how do they give rise to the complex dynamics of living organisms? Can quantum coherence be observed in biological systems? Can we understand irreversible processes and matter far from equilibrium? Can we design and develop new materials to provide cost effective and sustainable energy capture, storage and delivery? What other innovative applications can we find for the exciting new knowledge being discovered in the above research?

6. Our overall strategic approach to achieve these research aims is to nurture a first-class intellectual and technical capacity across the discipline of physics, identifying exciting new directions, influencing and responding to external priorities, and exploiting good links with areas of strength in UCL, particularly in chemistry, engineering, biomedical and life sciences (including the Francis Crick Institute under construction about 500m from the main UCL campus). This capacity advances the discipline by producing outstanding academic results and impact beyond academia.

The benefits of the linkages to UCL researchers in other disciplines are enhanced by our share in substantial common investment in facilities such as the library, high performance computing, networking and data storage.

7. The key to delivering these strategic aims is an excellent and well-supported body of academic staff. We provide an environment that motivates and encourages innovation by promoting decision-making at research group level and by individuals, as appropriate, with the oversight of departmental strategic boards. Distribution of non-research tasks is managed using a transparent workload management system. Investment in equipment, the estate and staff, as well as other developments, are steered by rolling strategic plans on an approximate five-year timescale at both departmental and faculty level, with an annual budget cycle where investments such as those described below, including new appointments (those made during the period are <u>underlined</u>) are discussed and agreed. These plans are reviewed by the UCL senior management team, and influence inter- and intra-faculty themes. We commission periodic external reviews (most recently in 2009), and encourage staff members to play a role in driving national and international strategy, for example through membership of research council advisory bodies. Opportunity scanning, and optimisation of funding applications, are strongly supported by research facilitators at the School level (BEAMS).

<u>Research Areas</u>

8. **Cosmology and Galaxy Formation (AP):** We are at the heart of recent, current and future instruments to study the origins and evolution of the Universe on astrophysical scales. <u>Hiranya Peiris</u> and <u>Jason McEwen</u> played an important role in the analysis of the recently published Planck data, making the most precise measurements of the cosmic microwave background (CMB). Peiris is a member of the High Frequency Instrument core team and Giorgio Savini is a member of the Instrument Calibration Team. Savini and McEwen are part of the Planck Core Team, McEwen applying his Bayesian and wavelet analysis methods to study the Gaussianity and isotropy of the CMB. Ofer Lahav and Peter Doel delivered the lenses and obtained first light with Dark Energy Survey in Sept 2012, with observations starting in Sept 2013. <u>Andrew Pontzen</u> uses large-scale cosmological simulations to study structure formation and dark matter, and has demonstrated the importance of supernova feedback in structure formation. <u>Benjamin Joachimi</u> is a core member of the RCSLens and VST Kilo Degree Survey collaborations, developing optimal analysis and systematics control techniques for large-scale structure probes, and applying his methods to constrain properties of dark energy and gravity. <u>Filipe Abdalla</u> and Raman Prinja are using LOFAR observations to quantify the epoch of reionisation; this is also a preparation for the Square Kilometre Array (SKA), which we have recently joined, after investing £76k in preparatory work. Cropper calibrated and characterised all 106 detectors and associated electronics for Gaia (likely launch date 17 Dec 2013), and with Daisuke Kawata will use Gaia data to study the formation of the Milky Way and near field cosmology. PA is investing £150k in refurbishing the optical development laboratory used by Doel and others. Computational science in general, including modelling and “big data” analysis, is an area of strategic strength at UCL cutting across all these projects. We are working, with UCL financial support, on plans for a spectroscopic follow-up for DES (DESI) and are participating in science preparations for the LSST, where Peiris is developing novel algorithms to extract reliable information from the coming era of "Big Data" surveys (SKA as well as LSST) and petascale computing. We have a strong role in the ESA Euclid mission: Mark Cropper leads the VIS instrument, <u>Tom Kitching</u> coordinates all Euclid science working groups (>1000 members) and Abdalla and Joachimi work on data management.

9. **Galaxy Evolution and Star Formation (AP):** Over the period, we have made major advances using data from a wide range of instruments and sophisticated UCL-led modelling codes. Instruments include HST-ACS and WFC3 (Ignacio Ferreras) and the Herschel SPIRE instrument (<u>Bruce Swinyard</u>, Mat Page), where we completed the thermomechanical structure and calibration. Herschel has been used to understand the roles of active galactic nuclei and star formation in controlling galaxy evolution (Page, <u>Thomas Greve</u>) and to show that supernovae can create large masses of dust (Mike Barlow). Serena Viti also used Herschel to investigate the astrochemistry of star-forming regions, and with Jonathan Rawlings showed how molecular lines can be used as tracers of galaxy development. <u>Amelie Saintonge</u> is studying the distributions of cold gases in galaxies and has demonstrated important relationships between gas content, structure and stellar properties. Ian Howarth and Prinja demonstrated the importance of mass loss, rotation, non-radial pulsation and magnetic fields in determining the characteristics and history of hot stars. Cropper delivered the in-flight and on-ground calibration systems for JWST NIRSpec to Astrium. We are

leaders in modelling star formation and are working on major code development for analysis of data from JWST-MIRI and proposed SPICA-SAFARI mid- and far-IR instruments. The European Extremely Large Telescope (E-ELT) is the most important instrument for the future of this area: David Walker has developed novel techniques for polishing its hexagonal segments to specification, and is working on wider industrial applications. A new spectral and spatial modulation technique has been developed for the THz observational domain, with applications to space-borne far-infrared interferometry (Savini), and we are investing in £50k in developing this.

10. **High Energy Astrophysics (AP):** High spectral resolution X-ray observations of nearby and distant active galactic nuclei (AGN) have been used to examine outflows to understand their influence on galaxy evolution at high redshift (Graziella Branduardi-Raymont, Page). We have developed detailed spectral and timing models for the X-ray emission from magnetars, based on 3-D Monte Carlo simulations of resonant up-scattering of thermal surface photons including all QED effects and polarization (Silvia Zane). We are also leading the exploitation of our NASA Swift mission gamma-ray burst lightcurves to infer the physics of the expanding fireball produced in a gamma-ray burst (Page, Zane). We have constructed a fully self-consistent and covariant general relativistic radiative transfer formulation including the first covariant Compton scattering kernel in closed form, and from it developed a relativistic transfer code, efficient and accurate in the calculations of radiation from accreting black holes and neutrinos from merging neutron stars (Kinwah Wu). Zane is leading the study of the LAD instrument for the proposed ESA LOFT X-ray timing mission.

11. **Positrons and Positronium (AMOPP):** Gaetana Laricchia discovered that positronium (Ps) scatters from a wide variety of atomic and molecular targets in a similar manner to that of an equivelocity electron, made the first observation of Ps resonant scattering, and the first cross-section measurements of positron-induced ionisation accompanied by the excitation of positronium and/or target ion. Jonathan Tennyson developed a new pseudo-state procedure and applied it to positron-molecule collisions to obtain rare *ab initio* low energy cross-sections. PA invested £200k in a new laboratory for <u>David Cassidy</u>, who produced a fully spin-polarized ensemble of Ps atoms in vacuum by implanting high density bursts of polarized positrons into a porous silica film and observed the efficient production of long-lived Rydberg Ps in a high magnetic field. The former is a required precursor to the formation of a Ps Bose-Einstein condensate and the latter may make it possible to perform a direct measurement of the gravitational free fall of Ps. Both will be the objects of future research at UCL funded by EPSRC and Leverhulme grants (Cassidy, Barker and <u>Stephen Hogan</u>). Peter Barker has proposed a novel method for the creation of an energy-tunable positronium beam using the optical dipole force from short, pulsed travelling optical lattices.

