Institution: University of Cambridge

Unit of Assessment: B9

a. Context

The UoA has always believed in the importance of making sure that the outputs of its physics and astronomy research are relevant in the world beyond the university laboratory and has a long track record of demonstrating this commitment. The UoA's research impacts on a diverse range of non-academic beneficiaries, including industrial companies (established companies, start-ups, and consultancy organisations), policy makers, and the general public as well as having international reach, as will be apparent from the impact case studies.

The UoA has world-leading research groups in condensed matter physics including novel materials, semiconductor devices, and materials characterization, each with natural and department-led opportunities for **technology transfer to the relevant industrial sectors** through spin-out or licensing. Theory of condensed matter is another strength, with a strong track record of **commercialisation**. More fundamental research in quantum devices and cold atoms is relevant to impacts benefitting **society** fundamentally across a wide spectrum of applications, such as communications and commerce. The UoA has major activities in astronomy, astrophysics and high-energy physics, all contributing to **economic** impact. Recent strategic developments in biophysics and the physics of medicine are expected to generate impact in the field of healthcare, but it is premature to discuss their impact in our case studies, although licensing arrangements are already in place for a couple of emerging technologies. Another strategic priority is the Physics of Sustainability, supported by the recent externally-funded Winton Programme for Sustainability which will lead to significant impact in due course.

In addition to the mechanisms for achieving technology transfer and industrial collaboration which will be outlined below, the unit also supports its staff in achieving impact through influencing public policy, engagment and outreach.

b. Approach to impact

The UoA has a long track record of developing a strong interdisciplinary and applied research programme and its ethos encourages **industrial impac**t and diversification into new fields, in line with but in advance of the recommendations of the 2008 Wakeham Review. Our approach is to draw on other disciplines to ensure we can deliver impact. In practice this means that our strategy maintains an inclusive vision of what constitutes physics research, keeping within the UoA activity that elsewhere might be pushed out to materials, chemistry, engineering, biomedical sciences or even the social sciences. We continue to focus on fundamental research but always with an eye on where there may be opportunities for exploitation and then ensure that through our networks of contacts such exploitation occurs. This benefits the activity by maintaining a clear core of physics at its centre, and allows the UoA to engage with a wider range of beneficiaries than would be possible if it restricted its activity to "pure" physics and astronomy.

Technology Transfer and Industrial Collaboration The environment for encouraging impact at Cambridge, and in the UoA in particular, is characterised by strong support for technology transfer, industrial engagement and public engagement activities, accompanied by considerable flexibility in the mechanisms that individual staff and research groups are able to apply to achieve impact. The UoA recognises that **industrial** and **economic impact** can be achieved in different ways, with the optimum strategy depending on the nature of the research, the requirements of the funder, and the motivations of the investigators involved. Different strategies, supported by the UoA are illustrated below.

The University's vehicle for technology transfer is Cambridge Enterprise (CE), a company wholly owned by the University. CE works within the University's Intellectual Property Policy (substantially revised in 2005). This policy requires disclosure of, and asserts University ownership of, registerable IP (patents), in order to ensure that inventorship is fairly established, that obligations to sponsors are honoured, and that an equitable return is made to inventors and to the University. This generous return and flexibility in approach has proved important in encouraging and rewarding entrepreneurial activity within the UoA and in attracting staff with entrepreneurial inclinations from other institutions. Cowburn, with prior start-up experience when he arrived in 2010, comments that the unusual Cambridge model encourages creativity, risk-taking and the

formation of high-impact businesses, not least by allowing the inventor to exploit their invention independently if they desire. Additionally CE, being wholly owned by the university, is less constrained by 'shareholder' interests in taking inventions forward than other models. **Overall, during the census period there have been 62 IP disclosures, 29 Patents filed, 48 IP transactions signed, 21 revenue generating licenses agreed and close to £1M returned to the UoA through licensing agreements,** reflecting the high level of activity in IP-related activities within the UoA.

Beyond simply managing the technology transfer process, CE provides training on technology transfer, and specific advice on strategy for individual technologies through meetings and IP clinics. It facilitates consultancy through negotiating contacts, invoicing and providing professional indemnity insurance in return for a small percentage fee. CE also manages a Seed Fund for up to £125k funding to university start-ups as a convertible loan or in return for equity in the first instance: 7 PIs have been awarded funds for such Proof of Concept work during the period. Payne is the **CE "Champion"** within the Department, promoting CE's activities and facilitating individual interactions; Friend was a **Director of CE** from its founding until 2012.

