**Institution: University College London**

**Unit of Assessment: 9 - Physics**

**a. Context**

UoA9 at UCL comprises the Departments of Physics & Astronomy (PA, 93 staff) and Space & Climate Physics (SCP, 23 staff) based at the Mullard Space Science Laboratory (MSSL). In addition, 20 of our researchers hold co-appointments with the London Centre for Nanotechnology (LCN), which is a joint UCL/Imperial College initiative operating across the conventional subject boundaries in engineering, physical sciences and biomedicine. The UoA has a broad portfolio of research ranging from the directly applied, for example the design of new functional materials, to the truly fundamental, for example the search for hitherto undiscovered sub-atomic particles. Accordingly, the UoA can demonstrate significant impacts to a broad range of end-users and beneficiaries. These include business and industry, the media, the general public, school children and non-HE educators, the public sector (NHS, Government Departments), and policy makers. ***Economic Impact*** arises from our engagement with existing businesses and industry, and has led to improved performance and numerous new products, with beneficiaries including the aerospace, chemical, defence, energy, health, IT and transport sectors. Our space science programme has allowed us to act as a *de facto* member of the UK's space technology supply chain, providing key technologies under competitive contracts and a hands-on environment for the creation of a skilled workforce. Our Centre for Systems Engineering undertakes research, teaching, training and consultancy in the areas of systems engineering and systems engineering management, and is concerned with the issues involved in the development of complex systems within an enterprise context. IP and know-how generated by our research has been taken up to create spin-out companies, licencing agreements and new products. The associated underpinning research has enabled a portfolio of commissioned research contracts, problem focussed consultancies and professional training. ***Impacts on society, culture and creativity*** derive from the fact that many of our research topics attract strong public interest (including astrophysics, condensed matter physics, particle physics, space science); our formal and informal outreach programmes lead to improved public understanding of science issues and inspire the next generation of physicists. ***Impacts on practitioners and professional services*** include the influencing working practices and skills transfer**;** for example understanding of complex systems and their development has enabled training engagement with a broad range of industries (aerospace, defence, transport). ***Impacts on health and the environment*** have resulted from our research into diagnosis and screening, and have led to new and enabling technologies, while our space systems research has permitted us to provide process improvement recommendations within the health sector particularly related to hospital discharge planning.

**b. Approach to impact**

Within our UoA, impact activities are defined in the broadest sense and are formally recognised and rewarded via the appointments and promotions criteria. UCL's Enterprise Strategy, launched in 2011, has provided the framework for activities; enterprise is a fixed agenda item at all Departmental Board and Staff meetings, and is coordinated by a senior academic (currently Smith for SCP and Skipper for PA). Our workload model allows appropriate time credit for staff to further their enterprise and engagement activities by reducing their teaching/administration load. For example, Walker and Pankhurst were given full teaching sabbaticals while they established their spin-out companies Zeeko and Endomagnetics. In addition, academic staff contracts allow them to spend up to 40 days per year engaged in external consulting. Our UoA also makes extensive use of UCL's central support and resources for commercial and engagement activities, which enable our Departmental-level strategies. In particular: UCL Business PLC (UCLB), UCL's technology transfer company, support us in matters related to intellectual property including proof-of-concept funding, the creation and management of spin-outs, licencing, patenting and contract research; UCL Consultants Ltd (UCLC) facilitate and negotiate consultancy contracts; the Office of the Vice-Provost for Enterprise (OVPE) allocates research council Knowledge Exchange funding for activities including secondments, and development projects. We take advantage of UCL Impact Awards, a scheme that was launched in 2010 to bolster research student numbers and interactions with external organisations, through which UCL provides 50% co-funding for collaborative PhD projects with external organisations including charities, companies, government institutions and social enterprises. Our UoA is hosting 43 Impact Award studentships, and it is therefore a major

element in the delivery of our impact and engagement strategy.

***Fostering Links with Industry and Business***

Engagement with industry and business end-users is a cornerstone of the UoA's approach to delivering non-academic impact. Within the UoA, SCP and LCN have full-time post-holders dedicated to supporting business interactions; they are representatives on the Faculty Enterprise Forum, and proactively contact, and engage with potential partners through visits and hosting of networking events. In the LCN our Deputy Director (Business) initiated and manages our on-going relationships with 18 companies including BP, Linde AG, Lockheed Martin, Flexitallic, MI Swaco, and Nokia. In addition the director is complemented by our specialist advisory and commercialisation spin-out company, Bio Nano Consulting (BNC, registered company 06389520). BNC was founded in 2007, and is the first consultancy in Europe to focus primarily on the increasingly important intersection between bioscience and nanotechnology; its 2011-12 turn-over was £736k and on 31st July 2013 it had 8 FTE employees. Within SCP the Commercial Manager focuses on securing research and development contracts within the space sector (total volume since 2008, £4,365k), while within the Centre for Systems Engineering there is a business manager who coordinates bespoke training programmes (total volume since 2008, £634k). For SCP the on-going relationships include those with Astrium, BAE Systems, e2v, General Dynamics, Selex, and Ultra Electronics. The UoA's business/commercial directors are also experienced in IP and related issues, and work with UCLB to advise and support staff in this context. Individual researchers are often well-placed to create collaborative links with industry, and this is encouraged and facilitated at all levels.