12. **Cold Matter and Trapping (AMOPP):** Atoms and molecules in highly excited Rydberg states are also being exploited for studies of cold molecules and anti-hydrogen. PA has invested £220k in a new laser laboratory for Hogan, who has demonstrated Rydberg-Stark deceleration and electrostatic trapping of atoms and molecules in Rydberg states, and the development of the technique of multistage Zeeman deceleration of paramagnetic atoms and molecules. Barker, Tania Monteiro and Sougato Bose are studying the cooling of larger scale objects, with the aim of determining whether the quantum mechanical nature of the centre-of-mass motion can be measured and to explore the quantum/classical divide. Feruccio Renzoni, in collaboration with the Atomic Weapons Establishment, has initiated an effort to develop Magnetic Induction Tomography as an imaging tool to address Nuclear Arms Control issues.

13. **Ultrafast Laser Spectroscopy & Strong Laser Interactions (AMOPP):** Agapi Emmanouilidou's formulated a novel two-electron streak camera. Jonathan Underwood studies laser matter-interactions using free-electron lasers, and will focus on developing new ultrafast electron diffraction techniques in collaboration with Daresbury (ASTeC). Carla Faria has modified the strong-field approximation in order to incorporate electron-electron correlation, excitation and the influence of residual binding potentials, and will develop orbit-based approaches for multielectron in strong fields, in an interdisciplinary effort with quantum chemists and mathematical physicists. Angus Bain has shown highly restricted state selection in Förster resonance energy transfer (FRET) involving commonly used fluorescent protein pairs, with consequences for the accurate interpretation of a vast amount of FRET data. He will develop radiative lifetime engineering techniques for obtaining sub-wavelength resolution in fluorescence imaging, commercial collaborations with Picoquant, and accurate characterisation of the transition dipoles in FRET.

14. **Quantum Information (AMOPP/CMMP):** This area has seen major expansion, as planned at the time of RAE2008. The aim is to understand fundamental quantum physics and its connection to information, and to work towards devices that can be used to bridge the two. Jonathan Oppenheim applies information theory and computer science to physics and recently proved that the strength of non-locality in quantum theory is determined by the uncertainty principle. Future work will include constructing laws of thermodynamics for the quantum regime, where major progress has already been made. Dan Browne discovered new approaches to the computational power of quantum correlations and is working in a theory-experiment collaboration on quantum computation with Rydberg atoms, on fault tolerance in higher dimensional systems and on implementation of scalable photonic quantum computation. Bose has developed new approaches to information processing and transmission using spin chains and is collaborating with LCN colleagues to implement them in quantum wires. Also in the solid state we have a major activity, funded by an EPSRC programme grant, involving Gabriel Aeppli, David Bowler, Andrew Fisher and Stephen Schofield on the coherent manipulation of spin and orbital states of donors in silicon, with significant advances in atomic-scale manipulation of the Si surface and in far-infrared coherent spectroscopy. This work also closely involves LCN colleagues returned in UoAs 5, 8 and 13. In collaboration with the LCN group, Monteiro showed theoretically that bismuth dopants have major advantages over phosphorus for speed-up of quantum gates as well as suppression of decoherence, and the speed-up of NMR gates by a factor of 1000 has now been shown experimentally. In molecular materials Mark Buitelaar uses low-temperature transport to probe spin states in nanotube quantum dots, while Alexandra Olaya-Castro uses quantum open systems approaches to understand coherence in photosynthetic reaction centres. In optical and atomic systems, Alessio Serafini gave the first demonstration of coherent quantum storage of an entangled state of light and developed new control procedures, and is now applying feedback control to opto-mechanics, where Barker is working to realise optical levitation and ion-trap experiments to observe previously inaccessible under-damped classical dynamics and quantum non-equilibrium. Hogan will use a chip-based architecture for manipulating the translational motion and the internal quantum states of highly excited Rydberg atoms and molecules (recently demonstrated experimentally) in the development of hybrid approaches to quantum information processing. Marzena Szymanska has pioneered new approaches to the description of non-equilibrium quantum effects, including high-temperature Bose-Einstein condensation, in optically pumped semiconductor structures and also studies other light-matter hybrid systems. Future plans include strengthening the links to fundamental computer science with new appointments and to device physics through the LCN and Electronic & Electrical Engineering (EEE).

15. **Imaging and Manipulation** (**AMOPP/BP/CMMP/SSP)**: Investigators across four research groups develop advanced physical methods to image, probe and manipulate biological materials on nanosecond to millisecond timescales and from molecules to cells. These methods include laser systems to manipulate matter from single molecules to micron-sized particles, STED and two-photon approaches, atomic force microscopy, and scattering methods with neutrons and X-rays. PA is investing £400k in a new laboratory for Pierre Thibault, working on imaging living systems with free electron lasers (FELs) and other techniques. Phil Jones and Isabel Llorente-Garcia work on novel optical and magnetic manipulation and imaging methods applied to colloidal and biological systems. Angus Bain has devised a new technique for sub-optical wavelength imaging using lifetime image reconstruction in the presence of CW STED, and applied this to imaging of fluorescent nanoparticles within live cells. Bart Hoogenboom develops and applies atomic force microscopy techniques for real-time and (sub)molecular-resolution imaging of biological processes, and has recently been the first to visualise the DNA double helix in aqueous environment. Ian Robinson applies the latest X-ray diffraction methods to study the structure of the genome and leads a significant research group at the Research Complex at Harwell for this purpose. Thanh Nguyen has developed a novel contrast agent for tracking stem cells in tissue engineering imaged by magnetic resonance imaging. Hoogenboom works with new nanometrology lecturers in Chemistry and EEE, extending the state-of-the-art in nano-imaging and nanomanipulation using scan probe techniques, X-rays and associated theoretical modelling tools, with particular applications to biology and quantum information processing. Novel 3D, hyperspectral and fluorescence imaging systems are being developed in SCP (Jan-Peter Muller) for planetary exploration and climate physics applications.

16. **Soft Condensed Matter** (**BP/CMMP)**: As planned in RAE08, this area has seen significant recent expansion particularly in biologically related research, leading to the formation of the new

Biological Physics (BP) group. Nguyen develops new, mostly magnetic, nanomaterials with biomedical applications. These novel nanoparticles have interesting physical properties that would be suited to drug delivery or *in vitro* and *in vivo* diagnostics and therapeutics, especially for cancers. There is also significant effort in creating and understanding surfaces and surface-solute interactions, including proteins and other biological molecules. The groups are also creating nano-patterned surfaces and novel nanomechanical cantilevers that are used to facilitate measurements on biological materials. Silvia Vignolini studies photonic materials occurring in animals and plants, and performs experiments to understand and replicate naturally occurring structures for diverse applications. Chris Howard and Neal Skipper's research into nanocarbon solvation and dissolution has led to commercialisation of a new route to disperse and separate carbon nanotubes, and provided the first detailed picture of graphene in solution. Ian Ford's theoretical studies of non-equilibrium and irreversible processes and entropy production have led to new insight into nucleation in a wide range of systems including soft colloidal matter and aerosols.

