Institution:	University of Warwick (UoW)
Unit of Assessment:	UOA 9 Physics

a. Context

The Warwick Physics Department conducts research across astro-, particle, plasma, condensed matter and materials physics. As a result, our research and expertise is relevant to diverse user groups in application areas such as energy, materials, electronics, pharmaceuticals, as well as satisfying curiosity to understand how the universe functions.

The Department was originally built up around Physics for applications, especially the physics of materials, so impact has always been central to our ethos. A change in recent years has been more emphasis on business innovation, seeking to seed future economic growth and employment through creating new companies, whilst we retain a strong focus on collaborating with established businesses. We have a strong tradition of using major external facilities, and have contributed to their development to generate impact beyond academia. Research-based outreach is delivered enthusiastically to the general public, and has been invigorated by broadening of the Dept. into areas of strong public appeal, such as Astronomy and Particle Physics.

b. Approach to impact

Impact beyond academia is embedded, rather than managed as a bolt-on activity, and we use a number of approaches for engaging new non-academic parties. These range from bottom-up networking events and international conferences organised by individual academics and financially supported by the Department, through to contracts that are channelled via the University's technology transfer, corporate relations and business engagement units.

Business Engagement.

The **Science City Research Alliance** (SCRA) provides a focus for business engagement across much of our condensed matter activity. Set up in Warwick & Birmingham, with support from the European Research & Development Fund and by Advantage West Midlands, it provided a £58 M investment in state-of-the-art equipment, housed in purpose-designed buildings that represent a significant new investment by UoW (£24 M Materials & Analytical Sciences, £5 M Milburn House Magnetic Resonance Centre) with dedicated technical support and HEFCE funded (£10 M) research fellows. Companies can access the equipment and expertise that they need for their materials' analysis, thus tackling a range of commercially driven research challenges that would not otherwise be possible for them. Dedicated Business Engagement Managers encourage activity in three main themes: Advanced Materials, Energy Futures, and Translational Medicine. Our research underpins large sections of the first two of these and Warwick Physics has supplied the SCRA Director for the entirety of the project through secondment of **Thomas** and, since 2011, **McConville**. To date, SCRA has worked with 180 businesses on in-depth activities (KTPs, consultancy, analysis, product development, collaborative research) and run over 150 workshops including business breakfasts, 'discovery days' and industry focused seminars. As a result many academic research projects have been initiated or steered to satisfy the company's requirements. Physics has interacted with SMEs, 3Cs, IQE, Irisys, Micronics, Paintbox, Sandvik Hard Materials, and household names mentioned below. 12 new businesses and over 350 new jobs have been created – the majority in high-technology businesses in the West Midlands.

In a parallel development for high performance computing, we have a long-term agreement with IBM through our MINERVA project, whereby IBM act as intermediaries for commercial access to some of the regional scale HPC resources available through our *Centre for Scientific Computing*.

We have successfully nurtured **start-up companies**, employing a simple facility agreement that allows these new ventures to flourish. Within this model, *Circadian Solar* [Case Study #2] could easily access the Dept's infrastructure (worth over £500 k) before 'leaving home' and becoming a fully independent, multi-million pound, company funded by venture capital. The company then benefitted from incubation space in the UoW Science Park for 6 years. By contrast *Sonemat* [#3] remains intimately connected with the Dept., acting as the commercial face for our ultrasound and NDT research and as a conduit for exploitation of our IP.

Staff work with *Warwick Ventures* to **identify and protect IP**, with 18 different patents having been filed since 2008 e.g. novel photovoltaic source, germanium membranes, diamond sensors, non-contact ultrasound. By securing the commercialisable IP arising from our academic research we

can offer appropriate protection to companies engaging with us, so they could potentially exploit it. This is the main benefit of protecting IP: direct royalties are welcome but secondary. With limited resources to invest in full (as opposed to less expensive interim) patent protection, we have used a licencing model whereby we devolve securing full patent (with a licence back to us) to the licensee on the basis that such a commercial decision is best taken by the commercial partner.