The importance of innovation and entrepreneurship is embedded in our culture: it is simply seen as something which the best physicists in the UoA are expected to do. Our case studies include several examples of successful technology transfer through the traditional start-up model (**CDT**, **TeraView**, **Plastic Logic**, **CASTEP**, **Cavendish Kinetics**). These activities are driven by the quality and innovative nature of the underpinning research and by the entrepreneurial flair of the individuals responsible supported by institutional policies: in addition to the University's generous IP policies, start-up activity is assisted by the University's liberal policy on external work undertaken by its academic staff, which is constrained only by the requirement that it "must not interfere with the performance of the duties of the office". This allows staff to engage heavily with start-up activities in their initial stages and to retain a role as the company develops. In certain cases (e.g. Duffett-Smith, associated with **Cambridge Positioning Systems** case study), the UoA has also allowed staff to take extended, unpaid leave in order to work full-time for a start-up. It is important to note that the spin-outs have been much more than one-way technology transfer events; instead they have led to ongoing research collaborations and have formed the basis for joint bids for external funding to further the work. For instance **Plastic Logic** and **CDT** (see case studies) have both been involved in TSB-funded programmes in collaboration with the UoA.

Given the long timescales often involved in the development of technologies, the development of durable bilateral relationships with large companies with strategic technology interests related to research interests in the UoA is often effective. The embedded Hitachi Laboratory (**Hitachi** case study led by Sirringhaus) represents a collaborative activity (set up in 1989 and still going strong) with the aim of creating new concepts in advanced electronic and optoelectronic devices. The Toshiba Research Laboratory was established at the Cambridge Science Park in 1991. Its major aim, in collaboration with UoA researchers (**Toshiba** case study led by Ritchie), is to develop novel devices which directly exploit the laws of quantum mechanics in their operation, and there is a constant flow of knowledge and students between the Cavendish and the Toshiba Laboratory.

The **Winton Programme for the Physics of Sustainability**, started in 2011 through a £20M donation from David Harding of Winton Capital Management, is seen as an increasingly important vehicle for impact delivery. The programme aims to support research that explores the basic science able to generate the new technologies and industries needed to meet the demands of a growing population (further details are in the Environment template). It is overseen by an international advisory board to ensure that its international reach and positioning is as effective as possible. Each year a **Winton Symposium** is held to bring together the community both within and beyond Cambridge to stimulate new interactions.

The **Laboratory for Scientific Computing** (supported in part from the University of Cambridge's HEIF allocation) is an activity that connects particularly strongly to applied and industrial problems, with key links to Government agencies such as the Met Office and defence establishments such as AWE. This group moved from the Maths department in 2008 and the relevant impact case studies are not based in this UoA, but the continuing application of hydrodynamic, detonation and flow simulations continue and new end-user partners continue to be sought.

We are strongly engaged with national laboratories (eg NPL), companies big and small, and, through EU Consortia, this includes industries beyond those with a UK base. There are numerous

examples of CASE studentships (more than 28 with 12 companies since 2008) and fully-industrially-funded students supported within the UoA. The UoA recognises the need to seek out new industrial partners, to inform them about our research directions, and to learn about their needs. To facilitate this process, the Cavendish employs a **Knowledge Exchange Programme Co-Ordinator** (funded in part with HEIF money) to manage this process. He organises the **Cavendish Laboratory Industry Engagement Forum**, sponsored by CE, where selected companies are invited to one-day events at the Cavendish in order to identify and brainstorm problems of common interest. Recent participants include BP, Unilever and AWE. These Forums are particularly designed to engage postdocs and PhD students in the discussion, and hence provide a training element in addition to their primary aim.

A well-recognised problem in physics-based technology transfer is the so-called "valley of death" bridging between scientific discovery and profitable exploitation. The UoA has engaged in an innovative approach to bridge this gap to solve this problem, through the **Cambridge Integrated Knowledge Centre in Advanced Manufacturing Technologies for Photonics and Electronics** (CIKC--joint with the Engineering Department), co-funded by the EPSRC and industry: Sirringhaus, Friend and Greenham are all involved. Through CIKC funding in the Judge Business School and the Institute of Manufacturing, new routes for providing commercialisation advice and research into the process of technology transfer have been established. The CIKC has been particularly effective in supporting organic photovoltaics development (**Low Cost Solar Cells** case study). CIKC now continues as part of the **EPSRC Centre for Innovative Manufacturing in Large-Area Electronics**.

The UoA also recognises the impact that arises simply from the **open publication** and dissemination of research outputs. Whilst this form of impact is more difficult to quantify in terms of financial returns and geographical location, it is often the most effective in terms of the overall goal of promoting all kinds of impact. The University's IP policies allow freedom for staff to choose this route, subject to the requirements of the research sponsor; **Dasher** (case study) is an example of effective use of this route. For software licensing, hybrid models can be particularly effective, allowing open access to code for academic use whilst licensing on commercial terms to for-profit organisations (**CASTEP** Case Study).