17. **Theory and Modelling (AMOPP/BP/CMMP):** We develop new theoretical and modelling methods and algorithms, and use them to identify and understand new materials and properties, and to underpin experimental research. The research is driven by current challenges in materials physics, and often working with partners in the Thomas Young Centre for Materials Modelling (TYC). Chris Pickard has applied his *ab initio* random structure searching to predict new stable crystal phases particularly in the field of terapascal physics, revealing rich structure of matter in a regime that simple close packing was assumed to dominate, with immediate application to the structure of massive (exo-)planets and laser fusion. Olaya-Castro researches quantum effects in biology, most notably quantum coherence effects in electronic energy transport, vibrational dynamics and sensing processes of biomolecules. Bowler has created *ab initio* computer models of molecular structures and molecular systems up to and including the scale of biological molecules, and Ford has developed new numerical models to describe the behaviour of disordered proteins in confined environments. Jochen Blumberger develops and applies numerical simulations to electron and proton transfer in proteins and energy materials, as well as to small-molecule transport in biological systems. Dorothy Duffy is studying biomineralisation as part of a major EPSRC funded consortium, and uses molecular dynamics to quantify the effects of radiation damage and heat load on prospective materials for fusion power plants. Alex Shluger and Peter Sushko focus on defects in solids and at surfaces, and tackle problems ranging from photo-induced processes at ionic surfaces, mechanisms of CO_2 conversion, models of self-trapped excitons and hole polarons in solids, through to the effects of interstitial doping on epitaxial metal/oxide heterojunctions. Blumberger, Bowler, Duffy, Fisher, Pickard, Shluger, Sushko and Szymanska all develop new methods and algorithms: embedding methods to move beyond density functional theory; first principles approaches to structure prediction and crystal growth, the inclusion of electronic effects in radiation damage, and linear scaling methods to describe the millions of atoms in nanostructures from first principles. These techniques are applied widely, and in an increasingly integrated manner. A major theme of their work is the bottom up simulation of devices, including energy storage devices, low-voltage electronics, quantum devices and photovoltaics, with particular focus on the defects that control their operation. Tennyson and Sergei Yurchenko work on Molecular Structure and Spectroscopy, making the *ab-initio* calculations of the characteristics of molecules of increasing complexity and in exotic and/or excited states, with has wide applications in remote sensing, astrophysics, atmospheric physics and beyond, including commercial applications.

18. **Quantum, Strongly-Correlated and Many-Body Electronic and Magnetic Systems (CMMP):** In a series of landmark experiments, Steve Bramwell has proven the existence of emergent magnetic monopoles in classical spin-ice, generating intense interest from national and international media. Quantum magnets have also produced important results, including the direct observation by Des McMorrow of fractionalisation of magnons into spinons at the formation of a Luttinger liquid in a spin ladder, and the STM imaging by Schofield of candidate spin and charge qubit structures formed from impurity atoms in silicon. Robin Perry produces high quality single crystals of several families of novel or unconventional strongly correlated transition metal oxide systems, and has recently tracked the development of the entropy on approach to a quantum critical point. Analytical theory of quantum critical magnets has been developed by Andrew Green, including building on concepts from string theory, leading to predictions of new mechanisms for exotic superconductivity. Theory by Meera Parish has investigated the nature of the order parameter in iron-based superconductors, and made predictions of stripe formation in 2D dipolar

Fermi gases. The latter has relevance for the interpretation of the discovery, by Mark Ellerby, Howard, Schofield, Aeppli and a colleague in Chemistry/LCN, of charge density wave stripes in graphite intercalated superconductors, and their studies of electron-phonon interactions and dimensionality in doped graphenes. X-ray and neutron techniques have been developed for revealing the role of competing ordering phenomena in superconductors, with major contributions to our understanding of cuprates by Aeppli, showing how the highest critical temperatures are associated with the fractal organization of defects, and McMorrow, through the discovery of a soft-mode quantum phase transition. Pavlo Zubko has investigated a number of fundamental and practical properties of artificially-layered complex-oxide hetetrostructures, including ferroelectric nanodomains in ferroeletric superlattices and interfacial magnetism in nickelate/manganite heterostructures, while Stan Zochowski has fabricated U-based multilayers to examine 5f magnetization. McMorrow and Robinson play a leading role in the development and exploitation of new facilities being constructed at ISIS and Diamond which will allow us to address fundamental questions in magnetism. Planned investigations are expected to result in additional major advances in the both the discovery and understanding of novel superconductors.

19. **Organic and Molecular Electronics (CMMP):** Our research focuses on single molecule characterisation and control, organic semiconductors, and device applications. Franco Cacialli is developing printable semiconductors and related nanostructures for opto-electronics and photo-plasmonics, and in particular: self-assembled supramolecular semiconductors; printable photovoltaics, and new thermoelectrics and transparent oxide semiconductors. Discovery of a new route to produce nanostructured polymer/hydride composites by Skipper and collaborators at ISIS led to the formation of a new energy storage spin-out company (Cella Energy). Buitelaar, Schofield have engineered new supramolecular semiconductors for optoelectronics, and in parallel applied new theoretical approaches to electronic phenomena in large organic molecules. With Fisher, Aeppli and LCN colleagues they have advanced the discipline of organic spintronics and initiated the use of aromatic molecules for quantum information. We plan to further develop on our activities in organic-based energy capture and storage devices.

20. **Electroweak symmetry breaking and the high-energy limits of the Standard Model** (**HEP):** As planned at the time of RAE2008 are at the forefront of physics at the Large Hadron Collider, holding several key leadership positions and technical roles. Emily Nurse, Mario Campanelli, Nikos Konstantinidis, Andreas Korn and UCL technical staff have made major contributions to the ATLAS current and upgrade triggers. A major highlight was, of course, the discovery of a Higgs boson in July 2012. Jon Butterworth worked on analysis of the Higgs b-decay channel, where he developed techniques for tagging boosted massive particles decaying to hadrons by use of jet substructure, now applied in many of LHC physics channels. Andrew Pilkington made the first measurement of a Higgs differential cross section in a defined fiducial region, in the two-photon channel. Tim Scanlon (RS URF, arriving Jan 2014) now leads the ATLAS Higgs-to-bb analysis. Butterworth, Campanelli, Gavin Hesketh, Konstantinidis, Nurse, Pilkington and Korn all characterised important Standard Model backgrounds, including diboson, jet, boson+jet and b-hadron production, using the groups' strong expertise in analysis and in Monte Carlo simulations. We supported Butterworth and Konstantinidis in attachments at CERN, leading first physics results from ATLAS and upgrade preparations, especially for triggers and data acquisition. Mark Lancaster has been electroweak convener of CDF for several years, and was supported in a year sabbatical during the assessment period. With David Waters he led the most precise CDF measurement of the W boson mass. Frank Deppisch has used LHC and other data to develop and constrain models for physics beyond the Standard Model (BSM) at high energies. Keith Hamilton discovered a technique for seamlessly combining next-to-leading order (NLO) Higgs plus jet production with NLO inclusive Higgs production, opening the door to a next-to-NLO parton shower matched description of Higgs production at LHC. We will continue to lead exploitation of ATLAS and LHC data in these areas.