In our wider **commercial activities** the UoW *Research Support Services* assists with contract negotiation. We have moved to simplify our contracting, offering minimal simple contracts for small facility usage which has generated real returns in external funded usage of and better overall use of facilities such as XPS and Electron Microscopy.

Industrial Collaboration.

We engage directly with a wide set of **established companies** and organisations on an open collaboration basis, and enter more-commercial partnerships with a few to drive new ideas to market. In NMR, we collaborate with the pharmaceutical industry to establish new diagnostics and improve products. Astra Zeneca, GlaxoSmithKline, and Daiichi Sankyo have all now adopted our high-resolution ^{1}H solid-state NMR methodology in their development of active pharmaceutical ingredients [#4]. Our solid-state NMR has also been key to a major company's long-term investment strategy in what could become a multi-million pound catalysis business.

Diamond research with Element 6 has produced a string of 13 joint patents and diamond based products for E6 Technologies worth £37 M since 2008 [#6]. This interaction was promoted by granting study leave to **Newton**, who now also leads the EPSRC *CDT in Diamond Science and Technology* that will bring together industrially supported PhDs from across the country. A novel methodology for gem identification is also being developed with the Gemological Institute of America that could replace manual inspection with commensurate savings.

Building on our solids oriented ultrasound research, Elster funded a Chair to develop new opportunities in industrial fluid measurement applications for which **Dixon** was released from other commitments to spend time with the company. Ultrasound also collaborates with a wide range of companies working in power generation, petrochemical, nuclear and aerospace [#3], both through the UK Research Centre for Non-Destructive Evaluation and EngD company placements. With Warwick Engineering, and following 'focus group' consultations with a wide range of companies, in 2011 we set up a *Centre for Industrial Ultrasonics* that already embraces 25 companies.

Our Centre for Fusion Space and Astrophysics (CFSA) is unique as a Plasma Physics group dedicated to spanning applications in both Astrophysics and in Fusion Power, built around collaboration with Culham Centre for Fusion Energy (**Dendy**). Despite fusion research having a long time horizon, the promised eventual impact is extremely high; meanwhile, CFSA also deliver impact by training the next generation of fusion researchers and by using codes developed for fusion plasma research as a springboard for impact in other areas.

Other significant companies/agencies with which we collaborate include AWE, BP, Cameca, CCFE Corus, Cummins, DeBeers, DERA, Element 6, GSK, Ionoptika, Inteq, Intrinsiq, JET, JLR, Johnson Matthey, National Nuclear Laboratory, Network Rail, NXP Semiconductors, QinetiQ, Rolls-Royce, RWE npower, Shell, STMicroelectronics, Tenaris, UKAEA, and Unilever.

We foster industrial sponsorship of, and engagement with, PhD students (31 in period): in addition to CASE awards, we have the Warwick Collaborative Postgraduate Scholarships where the University and the external sponsor share the cost equally. Within the Midlands Physics Alliance Graduate School (MPAGS) we have also instigated 3 month placements opportunities for all PhD students: as an example, an electron microscopy student worked at Paintbox to help this Midlands company better understand their process for high-end automotive paint application. Beyond PhD, we have exploited the Knowledge Transfer Partnership scheme: e.g. a KTP Associate used his Warwick experience to help Johnson Matthey develop a new in-house NMR facility. Collaborations have also emerged through industrially supported undergraduate summer research projects.

Equipment and Facility Development.

There are many areas where we start out as customers and/or users and naturally progress to being developers. This is fostered and promoted by the department maintaining full mechanical and electronic workshops. We are also party to developing new national capabilities from scratch.

