Institution: Queen Mary University of London (QMUL)

Unit of Assessment: Physics (B9)

a. Context: Research in the School of Physics and Astronomy (SPA) is focussed in four Research Centres: the Astronomy Unit (AU); the Centre for Research in String Theory (CRST); the Particle Physics Research Centre (PPRC); and the Centre for Condensed Matter and Materials Science (CCMMP). The CCMMP is an integral part of the School and is central to its impact strategy, but also plays a leading role within the cross-faculty Materials Research Institute. It is being submitted to UoA13b as part of a multidisciplinary materials submission. A key strategic aim for the School is delivery of research that generates impact with high levels of significance and reach by *each* of the Research Centres. Our submitted case studies describe contributions from all Centres. CCMMP and PPRC research includes experimental and theoretical work that has proven and/or potential economic, cultural, environmental and health impact. The main non-academic users are PLCs, SMEs, museums and the general public. Research within the AU, CRST and PPRC aims to understand the fundamental physics of the Universe. We have harnessed its popular appeal to generate impact through developing educational resources and via direct engagement with school pupils, teachers and the public. A cornerstone of our activity is collaboration with artists whose physics-inspired artworks have led to secondary impacts on the viewing public.

b. Approach to impact

One of the School's primary objectives is to generate significant impact from its research. The SPA's Research Committee provides oversight of impact-related activities across the School. Research Centre heads monitor and report on the impact arising from research within their groups at regular Research Committee meetings, and the Director of Outreach coordinates public engagement activity across the School and reports on it to the Research Committee. The School encourages staff to follow their own unique research interests as the best means of achieving the novel insights and innovations that will have lasting impact. As illustrated below, our research, impact activities and interactions with non-academic users are well-established and wide ranging.

Real-world and commercial applications: Prof. Dunstan's spectroscopy research underpins the case study *Let there be light*. His innovations for Renishaw plc were brought to market through Dunstan initiating contact with Renishaw once prototypes had been built at QMUL, followed by collaboration with Renishaw for product refinement. Absolute Action Ltd contacted Dunstan seeking help on lighting public displays of gems. His rapid and insightful responses have led to an on-going consultancy. Current projects include illuminating the Alexandrite gems housed in the Smithsonian, and the design of algae photobioreactors for increased productivity of biofuels with QMUL biologists. Profs. Dunstan & Gillin have on-going collaboration with Renishaw and Absolute Action on developing laser sources for calibrating pain-levels in medical patients. Diabetes patients will be major beneficiaries, and there are applications to clinical drug trials. Gillin's research depositing conducting oxides onto substrates, with application to touch-screens, is supported by a Knowledge Transfer Account (KTA) part-funded by the tech-company M-Solv Ltd (£96K). His research on Erbium organic materials, with application to integrated optical circuits, is supported by a Proof of Concept (PoC) grant (£50K) in preparation for spinning-out a company in partnership with investors IP Group Ltd. Prof. Dove and Dr. Trachenko are developing novel simulations to examine radiation damage in materials with application to nuclear waste encapsulation and fusion reactors, supported by a KTA (£45K) and an EPSRC Pathways to Impact award (£22.5K), in partnership with the Culham Centre for Fusion Energy and the Nuclear Decommissioning Authority. Dove has a Knowledge Transfer Partnership grant (£194K) with CrystalMaker Software Ltd for modelling and visualisation software development. Dr. Baxendale's discovery of magnetic carbon nanotubes may have applications in energy generation and magnetic hyperthermia particles for cancer therapy. Patent and PoC applications have been submitted as a first step toward commercialisation, and a joint PhD studentship application with QMUL cancer specialists has been submitted. The development of imaging sensors for particle physics applications (Dr. Bevan, PPRC) is being expanded for applications in medical imaging. Collaboration with cardiologists from the London Chest Hospital has been initiated to explore application of particle physics pattern recognition techniques in diagnosing heart conditions from cardiograms.