21. **Neutrino physics** (**HEP):** This area, the subject of significant new investment at the last RAE2008, has since delivered several exciting results, and remains a priority. Anna Holin, Ryan Nichol and Jenny Thomas have produced some of the most precise measurements of neutrino oscillations using MINOS and now MINOS+. Ruben Saakyan and Waters have produced measurement of double beta decay with NEMO III and after substantial R&D are constructing the SuperNEMO demonstrator module at MSSL in a collaboration between PA, SCP, Manchester University and Imperial. This is designed to be a background-free experiment searching for neutrinoless double-beta decay with sensitivity to the inverted neutrino mass hierarchy. Deppisch works with experimental and AP colleagues on neutrino parameter fitting and BSM physics. We

plan to continue this program into the next generation of long-baseline and double-beta decay experiments.

22. **Probing QCD in new environments (HEP):** Measurements at high scales and multiplicity, at large boosts and at low momentum fractions utilise the phase space opened by the LHC and recent theoretical advances to better understand the Standard Model and benefit our electroweak symmetry-breaking programme. Butterworth and Campanelli made the first jet cross-section measurements with ATLAS; Butterworth also measured jet mass and substructure, and Konstantinidis made the first measurements of b-tagged jets at the LHC. Pilkington and Campanelli measured dijet systems containing wide rapidity intervals, probing a new region of QCD and building towards ongoing searches for vector boson scattering with Nurse and Pilkington. Pilkington also applied this technique to make the first measurement of QCD radiation in top-pair events, which has been used to reduce systematic uncertainties in the ATLAS measurements of the top cross section. Korn made several key measurements in b-physics. Nurse played a leading role in the very first ATLAS physics papers, on charged particle multiplicities, and also measured high-rapidity energy flows. Hesketh made the first measurements of Z+b jet production at the LHC and has subsequently made more precise measurements. Robert Thorne is a leader in parton density determinations and he and Butterworth are members of the PDF4LHC steering group. In ATLAS, Butterworth was convener of the Standard Model group, Korn of the B-physics group, Nurse and Pilkington of the Soft QCD subgroup, and Campanelli of the Jet subgroup. Matthew Wing has made precision measurements in deep inelastic scattering using the final HERA data set, and was elected spokesperson of the ZEUS experiment, directing the publication of legacy papers on precision ep scattering data, including the final combined parton density fits. Hamilton is a leader in higher-order Standard Model calculations and their implementation in Monte Carlo simulations.

23. **Particle Astrophysics (HEP):** Nichol is UK leader of the search for new physics through the study of ultra-high-energy (UHE) neutrino interactions with ANITA/ARA detectors. Chamkaur Ghag has produced some of the world best limits on Dark Matter as part of the Xenon and Zeplin III collaborations, and is now working on LUX and LUX-ZEPLIN. His expertise in low-background detectors, also relevant to the neutrino programme, where Saakyan, Thomas and Holin are collaborating on low-background future neutrino detectors.

24. **Muon Physics (HEP):** Lancaster and Wing are leading the UK involvement in the search for charged lepton flavour violation with COMET, and a very precise measurement of the muon's magnetic moment, g-2. This is a new area for the UK, and provides indirect access to energies well beyond those accessible at the LHC.

25. **Accelerator Development (HEP):** This is a crucial area for the future of particle physics, as well as a fruitful route to impact beyond academia. Simon Jolly works on accelerator initiatives both within particle physics and beyond. These include the Front End Test Stand at ISIS/ESS, the AWAKE plasma wakefield project led by Wing, and the UCLH hadron therapy unit currently under development.

26. **Solar and Terrestrial Physics (SSP):** Key aims during the assessment period included exploiting HINODE, securing a major role in ESA's Solar Orbiter mission, micro-satellite development for terrestrial studies, and general instrument development to maintain the cutting edge of space technology. These were all achieved. Scientific highlights include the realisation that high-temperature plasma upflows are persistent from solar active regions (Louise Harra). Further investigation led to the discovery that these flows escape the Sun to form the slow component of the solar wind via ongoing 'opening' of magnetic field structures (van Driel-Gesztelyi). Being able to say which upflowing plasma will make it out into to the solar wind has led to a unified model of the solar atmosphere/slow solar wind flows. A new method for determining plasma density in the solar atmosphere has been developed (David Williams). This "polychromatic opacity imaging" method offers a powerful way to track partially ionized plasma that regularly erupts from the solar atmosphere (in addition to the solar wind) and provides realistic mass-distribution estimates for theoretical models of these eruptions. Also in the area of solar eruptions, Lucie Green answered a long-standing question about their magnetic configuration when we found the presence of twisted flux ropes. This discovery allows the physical processes that drive these dramatic events to be understood. Our work on the origin of transient seismic activity in the solar interior (sunquakes) showed for the first time that they are related to solar eruptions revealing that sunquakes can be triggered by instabilities in the atmosphere magnetic field (Sarah Matthews, L. Green). Major advances in understanding the temporal evolution of Earth's auroral acceleration region have also

been made using simultaneous data from multiple Cluster spacecraft (Andrew Fazakerley). Through Harra and Chris Owen we are uniquely placed on Solar Orbiter to link in situ measurements of the solar wind with remote sensing observations of the Sun itself, in order to trace for the first time the evolution of the interplanetary plasma environment. For the future, we are leading the proposal of the SPARK mission for ESA's Cosmic Vision programme (Matthews) and Solar-C (Harra). Additional missions for launch in 2014 TechDemoSat (UKSA) and Sunjammer (NASA) have UCL instruments on board (Dhiren Kataria, with science expertise from Andrew Coates, Fazakerley).

27. **Planets and Comets in our solar system (SSP):** Following the discovery by Cassini of massive negative ions in Titan's atmosphere, its atmospheric escape rate was found to be 7 tonnes/day, hugely significant over solar system timescales. We discovered water cluster ions and charged dust in the plumes of Enceladus (Coates, Geraint Jones). We developed the first coupled magnetodisk/upper atmosphere model, allowing for explicit solar wind driving of the Saturnian upper atmosphere (Nick Achilleos). Combining Chandra and Hubble Space Telescope STIS observations, we studied the X-ray and UV morphology of Jupiter's aurora, identifying the energetic electrons responsible for the hard X-ray emission with those producing the UV, and studied the evolution of Saturn's X-ray emission during the decay phases of the last solar cycle (Branduardi-Raymont). The Cassini mission proximal orbits (2017) will allow UCL to pioneer the exploration of the planetary and ring ionospheres. The shift in emphasis from Saturn to Jupiter exploration in the next few years (JUNO and JUICE) will be matched by our modelling and observational work. We invested early in science and instrumentation for the JUICE mission (Achilleos, <u>Chris Arridge</u>, Coates, G. Jones) and have scientific roles in the UK led magnetometer and camera, and hardware and science roles in the plasma instrument recently selected by ESA. Our world-leading expertise on comet-solar wind interactions and observational techniques will be crucial for Rosetta's arrival at Comet Churyumov-Gerasimenko in 2014, on its way towards the Sun (perihelion 2015). Further ahead, we intend for the next ESA call to lead proposals for missions to the ice-giant Uranus (Arridge), to a main-belt comet (G. Jones) and to further study the physics of the terrestrial aurora (Fazakerley). We demonstrated the role of water in shaping Mars' surface from new 3D elevation models developed from ESA and NASA images. Coates leads the PanCam instrument for ExoMars, which will provide unique contextual data on the geological and atmospheric environment for the entire rover scientific operations.