The Floating Ion Gun (FLIG) developed by **Dowsett** [#1] is now incorporated in many commercial

analytical instruments sold worldwide, which themselves underpin modern microprocessor development. In electron microscopy we collaborated with JEOL and assembled an add-on to the latest generation of TEM machines in Warwick, which JEOL will now themselves sell. There is a long standing relationship with Bruker, notably centred around the UK 850 MHz solid-state NMR facility at Warwick, for which Bruker, in collaboration with **Brown** and **Iuga,** designed and built 10 new magic-angle spinning (MAS) probes and for which they provide on-going support with a student travel fund in recognition of the publicity they receive. That same facility also saw the first installation of JEOL's 80 kHz spinning probe in a 20T NMR system, and JEOL scientists continue to use Warwick as the testbed and showcase for the performance of their probe for such high field NMR. The NanoSilicon group worked with VG Semicon to develop Si based MBE systems and continues to provide bespoke materials to companies. Our custom commissions from suppliers also expand their product capabilities, such as the custom CCD detectors for our UltraCam2 telescope camera development (**Marsh**) being consolidated into Marconi's regular product range.

In other areas we have developed or enhanced **Research Facilities** with impact beyond academia. The XMaS beamline, directed by **Hase** for Warwick and Liverpool [#5], has provided powerful and unique X-ray scattering facilities for a range of different classes of materials at the ESRF in Grenoble, that has been used extensively by industry and academia. Whilst this stemmed from a UK academic desire to measure magnetic Compton scattering, the beamline developed is now as likely to be used by an Eastern European company measuring polymers, a national standards laboratory (NIST, NPL, EMPA), or a museum looking to preserve cultural heritage (Rijksmuseum and the Academy of Fine Arts, Vienna). In addition, equipment developed for XMaS has been supplied to many synchrotron facilities worldwide where it is making the experiments more efficient to run, both saving running costs and enabling more measurements to be completed, as well as generating a small income to Warwick. The MAPS beamline at the ISIS facility, developed by **Paul**, enables inelastic neutron scattering to map out large areas of reciprocal space and detect features that would otherwise be missed. Again, MAPS has become thoroughly integrated into the suite of ISIS beamlines with a diverse industrial user base.

In Plasma Physics we developed the Extendable Particle-in-cell Open Collaboration (EPOCH), with Oxford and Imperial, as an open-source code now used in both national defence and fusion power development applications, and we provide direct support to its growing user community. **Arber** chairs the Collaborative Computational Project in Plasma Physics that encompasses some 50 UK plasma physics groups, all of which, and researchers from Europe, USA, India and China, now use EPOCH. It is also one of the core declassified codes used by AWE for benchmarking as part of their multi-million pound high-performance computing procurement. The novel data formats and visualisation tools developed have proved useful for other computational science applications; Fluid Gravity Ltd., a high-tech SME, now uses these extensively in their commercial operation.

Public Communication and Outreach In some areas of Physics, public curiosity is the ultimate driver for research, notably Astronomy and High Energy Physics, so here we return direct value to the funding public in terms of Outreach, e.g. a series of BBC1 *Midlands Today* broadcasts about neutrinos and the T2K facility (**Barker**); live local radio discussing the Higgs boson; **Pollacco** on *In Our Time* (twice) discussing comets & exoplanets, and BBC's *Richard Hammond Builds a Planet*; **Newton** with diamonds on BBC's *Bang Goes the Theory*. **Ball** received an Ig Nobel Prize for his work on ponytail physics, at a ceremony with a live audience of 1200 that made all the major TV news channels and daily papers, and attracted over 30 million viewers on YouTube. Underpinned by serious work on understanding materials made up of random fibres, this has direct implications both for the industrial collaborator Unilever's haircare products and for computer animation, incl. the massive games industry, which struggles to make hair and fur look natural in animated movies.