The success of Cambridge University in transfer of technology and trained people has been a key driver behind the clustering of high-tech businesses in and around Cambridge (variously known as Silicon Fen, The Cambridge Phenomenon or The Cambridge Cluster). One of the key players in this ecosystem, Hermann Hauser (founder of ARM, the world's leading semiconductor IP supplier), is a Cavendish PhD graduate who has always maintained close links with the UoA. This clustering provides important advantages, such as the availability of high-quality space, locally-generated IP, and the network of technology and services suppliers that allow rapid technology development; the UoA has supplied many researchers to these companies, thereby encouraging two-way flow of information and a low activation barrier to starting a new venture with top-quality staff. These factors have proved particularly valuable in the spin-out of **Eight19**. Ventures such as **CDT** and **Plastic Logic** are widely recognised as important exemplars of the Cambridge Phenomenon. In addition, a distinctive feature of the Cambridge Cluster is the presence of consultancy companies such as TTP, Sagentia and Cambridge Consultants, offering high-tech product development services to other companies. These consulting companies have close links to the UoA, and continue to recruit our graduates, particularly PhD graduates.

Consultancy In addition to their roles in direct technology transfer, many members of staff are engaged in consultancy for companies with needs for their individual expertise. The UoA and University support this activity by not attempting to regulate it but offering the services of **CE** to facilitate it if requested as described above; this service has been used by many of the UoA's staff (over 40 consultancy agreements have been signed during this period). Such consultancies bring benefit by nucleating research collaborations and ensuring that staff are aware of the current needs of industry.

People and Training A key mechanism for achieving impact from physics research is by transferring it as knowledge and skills to people via training, with students, postdocs and more senior staff moving from the UoA to positions in industry. (Research frequently directly informs undergraduate teaching material, mainly in the later year options, making sure the students are exposed early to the nature and importance of research. See also the **Teaching Biological Physics** case study.) This pathway is hard to capture in the case studies, but its importance

should not be underestimated. It has been the lynchpin for many long term industrial partnerships and funding into the UoA (eg Unilever, Schlumberger), as well as being an important factor for alumnus David Harding (CEO of Winton Venture Capital) in making his generous funding to the Winton Programme. Additionally, ex-UoA researchers have taken up key roles in spin-outs (eg, from the case studies, Burroughes as CTO of **CDT**, Doran at **Geomerics** and Reynolds at **Eight19**). Whilst the primary value of such people is their ability to problem-solve using analytical approaches, we increasingly recognise the necessity to provide them (whether at undergraduate, PhD or postdoc level) with training in the basics of intellectual property, innovation, and technology management. An **Entrepreneurship module** has been available to final year physics undergraduates for some time, which has now been exported by the Judge Business School to undergraduates in other subjects. All PhD students in our Doctoral Training Centre in Nanotechnology, plus some from the CIKC funded course, take the Management of Technology & Innovation course offered by the Judge Business School. The UoA also recognises the importance of exposing its ECR's to the ideas of entrepreneurship, knowledge transfer and industrial collaboration. Whilst for the UoA's graduate students the most common single destination over the past 35 years is into tenured academic posts, around 25% enter industrial, commercial or financial fields, ensuring knowledge transfer from the UoA's research into the industrial sector.

Policy The UoA has a strong track record of encouraging its staff to engage with **public policy**, thus achieving impact through the influence of research on policy decisions. Indeed, it currently has one MP (Huppert), one member of the House of Lords (Rees), and recently one Departmental Chief Scientific Adviser (Mackay, moved to Engineering in 2013) associated with it. Mackay is an outstanding example of how a member of the UoA has had an impact on policymakers. His book "Renewable Energy Without the Hot Air" is widely recognised as a landmark in applying quantitative physical reasoning to the discussion of energy problems and in itself represents real impact in Whitehall and beyond. Since 2009 MacKay has been 80% employed as CSA in the Department of Energy and Climate Change. Another example of impact through policy is Huppert, on following his election as MP for Cambridge. As the only MP elected directly from a scientific career, he is active in promoting evidence-based policy in a range of areas. The University's and UoA's leave policies have been instrumental in achieving this, with **Public Service Leave** available for a period of up to 5 years to allow staff to return to their academic positions following such an appointment. Other members of staff work closely with the **Cambridge Centre for Science and Policy** (CSaP), whose aim is to broaden academics' engagement with policy makers. CSaP fellows (key decision-makers from government and industry) regularly visit the UoA to discuss policy interests with relevant individuals. Over the last 2 years there have been more than 50 meetings held between UoA members and visiting CSaP Fellows. Rees is a member of the CSaP Executive Committee.