28. **Exoplanets** (**SSP):** Giovanna Tinetti is lead scientist of the Exoplanet Characterisation Observatory (EChO) under study by ESA for a 2024 launch, and Alan Smith is playing a lead role in the PLATO consortium and chairs the sensor selection working group of the EU-funded QB50 cubesat constellation project (launch 2015). We will provide instrumentation for all the spacecraft. Modelling by Anasuya Aruliah is driving the design and will enhance the science return via her membership, with other UCL staff, of the QB50 science payload working group. <u>Jay Farihi</u> is a leader in the characterisation of exoplanet composition using the spectral signatures of matter accreted onto the surfaces of stars. Tennyson and Yurchenko develop and maintain the large and widely used EXOMOL molecular line list programme for exoplanet searches.

<u>Interdisciplinary Centres</u>

29. The **Institute for Origins**, an institutional initiative to encourage cross-disciplinary activity across the large particle, astro and geological physics groups, and mathematics, within MAPS, has benefitted from substantial UCL investment, provides a forum and context within which questions spanning AP, SSP and HEP can be addressed, and also involves the Departments of Mathematics and of Earth Sciences. Examples include work on determining the mass of the neutrino from AP data (DES, Planck and KIDS), comparing with neutrino parameter constraints in HEP (SuperNEMO, MINOS/+) and interpretation in terms of new physics models. Other priority activities include AP tests of general relativity on large scales and HEP involvement in direct Dark Matter searches. A major RAE2008 strategic goal achieved was the development of the working space for the **Centre for Planetary Sciences**, which now functions within the Institute.

30. 13 PA and LCN staff, principally in the CMMP area, are part of the Thomas Young Centre for Materials Modelling **(TYC)**, the very successful London-wide centre for theory and simulation of materials which includes around 100 research groups. The TYC provides strong industrial links with around 40 companies, and other interactions for our substantial theoretical and computational expertise. This is enabled by major institutional support for HPC (Legion) and network, and recent SES-5 consortium funding from EPSRC (with Southampton, Oxford and Bristol) of a Tier 2 regional centre (Iridis and Emerald).

31. The Centre for Mathematics and Physics in the Life Sciences and Experimental Biology (**CoMPLEX**) is based in the main Physics building and funded via a EPSRC Doctoral Training Centre. It focuses on interdisciplinary research in the medical and life sciences. It brings together life and medical scientists with mathematicians, physical scientists, computer scientists and engineers to tackle the challenges arising from complexity in biology and medicine. As well as providing PhD supervision, PA and LCN staff participate in inter-disciplinary seminars and workshops. Aeppli is one of the CoMPLEX research strategy directors.
32. The **LCN**, an independent post-graduate research department including academic staff jointly appointed with departments in four faculties (engineering, MAPS, life sciences and medicine), is highly successful because of its unique operating model and is a major driver of interdisciplinary science and technology, as discussed throughout this document.
33. The Department of *Science, Technology, Engineering and Public Policy* (UCL **STEaPP**) has recently been created to mobilise the impact of UCL's world class scientific (natural and social), technological and engineering expertise within a broad range of public decision making environments. Expertise in the new Department includes serving in roles such as Chief Scientific Advisor across several government departments, and Director of Science and Technology in leading government agencies and corporations. Of the early appointments, Jason Blackstock brings the closest links to Physics. Lucie Green will move into a post which is devoted 50% to outreach and policy.

c. People, including: staffing strategy and staff development

Staffing strategy and appointments

34. The regularly updated departmental strategies include recruitment and retention targets across research and teaching areas. Appointments in SCP, PA or PA/LCN are justified on the basis of this overarching strategy and intellectual and financial case is made for each individual post. All appointments are openly advertised. For faculty positions, shortlists (generally of five or six candidates) are interviewed. Interview panels are chaired by the relevant Head/Director, and contain appropriate gender representation (now 25% minimum of each) and at least one external member. Shortlists have been extremely high quality, with the majority of candidates being deemed highly appointable. The vast majority of first choice candidates have accepted our offers.
35. Of the 38 category A staff recruited during the period, 21 have non-UK citizenship, 13 were recruited from positions outside the UK. Of those who have left UCL, 2 left to positions outside the UK. We have had 276 visiting scholars, of whom 66 are non-UK. Of category A staff, 8% are older than 60, 54% are aged between 40 and 60 and 38% are below 40. 22% are female. The cohort of category A staff (as of 31 Oct) comprises 49 professors, 12 Readers, 3 Senior Lecturers, 42 lecturers and 7 Research Fellows. This includes 29 Royal Society/STFC/EPSRC fellows and 8 ERC personal grants (two of which are senior awards, of £1.8 and £1.9 million). All category A staff hold a long term appointment or the promise of one, apart from two of the long-term fellowship holders. These fellowship holders will have the opportunity to interview for permanent positions during their fellowship term. The latest strategic plans (2011) identified the need for several appointments, all of which have been successful, as discussed below. In total 132 PDRAs were recruited and currently there are 75 employed in the department.
36. In **AP** the appointments of Abdalla, Savini, Saintonge (RS URF), Swinyard and Greve (STFC ERF) strengthen our activities in star formation and galaxy evolution. In cosmology, since the last RAE Sarah Bridle and Jochen Weller have left the department, but we have appointed Peiris (ERC), Pontzen (RS URF) and Joachimi (STFC ERF), in line with the strategy to strengthen this area outlined in RAE2008.
37. In **AMOPP** our experimental activity has been revitalised by the appointments of Hogan and Cassidy. Theory has been strengthened by the appointment of Emmanoulidou and Szymanska (both EPSRC CAF) and Oppenheim (RS Wolfson starting Oct 2013). Our expertise in *ab-initio* calculation of the characteristics of molecules was recently strengthened by the award of a senior ERC grant to Tennyson, and the appointment of Yurchenko as a long-term senior research fellow. These techniques have wide applications in remote sensing, astrophysics, atmospheric physics and beyond, including commercial applications.
38. As well as the new UCL-funded Crick fellow (Llorente-Garcia) the **BP** area has been strengthened by the recruitment of Blumberger (RS URF), Olaya-Castro (EPSRC CAF), Nguyen (RS URF), Thibault (ERC Fellow), Vignolini and Gerd Materlik (joint appointment with Diamond

Light Source). Prof. Tom Duke, a world-leader in the area, sadly passed away in 2012; the recruitment for his position (joint PA/LCN) will take place in 2013/2014.

39. In **CMMP**, our RAE 2008 submission picked out materials modelling and quantum information as priority areas. Green and Pickard were appointed at Professorial level, with Buitelaar, Howard, Parish, Perry, Zubko, Schofield and Thibault (ERC) appointed as lecturers. Three lectureship appointments (one joint with ISIS) in science at large facilities are underway. Gerd Materlik was recently appointed to a new chair in science at large facilities, at 60% FTE.

40. In **HEP** the appointments of Deppisch and Hamilton mean that along with Thorne, UCL now has a sustainable activity in particle theory and phenomenology, closely linked with the experimental group – an important strategic goal outlined in RAE2008. The appointments of Hesketh and Nurse (RS URFs) to lectureships and the attraction of a new RS URF (Pilkington), with another (Scanlon) starting in Jan 2014, increases our leadership in LHC physics. The appointment of Korn (STFC ERF) to a lectureship strengthens our role in the ATLAS upgrade. Jolly brings leadership in several accelerator physics projects, as well as interdisciplinary impact via his work on hadron therapy with UCLH/UCL Engineering. Ghag brings expertise in low background and noble gas/liquid detectors. Holin (Dorothy Hodgkin Fellow) strengthens our activity in MINOS and future neutrino developments.