We are strongly committed to engaging the next generation, with a dedicated full time outreach officer **Caldecote** on indefinite contract and currently in partnership with the Ogden Trust. This outreach supports schools, inspires teachers, and is linked explicitly to our research: our Exoplanet and Higgs research are headline assets here, but connections are also made with research fuelled by enthusiasm across all areas of the Dept. Initiatives include: taking Year 9 girls from schools across the county to CERN; touring primary schools with *Commotion* - a project exploring the science of sound and movement; exhibiting at *The Big Bang Fair* annually and speaking with over 5,000 young people, teachers and parents; hosting the regional *Physicists of the Year* 2012 & 2013 award ceremonies with the Ogden Trust. *ScienceSnaps* (2010) was run as a competition, in

collaboration with SCRA and Birmingham Think Tank, to celebrate the visual impact of scientific research and launch the exhibition of the winning images as part of the British Festival of Science. IOP Evening Talks, based on our research work, are held in Warwick twice a term and regularly fill a large theatre with local people and school children. An annual series of 3 *Physics Christmas Lectures*, given by our academics since 2011, now attracts over 1000 members of the general public each year. As well as academics, PhD students and RAs are supported to engage in outreach: Dan Scully has appeared several times on BBC radio, and John Halpin is in much demand to visit local schools with his physics demos in a bike trailer.

c. Strategy and plans

We recognise achieving Impact as part of our core activity and a key driver in new appointments, targeting new staff such as **Alexe** in CMP whose research is geared towards device and sensor development. Our strategic alignment of future research embraces consideration of commercial exploitation; e.g. in creating our brand new SiC epitaxy facility, the intention was in-built to sell wafers to companies, who cannot obtain one-off designs from the few commercial suppliers.

The achievement of impact is celebrated, encouraged and rewarded, with possibility of increased salary. Permission is given for diverse consultancy, and incentivised beyond the personal fee retained by allocating the resulting income to research group discretionary spending. For instance, expert witness services have brought a range of characterisation work into the department. Staff are encourage to participate in, bid for and run national and international research facilities that will have Impact outside their own fields of research, e.g. XMaS, MAPS, NMR 850 MHz.

The mechanisms established through the SCRA initiative for business engagement are being maintained, fostered and developed. We project our research facilities as a resource supporting and fostering commercial development across the region and beyond; promoted commercially through Faculty organised Business Engagement Managers and delivered on the ground by Facility Managers we have established. Within the business plans for these investments, a significant portion of their activity is expected to be commercially driven, e.g. rising to 50% for our recent XPS Facility Manager appointment. The University recently established *Warwick Scientific Services* to enable simple commercial access to both the equipment and our expertise, which avoids lengthy contract negotiations for each access. The long-term future of our research facilities is assured within the University *Research Technology Platform* framework, which includes ring-fenced capital for equipment upgrade and underwriting of support posts.

Networking events are held with industrial collaborators including SCRA thematic days, the two day launch of our Electron Microscope facility, industrial advisory and focus group meetings for the *Centre for Industrial Ultrasonics* and wider engagement with external advisory boards having industrial membership, such as the Science Faculty Advisory Board and Complexity Advisory Board. Impact from these is about community building and identifying future opportunities for collaboration. Warwick's highly regarded Conference Centre venues are a real asset for these stakeholder and other meetings. Our standing programme of Dept. funded 'Physics [Research] Days' (invited sandpit type immersion events) also encompasses actions to encourage and enable Impact, e.g. a lively meeting in 2012 on strategies for IP protection and exploitation.

d. Relationship to case studies

Our Impact Case Studies illustrate how we have encouraged collaboration and provided support to take research into a development stage and on to impact; their diversity shows our flexibility in responding to the particular needs in realising each opportunity. Some common themes emerge:

An aspect present in <u>all</u> the Case Studies is the creation of a new methodology and delivering this in applications where it has impact. Three Case Studies [#1,#3,#5] show that impact derives from combining a deep understanding of the underlying science with an ability to design and precisely build an instrument capable of taking the science to the next level. Long-term relationships that we have developed with companies are important, in #1 & #5 for production/sales of equipment, in #4 as access to a specific market, and in #6 the relationship with Element 6 is truly symbiotic. Protection of intellectual property, with the support of *Warwick Ventures*, has been crucial in setting up the spin-out companies [#2,#3] and in enabling other companies to freely work with us [#3,#6]. Finally, in recognising that achieving impact is an essential part of our activity, but takes time and effort, staff have been released from other duties with full support and encouragement from the Dept. to pursue the opportunities they have recognised.