Institution: PHYESTA (Physics at Edinburgh and St Andrews)

Unit of Assessment: UoA 9 - Physics

a. Context

PHYESTA's research activities have led to the establishment of new business enterprises; improved the competitiveness of existing industries; enabled direct quality-of-life improvements through medical and other advances; stimulated the public imagination through engagement and outreach activities; and influenced national and international policy.

Specific examples are as follows. Our photonics research has led us to develop disruptive source technologies in the infra-red and THz spectral regions, and to create liquid crystal over silicon device designs, all of which have been commercialized as new product lines (under license and/or via spinout). Our longstanding work on the programming and building of supercomputers for large-scale particle physics calculations has led directly to new-generation product designs that are used on every major supercomputer worldwide (software), or integrated into IBM hardware products with global sales exceeding $500M. Our research in biophysics and photonics has led to faster point of care diagnostics; to the development of improved medical instrumentation; and to portable and user-friendly treatments for skin cancer and acne that vastly improve the daily experience of sufferers. Our fundamental research in astrophysics and astrobiology has stimulated widespread public debate on the possibilities of extra-terrestrial life and its implications for humanity, and has informed policy advice to international organizations including the United Nations.

b. Approach to impact

Our approach to impact is governed by three principles. First, we aspire to excellence in both basic research and impact generation: so these should attract equal recognition and reward. Second, the various Business Development (BD) and Knowledge Transfer (KT) services offered to us by the Universities and external agencies should be used to the full, to enhance the working relationships between academics and stakeholders. Third, PHYESTA is willing to invest resources in its own in-house BD and KT operations, to complement those available externally. While these three principles describe commercial impact, they also apply, *mutatis mutandis*, to outreach.

We next describe our approach to impact in relation to four major stakeholder groups: industry and commerce; translational research organizations; policy makers; and the public.

Industry and Commerce

Since 2008, PHYESTA's staff have formed three start-up companies and one new UK subsidiary company; granted 43 licences for the exploitation of existing IP; and been awarded 24 patents. PHYESTA's total industrial income over the REF period was £4.0M, consisting of £2.2M from a variety of large and small companies, and a further £1.8M for computational projects at EPCC. In addition our cash income from IP (license fees, assignment fees and royalties) exceeded £1M in the REF period. We also received undisclosed but substantial hardware discounts from IBM, in lieu of royalties, on machines worth many millions of pounds.

PHYESTA's direct engagement with industry ranges from cutting edge applied science -- targeting disruptive technologies with exploitation plans spanning decades -- to short-term troubleshooting and development projects. The latter can generate new research ideas that in turn attract industry support for longer term strategic work, such as a £470K consultancy with Mars Chocolate (Poon). One major partnership, with IBM, involves joint study agreements, staff secondments, and product co-development (see case studies on supercomputers and translational biophysics for details). Other partnerships with multinationals include product licensing (CDT/ Sumitomo, Molnlycke Healthcare, TA Instruments), and consultancies/ contract research (AstraZeneca, Boeing, Johnson Matthey, Mars, Mentholatum, Petroleum Geoservices, Rhodia, Rolls Royce, Solvay, Schlumberger, Syngenta, Unilever etc.). We have very strong partnerships with both the National Physical Laboratory (NPL) and the Atomic Weapons Establishment (AWE). These focus on joint translational research, via long-term senior staff secondments (Crain, McMahon) and placements for industry-oriented junior researchers (NPL £0.7M, AWE £0.5M). We also have strong engagement with small and medium sized enterprises (SMEs), mainly through consultancy and contract research (Edinburgh Instruments, Elliot Scientific, Giltech, Hallin Marine, MacPhie of

Glenbervie, MSquared, Scalar Technologies, Thomas Keating).

These industrial partnerships have led to significant impact. Here we outline some examples that are *not* among our case studies. The first is the licensing of optical tweezer technology to Elliot Scientific (Dholakia). This technology won a 2005 Photonics Spectra innovation prize and was developed into a new product line with sales in more than ten countries. Since 2008 this allowed Elliot to increase exposure to the biophotonics sector and strengthen its interaction with major clients such as Nikon. A related example is Poon's license (still at a pre-marketing stage) to TA Instruments to commercialise a confocal rheometer for imaging of product samples under flow. Two further examples relate to work done in the 1990s; by Greated on particle imaging velocimetry of flowing fluids, and by G. Cameron on physics-inspired software (Paramics) to predict traffic movement. In both cases our technology was commercialized by spin-outs (Optical Flow Systems, Quadstone) but later marketed by larger firms (LA Vision, Pitney Bowes). We estimate that our contributions directly underpin current sales exceeding £20M annually (Paramics claims 2000 users in 40 countries), but we have not been able to validate these figures with stakeholders.