41. In **SSP** we have appointed Farihi (STFC ERF) in PA to broaden our exoplanet activities, and SCP appointments include the award of three RS URFs. In space plasma physics Rae has been appointed and in planetary science, as well as Arridge (post-RS URF). In solar physics Williams has been appointed to strengthen our ongoing commitment to understanding non-equilibrium plasma conditions in the solar atmosphere in preparation for Solar Orbiter. L. Green (post-RS URF) brings in the expertise needed to understand the real 3D structures that go on to cause solar eruptions. In astrophysics Kitching (post-RS URF) has been appointed to focus on two fundamental issues in physics: the determination of neutrino mass, and the mapping of the dark energy equation of state over cosmic time.

<u>Career development, gender issues and work-life balance</u>

42. UCL is committed to inclusivity and diversity; PA has been awarded “Juno Practioner” status by the IoP and is in the process of applying to become a Juno Champion in 2014. The chair of the Juno panel is a member of the PA departmental board, chaired by the HoD, on which the research group leaders, Director of Teaching and Director of Postgraduate Studies also sit. The Juno panel also monitors progress against the Concordat to Support the Career Development of Researchers. We have a policy of “core business in core hours” (10-12 and 14-16) to help accommodate flexible working arrangements. UCL overall has Athena SWAN Bronze status.

43. For all departments, career progression is managed and encouraged via a universal appraisal system (under which all staff are appraised at a minimum once every two years), an annual promotion round (which is merit-based, with no quotas, and for which candidates are raised through an annual discussion on the departmental boards or via their own initiative), regular salary reviews, and case-by-case discussions on regrading. Appraisals also identify training needs, and training is provided and supported by the department and college.

44. The research groupings form the major support mechanism for PDRAs; regular seminars and social events are organised, and well-attended by PhD students, PDRAs and faculty. PDRAs have an opportunity to become involved in teaching, and are expected to do so at a low level where compatible with their research commitments.

45. A cohort of professional, long-term teaching fellows provides core support for the teaching programme and enables flexibility in allocation of teaching activities, for example when a research-active staff member takes on a new major research role or grant, without disruption to other researchers or degradation of undergraduate teaching. This is a new initiative, with strong support at Faculty level. A sabbatical is generally available to research staff once every seven years, though in practice many staff operate on reduced teaching loads more often than this, and indeed are supported on long-term attachment at major facilities, in recognition of the importance of such roles to our research strategy and output.

46. PA/LCN share a colloquium programme involving internal and external speakers, with each colloquium accompanied by a social event; SCP runs its own seminar series.

47. All newly appointed long-term staff (including teaching fellows) are allocated a mentor. A voluntary mentoring scheme is provided for PDRAs. Research quality and integrity are monitored via the appraisal system, and supplemented via grant reporting, training, staff meetings and informal group discussions. Central support is provided for key skills training.

c. Research students

48. PA and SCP each have postgraduate admissions tutors and a director of postgraduate studies. LCN has a postgraduate tutor and is in the process of becoming an “admitting department” for PhD students; many PA PhD students are based in the LCN. PhD recruitment and training are primarily organised at the research-group level, with specialist lecture courses and other training provided by research groups. Teaching duties in these courses have equal status to undergraduate teaching. We are involved in several bids for new EPSRC Centres for Doctoral Training. Thus all PhD students operate in cohorts of four-to-ten students per year in a given research area. Each PhD student has a primary and a secondary supervisor, and an online logbook system provided by the UCL Graduate School is used to monitor progress.

49. General training opportunities and career services for PhD students are provided by the UCL graduate school. The directors of postgraduate studies provide departmental oversight and liaise with the Graduate School regarding the needs of physics PhD students. Funds are provided at departmental and Graduate School level to continue training activities previously support by “Roberts” money, and to support travel to conferences, schools and seminars. Outreach, secondment and volunteering opportunities with political, educational and community organisations are encouraged, and supported financially where appropriate.

50. As of 31st October 2013, 145 PhD students are currently in post, of whom 72 are female. 43 of the students in post are funded under the UCL “Impact studentship” scheme, under which UCL matches funds attracted from industrial or other non-RCUK sources. This scheme has greatly enhanced PhD numbers and engagement with industrial partners. Over the assessment period, funding sources include STFC (69), EPSRC (55), NERC (3), UCL (12), EU (7), foreign scholarships (5), corporate (3), charity (14). Funded places are typically heavily oversubscribed with high-quality candidates. Joint funding of studentships with industry is common, including 6 CASE awards over the period.

d. Income, infrastructure and facilities

51. SCP maintains extensive world-class facilities for design, construction and testing of space-worthy instrumentation for **AP** and **SSP**, including a vibration platform, CAD facilities and a major clean room, which is also currently used by **HEP** for prototyping and construction of low-background detectors. **AMOPP** runs a positronium beam and several laser facilities. which include laser and molecular cooling labs as well as optical tweezers and ultrafast spectroscopy. Over the past two years alone, £1.5M has been committed for refurbishing labs in PA for AMOPP and CMMP. The LCN is an 8-storey building with direct access into PA, completed in 2005. The current REF period has seen major further investment in facilities including a 200 m^2 clean room including a Raith e-beam writer with optical stitching, numerous scan probe, optical and electron/ion microscopes, X-ray scattering, low-temperature and magnetic characterisation, back-end facilities such as probe stations, a wafer dicing saw, and an array of other equipment vital to a cutting-edge nanotechnology and condensed matter physics programme. Its atomic force microscopy facility is extensively used by researchers from the various major London universities, as well as by some industrial partners. The physics share of investment in this suite of facilities over the period is an estimated £2.5M.

52. The MAPS faculty maintains a faculty workshop containing 46 machines, staffed by four technicians (3.6 FTE). **AMOPP**, **CMMP** and **HEP** use around 2000 hours of workshop time annually, valued at £129,000. An important strategic goal for the next period is to upgrade these facilities and put them on a sustainable footing.

53. UCL has invested substantially in HPC provision, with the £4.5 million UCL “Legion” machine providing 5680 processors with fast shared memory and storage. Usage of this machine, as well as Iridis and Emerald, is managed competitively by the College Computing Resource Allocation Group. Academics in UoA9 worked on projects receiving more than 45 million core hours from the allocation over the period.

54. **BP, HEP** and **CMMP** are major strategic users of UK and international central accelerator facilities, in particular for neutron and X-ray scattering, as well as infrared optics. In each of these areas we lead the technical as well as the scientific agenda, for example through development of algorithms, software and experimental instrumentation. In **HEP**, Wing leads a small team involving fractions of the HEP technical staff in contributing to the readout electronics for the X-FEL at DESY, a project of significant interest to staff working in the **CMMP** and **BP** groups.