Early-stage interactions with industry are catalysed through a number of joint- and fully-funded award schemes. The UoA has hosted a total of 65 PhD studentships with industrial or external joint sponsorship, with a total support of £2,041k over the REF period. Sponsors ranged from SMEs such as the drilling company MI Swaco who are investigating shale swelling inhibitors, to multinationals such as Chevron Oronite Llc who are interested in the surface binding properties and geometries of various molecules on metal oxide surfaces. We also have strong links with overseas industry, such as Infineon Technologies Austria AG (IFAT), who provide joint funding for modelling of point defects at wide-band-gap semiconductor interfaces with insulating dielectric materials. We encourage such projects to develop into longer-term relationships. [text removed for publication].. With Lockheed Martin, proof-of-concept funding was first used to develop adiabatic quantum computing, and has been followed by on-going PDRA-level support for algorithm development.

Over the period the UoA was awarded 18 knowledge exchange grants from institutional awards such as HEIF and the EPSRC Knowledge Transfer Secondments scheme, with total funding of £800k. These have supported activities such as in-flight demonstration of space technology, microscopic fluidic devices for rapid diagnostic testing of malaria, and secondment of researchers to QinetiQ, Illumina, and Quantemol. More established relationships are maintained and developed through mechanisms that include follow-on grants and joint funded discovery-to-use (D2U) projects, funded through the EPSRC Impact Acceleration Account. For example, we hold a D2U grant with Linde AG to develop bulk scale separation of high purity semiconducting single-walled carbon nanotubes that builds on our products already under licence to them.

***Commercialising our Research***

We have an established process for vetting and commercial exploitation of intellectual property. This begins with the submission to UCLB of an 'Invention Disclosure' form (31 since 2008) and is followed by an evaluation of commercial potential and discussion of possible exploitation routes (for example spin-outs or licencing) with the inventors. Patent submission and prosecution may then follow (11 filings since 2008). Flexible and encouraging equity and sabbatical arrangements within UCL and its departments makes establishing *spin-out companies* attractive to academics and the necessary support for spin-offs, including proof-of-concept and venture capitalist investment funds and helping with their governance and strategic direction is provided by UCLB. Over the REF period we have created or maintained 4 spin-outs: Zeeko (optical quality polishing), Quantemol (molecular detection and diagnostics), Cella Energy (clean energy storage) and Endomagnetics (cancer diagnosis). A second approach is *IP licensing*, which has been used to transfer carbon nanotube purification technologies to the Linde Group. In all, UCLB has closed 17 IP deals for the UoA's departments since 2008.

***Collaborative & Contract Research***

In cases where direct commercialisation is not appropriate, we adopt a flexible approach to gaining impact from our IP and expertise, and in many cases conduct collaborative and/or contract research at commercial rates. Since 2008, the UoA has successfully initiated/been involved in 89 such schemes (total value £9,545k), requiring either industry leadership or collaboration with partners. These are as varied as the European Space Agency (ESA), where we developed novel technologies for space plasma monitoring, and the gasket manufacturer Flexitallic Inc., with whom we are researching industrial sealing products. This approach has been particularly important to our delivery of benefits to industries including micro/quantum electronics (Nokia, Lockheed Martin), nanotechnology (Veeco/Bruker), space technologies (ESA, Astrium), cryogenic coolers (Astrium) and advanced optics (Media Lario Technologies). For example. UCL instigated a UK penetrator consortium in 2008 to investigate high velocity impact packages which included Astrium UK Ltd, SSTL Ltd and QinetiQ as industrial partners. Research was initially funded through a research council grant but has led to a series of research contracts from ESA, with Astrium as prime contractor and UCL providing specific technology-based services. The most recent success of the programme led to a very high profile trial of impact into ice in South Wales during July 2013 which received significant national media coverage. UCL used an IPS grant to develop the world's first flight level cryogen-free milli-kelvin cooler in partnership with Astrium. The cooler was supplied to ESA, and the transfer of knowledge to Astrium contributed to the winning of tenders from ESA (for example the International X-ray observatory assessment study) as well as programme of technology development for this consortium, managed by Astrium UK Ltd. We also have joint development agreements with advanced instrumentation and methodology-based companies. For example we have on-going collaborations with JPK Instruments on the development of high-speed atomic force microscopy (AFM), agreement with Bruker AXS/Veeco on cantilever development and AFM with atomic and submolecular spatial resolution and. In both cases, these partners have provided prototype instrumentation and free continuous technical support. With Numerical Algorithms Group, a major software business that works on computational and numerical solutions, we have provided distributed computational and scientific support as part of HECToR, the national supercomputer. Appropriate IP arrangements are put in place in a way which is mutually agreeable and does not distract from the underlying policy of flexibility, responsiveness and cooperation.