Our approach to creating spin-out companies focuses on quality rather than quantity, addressing long-term impact objectives rather than short term statistical targets. A very early-stage example is Blackford Analysis Ltd which started trading in 2010 and has so far received over £1M in investment. It is commercialising a novel data-compression algorithm, MOPED, to create rapid image-alignment tools for the medical imaging market internationally. MOPED was invented in 2000 by Alan Heavens (then Edinburgh, now Imperial) to deal with large datasets in astronomy, and developed by his postdoc Ben Panter (now Chief Executive of Blackford Analysis Ltd). Panter won the Thales Scottish Technology Prize 2009 and the RCUK Business Plan award 2010.

Translational Research Organisations (TROs)

Our industrial partnerships often win co-funding from TROs such as: the KT arm of SUPA; Scottish Enterprise (SE); the Technology Strategy Board (TSB); and RCUK's Follow-on-Fund (FoF). TROs are instrumental in linking our research to economic and quality-of-life impacts. Our approach is to make sure all PHYESTA researchers know what the TROs can offer, and have the time and resources to make proper use of them. We summarise our work with TROs as follows:

- Funding lines from SUPA, TSB, SE and FoF have all been used to the full. In the case studies we show how Samuel (photonics) used SE Proof-of-Concept funding for work that led to the launch of Ambicare Ltd, and how SE investment in Crain's work (soft matter) led Molnlycke to establish its first UK subsidiary. Watt is now using FoF to improve the resolution of medical PET imaging, using ideas from nuclear physics instrumentation.
- PHYESTA's membership of SUPA brings added value through a number of formal channels. One is INSPIRE (Industry SUPA People Innovative Research Exchange), run by the physics and life science (PALS) Theme in SUPA and resourced by the Scottish Funding Council Horizon Fund. INSPIRE supports industry-facing PhD studentships, staff exchanges and networking events. A second channel is PEER, which uses funds from the Scottish Funding Council to pump-prime joint EU proposals for partnership projects with SMEs. A third is "SUPA Start" which uses national and European development funds to subsidize early-stage relationship-building with local SMEs. We not only use these initiatives, but helped to create them: Dholakia has led SUPA's PALS theme (co-ordinating network events and the SUPA Industry Placement Scheme); MacPhee has also led PALS Theme in SUPA during the setting up of INSPIRE; Bonnell has led the Astronomy Theme and Samuel leads the Energy Theme.
- We encourage PHYESTA staff to apply for the various fellowship schemes that support commercial exploitation of basic research, including the STFC-funded Innovation Partnership Scheme, RS Industry Fellowships (Clegg 2011-13) and Scotland-Stanford Photonics Entrepreneurial Fellowships (O'Faolain 2012-13).
- PHYESTA participates in national and international networks targeting impact delivery to industrial and commercial stakeholders, such as TSB KT Networks. We are members of the Diet and Health Research Industry Club (DRINC), and the International Fine Particles Research Institute (IFPRI) which are funded in part (DRINC) or wholly (IFPRI) by industry subscription, and we have so far won nearly £0.3M of income from these networks.

Impact on Policy

Policy impact naturally flows from the research and interests of several of our staff. We are supportive of staff involvement in the provision of policy advice at every level as exemplified below:

Since 2008, Crain has been seconded part-time in a senior role as Head of Physical Sciences at NPL, responsible for its interaction with government departments, including BIS, and with the TSB. Crain is also a member of the Confederation of British Industry (CBI) Subcommittee on Industry-Academic Relations (2010-2013), and served as Panel Member on a 2012 UK Blackett Review of Civil Contingency Planning. During the period, PHYESTA staff undertook consultancy projects on new security technologies for both the Ministry of Defence (DSTL) and the Home Office (CAST). Dholakia chairs a panel advising the Finnish government on biophysics (2011).

In 2012 Cockell addressed the United Nations Office of Outer Space Affairs on his proposal to establish 'Planetary Parks' (areas of the Solar System free of contamination). This has since been embodied in policy proposals by the Committee on Space Research (COSPAR) of the International Council for Science. Cockell's 2013 book, "Extraterrestrial Liberty", offers the first serious analysis of the social and policy implications of mankind's future colonization of other planets.

Much of our policy advice is delivered through organizations that form part of academia but are mandated to inform and advise decision makers. Exemplary in that role is the Royal Society, where Cates now serves on Council, as earlier did Sibbett (emeritus), who has more recently served as Vice-Principal of the Royal Society of Edinburgh, and as invited advisor for the Scottish Science Advisory Committee. Halliday (emeritus) was Director of The European Science Foundation and served on EURAB (the EU's Research Advisory Board). Mackenzie was on EPSRC's Technical Opportunities Panel (2009 -2011) and now serves on its Strategic Advisory Network. Dholakia has advised EPSRC on healthcare and on manufacturing, while Kenway advises RCUK on HPC policy. Policy roles in EU FP7 and Horizon 2020 were played by Dholakia, Kenway, Samuel, and Turnbull. Jardine contributed to a 2009/2010 US white paper on dynamo research.