55. Between them, PA, SCP and LCN employ 65.78 FTE technical support staff for physics and 40.37 FTE administrative support staff, funded by a mixture of direct grants and departmental budgets. Balance between these and infrastructure expenditure is kept under review in the 5 year plans.
56. During the review period, 30 staff in PA/LCN and SCP held 50 consultancies, generating a consultancy income of £1.6M and a contract income of £9.5M. Consultancy activities are supported by UCL Consulting.
57. Of the research outputs submitted in this exercise, 20% made use of UCL HPC resources, 16% made use of national or internationl HPC resources, 28% made use of the technical support staff and infrastructure in PA, LCN or SCP, 12% made use of the faculty workshop, and 44% made use of large national or international facilities. Major resources not funded by UK research councils were obtained for much of the research, including more than 1.2M compute hours on the Chinook (HP 2310-Node Linux Cluster) at Pacific Northwest National Laboratory, more than 35M core hours at the JUGENE High Performance Computing Facility, beam time at Argonne National Lab worth over £1M, access to McMurdo Station and Amundsen-Scott South Pole Station, Antarctica, 12 nights observing time at the du Pont Telescope, Las Campanas Observatory, and unlimited time on the High Performance Computing Facility, CRAY XC30 (24,192 core) at the National Astronomical Observatory of Japan, significant observing time on many national and international space and ground-based instruments, and access to data from major high energy colliders and high intensity beams.

e. Collaboration and contribution to the discipline or research base

Scientific and industrial collaborations

58. Physics research is highly collaborative, and influential membership of major international collaborations is vital for success. Across all areas we aim for a mix of scientific leadership and technical excellence in world-leading collaborations. Major partners include ANL, BNL, CERN, DESY, ESA, ESO, FNAL, NIMR/Crick, NPL, PSI, Daresbury and Harwell Campuses, UCLH and many Universities and national research funders from around the world.
59. In **AP** and **SSP** we hold or have held PI, Co-PI, work package leader or equivalent roles in Cassini (Coates), Cluster (Fazakerley), DES (Abdalla, Doel, Lahav), EChO (Tinetti), EUCLID (Abdalla, Cropper, Joachimi, Kitching), ExoMars (Coates), HINODE (Harra), Planck (Peiris), Solar Orbiter (Harra, Owen), Venus Express (Coates) and JUICE (G. Jones, Coates). We have many additional team-leader and membership roles in these and other projects. We participate in the EuroPlanNet FP7 network, where Achilleos is a task leader. Savini is the leader of an FP7 network which has an IR instrumentation brief.
60. In **AMOPP, BP** and **CMMP** we have promoted the establishment of a cross-disciplinary facility exploiting our expertise in optical imaging, spectroscopy and optical manipulation in partnership with Cancer Research UK, the Francis Crick Institute, and the UCL Ear and Ophthalmology Institutes, the Hatter Cardiovascular Institute and with industries (e.g. Illumina Inc., PicoQuant GmbH). Cooperation with other groups, departments and centres in UCL (**AP**, Chemistry, Pharmacology, Biochemical Engineering) and national labs (e.g. Harwell and NPL) is common and is fostered by regular seminars. Our research benefits from a synergetic overlap with nano-biological activities in LCN and the NPL, as well as from the immediate proximity of leading biomedical institutes and institutions, such as the UCL/Birkbeck Institute of Structural and Molecular Biology, the UCL Cancer Institute, MRC Laboratory for Molecular and Cell Biology and UCH and Royal Free Hospitals. **BP** has become a significant presence in the Research Complex at Harwell, via a Harwell-based group (Ian Robinson) that uses X-ray diffraction to elucidate the structure of the chromosome. This is complemented by other research based on X-ray and neutron scattering experiments at large research facilities (McMorrow, Bramwell, Cacialli, Aeppli, Skipper, Thibault). We have made a professorial joint appointment with Diamond of Gerd Materlik, the ex-director of the facility, and are in the process of making a joint lecturer appointment with the ISIS group at Harwell. Robin Perry is a new UCL appointment based at Harwell, as part of a new UCL Centre for Materials Discovery. The opening of the Francis Crick Institute at St. Pancras in 2015 will bring the expertise of the MRC National Institute for Medical Research (NIMR), the CRUK London Research Institute (LRI) to within walking distance of our department and will significantly enrich both the physical and biomedical research environments. With multidisciplinary as a key value in its mission statement, it offers a number of possibilities for expansion of our activities. Llorente-Garcia was recruited as a tenure-track Excellence Fellow to carry out bridging activities

between the MAPS faculty and the Crick Institute, working closely with P. Jones. UCL staff will have the possibility to initiate/ participate in satellite groups at the Crick Institute, and **BP** members will play a part in this. Franco Cacialli coordinated an FP6 EU network on threaded molecular wires.

61. In **HEP** we provided ATLAS UK PI and deputy for two different terms (Butterworth and Konstantinidis), AWAKE Co-PI (Wing), CDF UK PI (Lancaster), g-2 UK PI (Lancaster), MINOS/+ spokesperson (Thomas), SuperNEMO spokesperson (Saakyan) and UK PI (Waters), and ZEUS spokesperson, (Wing). We are partners in the ERC-funded "Terascale alliance" led by John Ellis, and in two EU RTNs (MCnet and HiggsTools) which span experiment and theory.

62. Collaboration with industrial partners is a particular strength of the LCN and the London Thomas Young Centre for Materials Modelling (TYC) in **CMMP**. The LCN has direct links and common research projects worth £1.5M with 10 companies. 13 academics in PA and LCN are strongly engaged with the TYC, which works with around 40 different companies. SCP collaborates with industry on many space missions via ESA/UKSA and directly. An accelerator physics appointment (Jolly, **HEP**) has led to an involvement with the design and commissioning of the UCH hadron therapy centre. Also in **HEP** Nichol and Thomas are working on security applications of particle detectors, in collaboration with UCL SECReT, the £17m international centre for PhD training in security and crime science.

<u>Exemplars of Leadership in the Academic Community</u>

63. UK Research Council advisory roles include: **EPSRC-** Physical Sciences Strategic Advisory Team (Fisher); Quantum Technologies steering group (Fisher); Prioritisation Panel (Browne); Peer Review College: Bain, Barker, Bose, Browne, Cacialli, Fisher, Laricchia, McMorrow, Monteiro, Pickard, Schofield, Shluger, Skipper, Szymanska. **STFC** - Chair of ALMA Oversight Committee (Viti); Astronomy Advisory Panel (Lahav, Viti); Chair of Planetary Science subpanel, Astronomy Grants Panel (Coates); Committee reviewing STFC's grants system (Lancaster); Ernest Rutherford Fellowships panel (Page); ESA Science Programme Committee (Cropper) Chair of ISIS Excitations Selection Panel (McMorrow); Chair of ISIS Facilities Access Panel 5 "Molecular Spectroscopy" (Skipper); ISIS Review panel (Bramwell); Near Universe Advisory Panel (Matthews); Particle Physics, Astronomy and Nuclear subgroup chair (Butterworth); Particle Physics Advisory Panel (Wing); Deputy chair, Particle Physics Grants Panel (Lancaster, Wing); Particle Theory Grant Panel (Thorne); Physical and Life Sciences Committee (McMorrow); Project Peer Review panel (Saakyan); Public Engagement Review Panel (Miller); Science Board Chair (Thomas) and members (Aeppli, Butterworth, McMorrow); Solar System Advisory Panel (Achilleos); Space Science Advisory Committee Chair (Cropper) and member (Achilleos); UK BIS CERN Committee (Butterworth, Thomas); UK delegate to CERN Council European Strategy Group (Butterworth); Women in Science and Engineering Focus Group (Aruliah).