***Consultancy & Advice to External Bodies***

Expertise built up within UCL Physics has been transferred to external bodies through consultancy contracts, facilitated both by UCLC facilitation and our contractual allowances for academic staff consultancy. Selected examples include [text removed for publication]. In total the UoA has earned £1,685k from external consultancy or advisory roles. Considerable influence has been achieved through our expert advice to external bodies, especially those responsible for creation and implementation of policy and the direction of funds. For example, Smith informed the UK Space Agency National Space Technology Programme through committee membership, [text removed for publication] and Green has been a member of the Advisory Committee for the Science Museum.

***Industrial Training***

On the basis of skills and expertise developed through its research, our UoA has developed an extensive offering of Continued Professional Development (CPD) training programmes for industry partners. Typical provision involves 15 delegates on a 3-day course although the format is tailored as appropriate to the customers' needs. Since 2008, the UoA has delivered around 3050 person-days of training to UK-based companies including Astrium, BAE Systems, Devenport, General Dynamics, QinetiQ, and Ultra Electronics (UK, USA, Canada and Australia), and to overseas customers (ESA, Mahindra defence, Fundacion Chile). In a further example, members of the UoA provided BP with industrial training on computer modelling and simulation for 15 delegates via the Thomas Young Centre, and an on-line training course in systems engineering. This training, which constitutes a key component of the UoA's broader knowledge transfer activities, is mutually beneficial: as well as delivering direct benefits to the companies within which it is provided, the relationships that it allows us to foster with those companies help ensure their input into our research agenda. For example our input into the development of the INCOSE core competencies framework for systems engineering is based in part on our work in this area.

***Public Engagement***

This is carried out both directly (especially with schools) and via the media. P&A has a Schools' Liaison Officer, responsible for organising links between local schools and the department; within SCP this function is discharged by the departmental outreach coordinator. The UoA runs a yearly

work experience programme which involves more than 25, typically year 12, pupils undertaking one or two-week placements in either a research group or the teaching laboratories. During the census period 137 talks were given to schools, societies and related public events. PA runs weekly term time lectures via the UCL Science Centre; typically the audience is around 250 per lecture. The department also runs one-day master class events, such as the Particle Physics master class and the girls-only Dragonfly day. The University of London Observatory attracts roughly 800 attendees per year through public open evenings, school visits and the biannual Your Universe astronomy festival. The department encourages postgraduate and postdoctoral volunteering, in particular to support local schools through the organisation of extracurricular activities such as after school science clubs. UCL is the first university to be a sole sponsor of a school – the UCL Academy. We are developing strong links with science departments in the school, to place UCL staff and students in classrooms and give pupils access to PA and SCP, as well as beginning discussions on curriculum development.

Staff in the UoA are actively encouraged and supported in contributing frequently to public events, broadcast and the published media. Over the review period there have been over 190 media appearances. High profile examples include several editions of BBC Horizon and Sky at Night; events at the Latitude and Secret Garden Party music & literature festivals; participation in Science Festivals (such as London, Aberdeen, Cheltenham, Newcastle, Winchester, Big Bang Fair, Royal Society Summer Exhibition), contributions to science/comedy events at the Bright Club, and Science Show-off (organised by Steve Cross of the UCL public engagement unit) and the End of the World Show at Hammersmith Apollo and “Nine Lessons and Carols for Godless People” at Bloomsbury (organised by Robin Ince); numerous contributions to news media, including the Guardian, City AM, BBC Radio 4 Today, BBC News, Channel 4 News, GMTV and BBC Newsnight; and other BBC radio science programmes including Material World, The Infinite Monkey Cage, Frontiers and the Seven Ages of Science. We also address more targeted communities e.g. through publication in trade magazines and journals. Thanks to our leadership (Green) UCL was a “Beacon for Public Engagement” in the RCUK/HEFCE scheme which ran from 2008-2011. This led to UCL forming a very strong public engagement unit, responsible for several of the programmes above. The number and effectiveness of these activities is facilitated by strong links with this unit, and its members have spoken at our invitation in staff meetings and provide ongoing advice, training and other opportunities.