Impact through education and public outreach: AU, CRST and PPRC research addresses fundamental physics questions, and has not yielded commercial impact so far. Instead we have

focused on realising impact through educational initiatives, public outreach and engagement with artists. A key motivation has been to support the STEM agenda, but also to bring research insights to the widest possible audiences to raise interest and awareness. The *Astronomy in the classroom* case study focuses on engagement with school pupils and teachers through activities initiated prior to 2008 but which carried on through the REF period. These form part of a larger educational and outreach programme that includes media appearances (e.g. B. Carr on 'In Our Time' BBC Radio 4; C. Murray on BBC One's 'Sky at Night' and 'Wonders of the Solar System' 2010, J. Emerson & C. Murray on BBC Radio 4's 'Material World' 2009), Twilight Research Seminars for teachers, and The Physics Academy where Year 12 pupils work on research projects within the School. The School has developed novel LEGO kits for teaching particle physics in the classroom that include posters, booklets and workshops for teachers. Over 600 LEGO kits have been mailed to schools nationally, and the LEGO booklets etc have been downloaded more than 2000 times from the School website. The LEGO has been used at the Big Bang and Manchester Science fairs and BBC Stargazing Live events to engage 100's of members of the public in our particle physics research.

Artist-engagement: The case study *String Theory and Particle Physics Reach a Contemporary Art Audience* describes impact on the practice of artists. Dr. Berman (CRST) has been exploring the art-physics interface since exhibiting sketches at the Royal Academy (2004) and curating an exhibition at Clare Hall (2008). Dr. Still (PPRC) has collaborated with artists since the 'Super-K Sonic Booooum!' installation reconstructed the T2K neutrino experiment at a London nightclub and the Manchester Science Fair (2009/10). The motivation for their on-going, hands-on collaborations and public lectures is to continue the historical tradition of interaction between sciences and the arts, introducing the complex ideas of modern physics to the contemporary art world. Future activities include exhibitions to be held at Chelsea Space, the Ruskin gallery and Somerset House.

School support for impact: The School encourages and enables impact by reducing the teaching/administration duties for staff involved in impact activities, or whose research shows impact potential. Sabbatical allocations take account of impact activities. Appraisal and promotion schemes use impact as an indicator of academic success. Much of the experimental research with potential for commercial application relies on investment by the School in labs/equipment. Projects have been supported by School-funded summer internships that focus on developing impact from research, and numerous fee-waivers have been granted for PhD students working on projects with high impact potential. The School hired an Outreach Manager in 2007, and a SEPnet-funded Outreach Officer in 2009, to support initiatives in schools engagement. They were instrumental in realising impact from our Cassini-related activities and in supporting the LEGO kit innovations through creating and maintaining contacts with schools and educational charities such as The Ideas Foundation and Creative Thinking. They have collected evidence of impact, provided support in workshops and maintained the outreach pages on the School website. A Director of Outreach (DoO) provides academic oversight of the School's outreach programme and reports to the School's Research Committee chaired by the Director of Research. The DoO develops strategy, ensures that research is embedded in outreach activities, and spearheads funding applications.

Institutional facilities and support: Queen Mary Innovation (QMI) negotiate agreements with industry to commercialise innovations arising from QMUL research. They have provided PoC funding for Gillin to develop his Erbium organic materials, and are assessing an application from Baxendale to support development of thermoelectric batteries. They have supported patent applications from Gillin and Baxendale, and have provided contacts on Chinese technology boards where Gillin has significant activity. ImpactQM is an EPSRC-awarded Knowledge Transfer Account that links researchers with industry partners. This has enabled Gillin to share his research with M-Solv Ltd, and Dove and Trachenko to transfer knowledge to the Nuclear Decommissioning Authority. QMUL's Business Development Office links business with academic researchers. In 2010 they provided the contact between Berman and artists Flow Motion, and in 2011 assisted in interviewing candidates for the artist-in-residence programme and drafted contracts for artists. QMUL's Communications Office offer advice and training for academics to maximise their communication skills, and provide the media with contacts through their 'Find an expert' list. They have provided media training for numerous School staff including Murray. QMUL's Educational Liaison and Access Office facilitated contacts between the School, The Ideas Foundation and local schools during the Media Space programmes described in the *Astronomy in the Classroom* case study. School researchers have used cross-faculty experimental hardware in their impact-

generating research: electron microscope (Nanovision); optical profilometer (Dentistry); and Seebeck coefficient measurement system (Materials Research Institute).