Public Engagement

PHYESTA strongly promotes outreach and public engagement through school visits, roadshows, science festivals, radio, television and newspapers. Our outreach programmes involve 50-60 schools annually, with around 10,000 pupils taking part in two roadshows: SCI-FUN, and Particle Physics for Scottish Schools (PP4SS). PP4SS is led by Walker (emeritus) who received an MBE in 2013 for his outreach work. Additionally we organised IOP 'Lab-in-a-lorry' exhibits in 2009 and 2010, reaching a further 1000 secondary school students.

We estimate that PHYESTA's outreach work on Millimetre-wave instrumentation (subject of a case study with commercial and engagement impact) has had exposure to around 140,000 people since 2008, via Science Festivals, exhibitions at major Science Centres, and 150 schools workshops (5000 students). Our photonics group has run more than 100 schools workshops and presented at 15 UK Science festivals, engaging with 4000 people. These activities have won three EPSRC outreach awards. Recent exhibits at the Royal Society's Summer Exhibitions include Astronomy (Dominik) and Condensed Matter (McMahon). Liddle co-authored the Oxford Companion to Cosmology, and Taylor wrote a popular book "On Space and Time". Cockell in 2013 created a Massive Open On-Line Course (MOOC) on 'Astrobiology and the Search for Extraterrestrial Life'. This attracted 36,000 students, of which over 7,700 completed the course (nearly twice the average MOOC completion rate). This blurs the boundary between outreach and 'real' education.

PHYESTA's Astronomy Outreach, Public Engagement and Education Programme is detailed separately as one of our case studies.

Infrastructure for Knowledge Transfer and Business Development

PHYESTA's assets include several in-house centres focusing on impact delivery, as follows:

- **The Edinburgh Parallel Computing Centre (EPCC)** was founded in the 1980s to exploit opportunities arising from our work on large scale computational physics, and has done so ever since. Its 70 highly skilled staff offer consultancy and software development services to industry, and access to hardware that includes HECToR (the National HPC Service).

EPCC runs 'Supercomputing Scotland', which promotes industrial uptake of HPC solutions in key target sectors using Scottish Enterprise funds. During the REF period EPCC has had collaborative projects with over 70 companies of which over 80% are SMEs.

- **The Organic Semiconductor Centre (OSC)** is based at St Andrews. Here physicists and chemists undertake collaborative research on remarkable plastic materials that conduct electricity, can emit light, and have many emerging industrial applications including medical technologies and next-generation television displays. The OSC has working relationships with 5 different companies of which 3 are SMEs.
- **The Edinburgh Complex Fluids Partnership (ECFP)** provides consultancy and advanced measurement facilities to address industrial soft matter systems. It has access to unique facilities and expertise stemming directly from our basic research activities in soft matter. Many of these facilities are based in our COSMIC laboratory (detailed in REF5). COSMIC itself conducted KT work with companies (as reported in RAE2008) until the foundation in 2012 of ECFP, which now takes that role forward. Since 2012, ECFP has developed relationships with 48 different companies of which 22 are SMEs.
- **The Photonics Innovation Centre (PIC)** is based at St Andrews and bridges PHYESTA's photonics research to industrial users, whether looking to develop a particular product or to make wider use of our expertise and facilities. The success of this approach is exemplified by PhotoSynergy (PSL), a laser/fibre-optic lighting company working since 2010 and now providing safety technologies to the extractive industry and emergency services sectors. PIC has working relationships with BAe systems and 8 SMEs.

University and SUPA Support

PHYESTA receives support for impact delivery at University level from Edinburgh Research and Innovation, and St Andrews' Knowledge Transfer Centre. These provide full support services including legal, IP management, and company development. Each also acts as a gateway for companies seeking research expertise, and locally administers Knowledge Transfer Funds for market surveys, activity assessments, and pump-priming translational research projects. We also access a comprehensive range of KT resources provided by SUPA. Alongside several already mentioned, these include scoping projects with industry, market opportunity reports, networking events, and an industrial secondments programme targeted at early career researchers.

Supporting People

PHYESTA's senior management offers advice and mentoring to all staff that wish to pursue impact-generating activities. It also mentors those recruited to carry out such work, aiming to build their skills and contacts. The example of Ben Panter (astronomy PDRA turned CEO of Blackford Analytics) was mentioned above. In another example, Samuel used PoC funding to hire Andrew McNeill for translational research on organic light sources for skin cancer treatment. McNeill subsequently joined the Board of Directors of the resulting spin-out company as Chief Scientist.