Our aim is to inspire interest in STEM subjects and encourage a rational view of the world making the general public more able to deal with scientific and technological issues that they face. Media opportunities may be responsive (for example when the media contacts UCL when an event happens in the world), or targeted (when UCL physics declares a result to the world and adds value through its explanation in a broader context). Media training is provided to staff so that they can actively engage with these opportunities. Staff are provided time to engage in public engagement activities, and are rewarded for their contribution in this field (for instance SCP makes an annual Elizabeth Puchnarewicz award for ‘Outstanding Commitment to Public Outreach’), and public engagement is an accepted part of the portfolio for promotions. The UoA hosts 2 Science in Society Ambassadors: Dr Maggie Aderin-Pocock & Dr Francisco Diego.

**c. Strategy and plans**

The UoA aims to encourage all forms of impact, from commercialisation to public engagement. A key element of our strategy is to record and reward our impact activities, but also to recognise that not all of our academic staff will become entrepreneurs or media stars. With this in mind the UoA’s impact strategy and targets for 2014 - 2020 are as follows:

***Support and Recognition of Impact Activities***: We will continue to record knowledge transfer and engagement activities, with the planned addition to our data collection of outreach visits to schools, exhibitions and public lectures. This information for promotion cases and ensure equitable revenue share, to encourage further staff participation and motivation.

***Commercialisation***: We plan to create facilities for SME incubators on the MSSL site [text removed for publication]. We will seek to create an enhanced space technology manufacturing facility at the MSSL site, which will be partly used to support at least one spin-out but will also include space for incubators and a much needed enhancement in capacity. This additional capacity will allow greater engagement with industry in terms of contract research and development. We will also seek incubator space to support PA commercialisation activities, with a target of 2 physics-based spin-outs in addition to taking our existing companies into revenue and

profit. These initiatives will be supported by our application for STFC impact acceleration funding. ***Continuing Professional Development*** (CPD): Our current programme is targeted largely at the aerospace and defence sectors. Following recent work in the health and social services sector (examining systems issues within hospital settings) we plan to create CPD in this field. UCL has appointed an Associate Vice-Provost for CPD, and we will work with them on expansion of our offer. Moreover, we plan to provide systems management courses that are accessible to the general public. Following a very successful CPD delivery in Project Management to the European Space Agency, we plan to provide a similar course to its prime contractors across Europe. ***Public Engagement***: We will continue to focus, both via the media and directly, on inspirational interaction related to our science programme. One of our academic staff (L. Green) will move into a post which is devoted 50% to outreach and policy. We will work with UCL's department of Science and Technology Studies and the new Department of Science, Technology, Engineering and Public Policy (which is joint between our Faculty and Engineering) to ensure UCL's research expertise inform public and political debates. We will continue our active Schools programme and Science Centre and develop strong ties will with UCL Academy school, a highly innovative initiative will form a natural vehicle to develop and disseminate novel outreach approaches.

**d. Relationship to case studies**

Our broad-based approach to impact is demonstrated in the 12 case studies that form REF3b. We have grouped these below according to the impact strategy headings discussed in section b. ***Commercialising our research:*** UCL09-WAL *Economic impacts of computer controlled polishing and metrology of ultra-precision surfaces*, UCL09-TEN *Growth and success of spin-out company Quantemol Ltd.* and UCL09-SKI *The formation and growth of the spin-out Cella Energy Ltd.* case studies demonstrate the creation of successful spin-out companies with an ongoing mutually beneficial relationship with UCL. UCL09-SKI2 *Enabling Linde AG to establish a new line of business in nanomaterials* is an example of close collaboration with industry underpinned by an IP agreement and including sponsored postdoctoral research. ***Collaborative and Contract Research:*** UCL09-COL *Enabling space companies to deliver contracts and supporting growth of the space sector* shows how UCL supports industry through the provision of specialist services which in turn enhances their competitiveness and has helped enable very large contracts. In the case study UCL09-SMI *Supporting e2v Ltd. in developing capability as a supplier for major space science missions* we show how we have added value in increased the market of commercial products and so helped secure very large purchase orders for the company. UCL09-BOW *Enabling Zyvex Labs to develop atomically precise manufacturing processes* and UCL09-SHL *Enabling SEMATECH and industrial member companies to improve their transistor technology* shows how physics research at UCL has contributed to the creation of new products in a technically challenging area. ***Industrial Training:*** The provision of a training and consultancy to industry is demonstrated in UCL09-EME *Systems engineering and project management training improving the performance of organisations*. ***Public and Media Engagement:*** UCL09-GRE *Stimulating public engagement with solar physics;* UCL09-BUT *Stimulating public engagement with physics through the LHC and discovery of the Higgs boson;* UCL09-LAH *Stimulating public interest in the dark side of the universe.* All show how we have engaged public interest in areas that are at the very leading edge of physics research at UCL.