c. Strategy and plans

Economic impact and real-world applications: Research being conducted within the CCMMP and PPRC has potential for significant impact. A key strategic aim is to bring this to fruition through increased allocation of resources for those projects that continue to display promise. The financial stability of the School has grown during the REF period through increases in grants and student numbers, and a strategic priority is to deploy the School's operating surplus in creating a new research group in applied physics as a means of increasing commercial impact. With impact through invention of real-world applications being a key driver of strategy, we will appoint a Director of Innovation within the School to provide oversight and coordinate activities. The visibility of our impact-generating research will be raised by inauguration of an Annual Research and Innovation Forum, allowing researchers within the School to showcase their research and its potential impact. We will liaise with the QMUL Business Development Office to invite businesses, external stake-holders and interested researchers to raise the profile of our activities and initiate partnerships. We will support new interdisciplinary research through allocation of joint PhD studentships with other schools within QMUL, with priority being given to applications that show the greatest potential for impact. One new initiative of particular interest is the *Life Sciences Institute* (LSI), which will bring together all QMUL health-related research into a single institute from 2017. Our research on laser-calibrated pain-thresholds, cancer therapy delivery, imaging detectors and pattern recognition for cardiograms will have substantial overlap with the core activities of the LSI. Further avenues for involvement through the AU/PPRC's expertise on analysing Big Data will be explored. We will develop our academic/industry partnerships in China where we have already established a joint research laboratory at Sichuan University funded by EPRSC's Global Engagement programme.

Impact through public outreach and education: Our key strategic aims are to build on existing activities to enhance the significance and reach of their impact, and to initiate new educational projects that are underpinned by our research. A prime motivation is continued support for the STEM agenda. The AU, CRST and PPRC continue to be involved in high-profile research that has broad popular appeal. We are developing ideas for new activities in collaboration with the educational charity Creative Thinking relating to our research in extrasolar planets and involvement in ESA's JUICE mission to Jupiter. We plan to run summer schools for pupils from local schools that do not normally have opportunities to engage with astronomy research. We will continue the Cassini Scientist for a Day competition and increase the number of schools that submit entries. We will develop our Astrophysics Summer Schools by strengthening and broadening the links between the activities we offer school teachers and our expanding research portfolio, and we will create long-term partnerships to support research-based curriculum developments and extracurricular activities. At the present time new educational resources, activities and events relating to the PPRC's involvement in the discovery of the Higgs boson and neutrino experiments, aimed at a secondary school pupils across the year groups, are being developed. The School's arts engagement programme will build on existing contacts and target a broader range of funding sources to support activities. Being London-based provides opportunities for expansion. We aim to increase the number of academics and research topics involved in arts-physics partnerships, and reach wider audiences by increasing the number of gallery-exhibitions of our collaborative artwork.

d. Relationship to case studies

Let there be light: The research and innovations derived from it were conducted from 1996 onward, and are indicative of Prof. Dunstan's long-standing interest in developing commercial applications from his research. School support was provided through summer internships and final-year project students, and the time and freedom to pursue these avenues of enquiry.

Delivering Astronomy Research into the classroom: The astronomy research was conducted from 2000 onward. School and institutional support were central to this impact occurring (i.e. outreach staff and QMUL Educational Liaison time, lecture theatres and other space plus staff time provided at no cost). The activities were motivated by our strategy of supporting the STEM agenda.

String theory and particle physics reaches a contemporary arts audience: Derived from long-standing personal interests of Berman and Still, these activities were supported by the School through staff time, office space for the artist-in-residence programme, and display space in the School Museum. The QMUL Business Development Office provided support.