Donald as Chair of the **Royal Society Education Committee** has been closely involved with discussions over curriculum and assessment reform in school education and has frequent meetings with DfE and BIS officials. The UoA's strong commitment to pedagogy can be seen in the **Cambridge Rutherford Schools Physics Project** led by Warner, in which the DfE is investing £7M over 5 years to develop the skills of sixth-form physics students. The **Outreach Officer** is a key player in the project, which additionally aligns with two sister initiatives, the **Cambridge Mathematics Education** project (also with DfE funding of £5M) and **"i-want-to-study-engineering.org"**, supported by the Underwood Trust. Warner has also been the driving force behind the **Senior Physics Challenge** over the past 5 years, a week-long residential course aimed at inspiring bright sixth formers from schools without a tradition of sending students to Cambridge to apply to study physics.

Outreach, Public Engagement and Media Interactions Effective **communication to and engagement with the general public**, including schoolchildren, of state-of-the-art physics and astronomy research is a form of impact strongly supported by the UoA through the provision of communications' training at all levels and through innovative outreach programmes; weekly IoA open evenings during winter months for public observing; and participation in the annual Cambridge Science Festival. The overall philosophy of encouraging outreach/public engagement by a variety of routes, including social media, is deeply embedded in the UoA's culture and has been for more than two decades. The expectation of the involvement of post-graduate students and postdocs in events such as Physics at Work, Lab-in-a-Lorry, the Cambridge Science Festival

and STEM ambassadors, is well-recognized and supported by UoA, which invests in 1.5 **outreach officers**, one in Physics and a part-time post at the IoA to ensure successful delivery. The Cavendish Laboratory has been running **Physics at Work** (see case study) for schools for more than 25 years. Year on year more than 2500 schoolchildren, mainly Y11's, pass through our doors to learn from around 25 exhibitors from industry, the public sector and the university. Each exhibit has physics at its heart and many senior Cavendish academic staff are involved each year. The Institute of Astronomy likewise has open evenings every winter week to entice the public in to its premises to be excited by the stars, and has a whole series of other public events to engage with the local population

Aside from these large-scale activities, many individuals take part in media-based activities, as well as individual visits to schools and science festivals. These more individual activities are strongly supported by the UoA and are recognized within the workload model for staff. For instance, around the work at the LHC Parker and Gibson have participated in many broadcasts, from Today and In Our Time to Start the Week, to explain what the experiments and results imply, ensuring that the wider public can appreciate the basic research. A number of staff have appeared on the radio and TV talking about their science, on programmes like Material World, The Life Scientific and the Sky at Night, as well as more generally about life in science on programmes like Desert Island Discs. Donald is a regular contributor to Guardian Science Blogs and other mainstream newspapers.

When high profile papers are due to appear, staff work with the University's **Office of External Communications and Engagement** to get publicity for their stories; many staff have participated in interviews for broadsheets or had their research described there. As a specific example Steiner's work on structural colours was featured in print (Times, Daily Mail, Guardian and Independent) and picked up by agencies around the world, as well as featured on BBC Look East. Such stories may also feature in the university's Research Horizons as well as the Cavendish's CavMag for alumni. Many other members of staff have similarly participated in interviews on TV, radio and in the press to talk about their work. During the REF census period, 4 different groups have exhibited (following a highly competitive application process) at the Royal Society's Summer Science Exhibition; such exhibits require a very substantial input from staff and students alike. The strong links between the UoA's high energy physics research and the Science Museum have led to the Museum's first ever fellow (working under the direction of Gibson), working on an upcoming exhibit about the LHC called Collider, due to open in autumn 2013. Donald is a Trustee of the Science Museum; Rees preceded her.

c. Strategy and plans

The UoA will continue to support impact as outlined above, supplemented by two major strategic plans which will enhance our approach. One is in hand – the **Winton Programme for Sustainability** – the other is about to get underway: the **Maxwell Centre**. Both of these are highly interdisciplinary, involving departments around the university but led from this UoA. Additionally, our training programmes will be significantly expanded by the award of two new EPSRC Centres for Doctoral Training in **Sustainable and Functional Nanotechnology** (building on the current DTC) and **Computational Methods for Materials Science,** which fit in closely with the UoA's strategic directions as well as having the potential to develop significant impact in due course. The Winton Programme will underpin the UoA's key strategic priority of the Physics of Sustainability. As more scientists are recruited, this developing activity is expected to generate both **environmental and economic** impact, building on the existing impact in the field of photovoltaics. Over the next few years this will represent a significant growth area of research within the UoA, strongly embedded in an entrepreneurial culture and with a key aim the 'output' of innovation in this key area, but it is too early to submit a case study in this area as yet.