64. Non-UK-Research-Council roles include: **Astronet:** European Task Force on Laboratory Astrophysics (Tennyson). **Diamond Light Source** - Science Advisory Committee (McMorrow). **ESA -** Solar System Exploration Working Group (Fazakerley, Miller); **European Synchrotron Radiation Facility -** Science Advisory Committee (Vice-Chair) (McMorrow). **HEFCW-** Research, Innovation and Engagement Committee (Walker). **IoP -** HEPP group chair (Lancaster); Quantum Optics, Quantum Information and Quantum Control subject Group (Underwood); Science Committee (Lancaster). **International Astronomical Union-** IAU Commission 10 (Solar Activity) (President) (van Driel-Gesztelyi); IAU Division E (Sun and Heliosphere) (van Driel-Gesztelyi); IAU Division XI (Board Member) (Howarth). **Institut Laue Langevin -** Member of Scientific Council (Bramwell); Beamtime Selection Committee (McMorrow). **IUPAP -** C11 (Particles and Fields) committee (Lancaster); Magnetism Commission (McMorrow). **Joint Information Systems Committee (JISC) -** Geospatial WG (Chair) (Muller). **Public Communication of Science and Technology -** Scientific Committee (Miller). **RAS-** Vice Presidents (Howarth, Lahav); elected members of the RAS Council (G. Jones, Matthews, Miller). **Royal Society -** Fellowships Panel (Lancaster). **Royal Society of Chemistry -** Faraday Division Council (Nguyen); Royal Society of Chemistry (RSC) Colloid & Interface Science Group and Society of Chemical Industry (SCI) Colloid & Surface Chemistry Group- (Nguyen). **Space Action Network (SPAN) -** (Chair) (Smith). **UK Space Agency-** Aurora Advisory Committee (Chair) (Muller) (Member) (Miller); BepiColombo Management Board (Smith); Programme Advisory Committee. (Miller); Project Review Panel (Harra); Space Projects Review Panel (Williams). In total, members of staff have served in more than 150 peer review and advisory roles for national and international funding agencies including UK Research Councils, ERC, EU, British Council, US DOE, US NSF, NASA, L'Oreal; and the

Canadian, Finnish, French, Israeli, German, Greek, Polish, Portuguese, Swiss national funding bodies or academies.

65. Leadership roles in industry and commerce: External consultancy roles have been undertaken by 30 staff, several bringing leadership in industry, for example_non-executive director of BioNano Consulting and Fellow of the ERA Foundation (Aeppli), Executive Board Member, Canon Foundation Europe (Fisher).

66. University research advisory panels: 12 members of staff have held positions on University Advisory panels. These include Academy of Finland - Panel evaluating the status of research in Physics in all Finnish universities (Cacialli); Cranfield - UPS2 IKC Steering Committee (Walker); Durham - Chair (Butterworth) and Member (Thorne) of the Steering committee of the Institute for Particle Physics Phenomenology; Hertfordshire - Review of plan to launch an MPhys degree programme (Ford); Oxford - Physics Department external review committee (Fisher); Paul Scherrer Institute - Scientific Advisory Board (Aeppli); Stanford University - Chair (Robinson) and Member (Aeppli) Linear Collider Light Source; University of Oulu (Finland) - Interview panel member (Cacialli); University of Padua - Assessor for Strategic Research Projects initiative (€18 Million) (Cacialli); Warwick University - External Review of Condensed Matter and Theorectical Physics (Aeppli); York - External Advisory Board, Physics (Fisher); Zhejiang University - International Evaluation Committee, Physics Department (Aeppli).

67. Fellows of learned societies: Staff hold 27 fellowships in various learned societies, including: 1 Fellow of the American Academy of Arts and Sciences (Aeppli), 2 Fellows of the Royal Society (Aeppli and Tennyson), 17 Fellows of the IoP, 5 Fellows of the American Physical Society, 1 Fellow of the Royal Society of Chemistry, 1 Royal Academy of Engineering ERA (Aeppli).

68. Conference programme chairs and organisation: During the period, members of staff have chaired or been on the organising committee for 231 conferences, including for example “ICHEP 2010” and “EPSC 2009” (programme chairs), and “Deep Inelastic Scattering 2008”, “Icy Satellites of the Saturnian System 2009”, “IoP High Energy Physics 2010” (hosted at UCL).

69. Invited keynote lectures: 892 invited plenary talks have been given at major international conferences. Examples of prominent lecture and seminar series’ are: Lord Kelvin Award Lecture hosted by the British Science Association (Andrew Pontzen), Harold Jeffreys Lecture by the Royal Astronomical Society (Steve Miller), IPPP Young Experimentalist and Theorists Institute (Thorne), ETHZ Lectures (Hogan), Morrison Lecturer at the Brockhouse Institute at McMaster University, Canada (Aeppli), JC Bose Memorial Lecture, Saha Institute of Nuclear Physics, Kolkata (Aeppli), Scottish Universities School of Particle Physics (Campanelli), International Master in Nanotechnologies, CIVEN, (Cacialli). In addition, staff have given many talks at national and international conferences and workshops and within international collaborations.

70. Over the review period, UCL Physics staff have been awarded 64 prizes and medals, this includes 10 IoP awards: Astroparticle Physics Early Career Researcher Prize (Ghag), Chadwick Prize and Medal (Butterworth), Holweck Prize (Bramwell), Maxwell Medal (Parish, Bose), Mott Medal (Aeppli), Moseley Medal and Prize (Wing, Tinetti), Occhialini Medal and Prize (IoP & SIF Societa' Italiana di Fisica (Laricchia), Thomson Medal and Prize (Laricchia); 9 Royal Society awards: Brian Mercer Feasibility Award (Aeppli), Kohn Award (L. Green), Wolfson Research Merit (Bose, Butterworth, Lahav, McMorrow, Robinson, Tennyson, Thomas); 4 RAS prizes: Chapman medal (Fazakerley), Fowler Award (Peiris), Group Award (Lahav), Winton Capital Award (Kitching); 1 EPS: Europhysics Prize (Bramwell); NASA group achievement award for Cassini (Achilleos, Arridge, Coates, G Jones, Owen x 2), First discovery of methane in an exoplanet (Tinetti); 2 ESA awards: Certificate for Mars Express (Coates), Excellence for ESA-NRSCC DRAGON (Muller); Other awards have included Times Higher Research Project of the Year (Aeppli, Bramwell, McMorrow); Phillip Leverhulme Prize, Gruber Cosmology Prize (Peiris).

71. Fellowships: Over the review period staff have held 48 fellowships comprising of 1 BBSRC, 1 Diamond Light Source, 8 EPSRC, 4 Leverhulme, 24 Royal Society, 9 STFC, 1 Humboldt.

72. Journal editorships and advisory boards: Staff have held more than 59 editorial roles on peer review journals, including Journal of Geophysical Research, Materials Today, Nature Communications, Solar Physics, Proceedings of the Royal Society, Monthly Notices of the Royal Astronomical Society.

73. Staff have carried out 135 external examiner roles, the majority for PhDs both in the UK and abroad. Overseas institutions include Australia, Barcelona, Bombay, Georgia, Gottingen, Helsinki, Mauritius, Oslo, Paris, Toulouse. Major undergraduate examiner roles include Leicester (Coates), Cambridge, Oxford (Fisher), Edinburgh (McMorrow) and Imperial (Butterworth).