The Physics-led Maxwell Centre will be the centrepiece for industrial partnership with all of the university's physical sciences, housed in a new purpose-built building located adjacent to the Cavendish Laboratory on the West Cambridge Science and Technology Campus and funded jointly by the University and a £21.6M HEFCE Research Partnership Infrastructure grant. It is expected to be completed in 2015. The aim is to double the level of industrial involvement through a combination of activities in the new building, in the collaborating Departments and in the commercial space on the West Cambridge site (the site already accommodates the recently completed **Hauser Enterpreneurship Centre** and CE). The industrial research, development and

manufacturing will generate an economic impact enormously greater than the co-investment committed to the programme. This new building will consolidate and significantly expand university-industry interaction space, and create a state-of-the-art central laboratory space for joint collaborative projects between internal and external users. By creating new, dedicated space where industrial partners can spend significant time, it will facilitate dialogue and serendipity to drive new areas of research and innovation.

The IoA's importance for future delivery of impact is highlighted in the recent Witty Review which specifically cites it (the IoS was ranked first in the Satellite sector in the citations analysis carried out by Witty) as having a direct relevance and impact to 'Satellite and commerical applications of Space technology' - one of the Government's eight great technologies - and of vital importance for the future economic wellbeing of the country. Additionally, there are several key cross-university initiatives which are well-placed to produce impact in the near future, although they (like the Winton Programme) are too early stage to identify key impacts yet. These are the **Energy@Cambridge Strategic Initiative** (supported by two new university-supported coordinators), which is bringing together key players across the University (including many from this UoA) with the goal of facilitating innovation in the energy arena; the **Big Data Strategic Initiative,** crucial to Astrophysics and High Energy Physics and led from the UoA but reaching into several other Schools; the **Cardiovascular Health Initiative,** which involves Simons; and the **Synthetic Biology Initiative** which has representatives from the UoA on its steering committee. This latter is closely allied to the less formal **Physical Biology grouping** across the university which will facilitate translational outputs from the physical sciences including this UoA. The UoA has used funding from the EPSRC Impact Acceleration Account and similar funding awarded to the University to promote impact, through Knowledge Transfer Secondments of researchers (7,5 outward and 2 inward, involving both large (e.g. Toshiba, Hitachi) and small (e.g.Glovebox Technology Limited) which provide opportunities for the extensionand exploration of results of EPSRC funded research projects toindustrial/commercial projects. The Department is currently extending its Knowledge Transfer support by recruiting a further, full-time, KnowledgeTransfer Facilitator to complement existing provision.

d. Relationship to case studies

The freedom provided by the over-arching University policy to choose the development route suited to a particular application, and the support of the UoA for whichever choice an academic makes, is central to the success of innovative physics-based developments. Different case studies have taken advantage of this in different ways, ranging from the publicly and freely available research used in **Dasher,** to **CASTEP**, whose software is freely available to academics but licensed on commercial terms to for-profit organisations. Versatility and agility are crucial factors in the success we have enjoyed in innovation and impact, as exemplified by Friend's various spin-out companies (**CDT**, **Plastic Logic** and **Low Cost Solar Cells** case studies all stem from his work). His commitment to such work is shown by his leadership of the Winton Programme and the Maxwell Centre. Our continued support for **technology transfer to the relevant industrial sectors** through spin-out or licensing is exemplified by these same case studies plus **Teraview** and the transformative effect on the UoA's impact approach is illustrated by new models for collaborative technology transfer developed through CIKC.

The UoA has major activities in astrophysics and high-energy physics, all contributing to **economic** impact through applications of their techniques and technologies in other fields, e.g. data handling and analysis, imaging, positioning systems and advanced model optimisation (exemplified by **Grid Computing**, **Dasher**, **Geomerics** and **Cambridge Positioning Systems** case studies). Theory of condensed matter is anotherstrength, with a strong track record of **commercialisation** of electronic structure modelling software (**CASTEP** case study). Our strategic plan of helping society to develop its understanding of the nature and value of science is illustrated by the successful development and preparation of teaching material in this field (**Teaching Biological Physics** case study). Because outreach work is so central to our activities, one specific example – **Physics at Work** – is highlighted in the impact case studies. This is the activity for which year-on-year over many years the UoA has gathered quantitative data on its success and how it is perceived, both by teachers and the pupils attending.