PhD students and early career researchers have access through SUPA to a range of workshops on entrepreneurship as well as the secondment programmes mentioned above. Established academics are supported through the provision of sabbatical leave to develop impact-related activities, and through release on secondment to government, industry, or national laboratories where appropriate. We impose no limit on the duration of these secondments.

PHYESTA recognizes that impact delivery has major implications for staff time. Its academic workload models include KT/BD and treat these (and to a lesser degree outreach) on a par with other academic duties. Our annual staff appraisal systems also now encourage reporting of impact roles and discussion of the support required.

PHYESTA recognises that its staff should have a financial stake in any cash-generative impact they produce. Its policy is that the inventors of patented and/or licensed technologies receive financial rewards proportionate the income generated. As examples, a high field pulsed ESR system invented in St Andrews has brought £75K of royalties to the inventors who range from academic staff to PhD students. Over £120K has been likewise distributed from IP deals arising from Crain's biosensor work, and £75K from Dholakia's optical tweezers technology.

c. Strategy and plans

Our impact plans identify specific goals regarding commercial interactions, staff development and horizon scanning, which we describe below. All these goals serve a single strategy: to support and grow the impact of our fundamental research without undermining its quality. Our in-house tech-transfer operations are particularly useful in allowing fundamental and applied research to work in tandem without one being mistaken for the other. Our priorities include:

1) **New Research Partnerships**: We aim to establish further strategic research partnerships with large non-academic partners, like those we have with AWE, IBM and NPL. These bring strong rewards through: sharing of unique facilities and expertise; tapping into pre-existing routes to market; leveraging additional resources from Universities and other funders; and allowing rapid identification and realization of impact opportunities.
2) **Aligned Incentives and Reward Structure**: PHYESTA plans to further evolve its reward structures for impact delivery. We will work with both Universities to create clear and rewarding career options for staff whose impact commitments are serious and successful.
3) **Presenting Impact**: Impact outcomes and industry partnerships will be made more visible on all our websites and promotional material. We will increase the proportion of industrial or impact-related speakers at our major seminar and colloquium series.
4) **Opportunity Scanning**: PHYESTA will encourage its staff to evaluate and identify a small number of major impact opportunities in their own areas. The best of these will then be coordinated and resourced at PHYESTA level. Likely targets include biophysics; physical modelling; solid-state physics; and detector science and technology.
5) **Existing Partnerships**: These will be sustained and/or developed further. We are currently working on plans for major bids to Horizon 2020 in partnership with IBM and NPL on novel materials for transistor and memory elements.
6) **In-house KT/BD units**: We will continue to develop EPCC, OSC, ECFP and PIC, focussing on ECFP in the near term as this is now in a rapid growth phase. New centres will be established if and when the needs for these are identified.
7) **Impact Acceleration Accounts and other KT funds**: We plan targeted use of these resources to leverage non-academic co-funding for work on new projects. The focus will be on pump-priming activities that could later bridge into the first EU Horizon 2020 calls.
8) **Enhanced collaboration within PHYESTA**: As the PHYESTA collaboration beds in, we intend to make strategic use of our KT/BD assets. Our long-term goal is that support staff are always those best matched to the task, regardless of University affiliation. This would likely begin with staff exchanges and joint appointments among our in-house KT/BD teams.
9) **Intellectual Property Management**: We intend to protect our IP wherever we judge there to be strong prospects for its exploitation. We will also seek to build coherent IP positions in targeted technology areas to ensure that full value can be obtained through licensing across a whole technology sector rather than by a piecemeal approach.
10) **Staff development**: We will identify those staff whose work has translational potential and offer them mentoring and entrepreneurship training. Broader impact-awareness training for all staff will improve our capacity to identify potential impact. We will encourage early stage researchers to do impact-related work, first by making business-focussed training sessions available, and second by promoting their access to training in science communication and outreach, for example via the STEM ambassadors scheme.

d. Relationship to case studies

Our case studies are chosen both to reflect the breadth of our impact, and to demonstrate how our supporting infrastructure promotes impact delivery. Some case studies show how a sustained research effort spanning several decades can continue to underpin an entire technology sector (*Ultrashort-Pulse Lasers*). Others show how targeted discoveries can lead to life-changing benefits on a much shorter timescale (*Wearable Light Sources*). A third key message of our case studies is that the technologies we invent to do our basic science research can yield far-reaching impact when partnered with the industrial muscle and vision needed to exploit them across broad client sectors (*Translational Biophysics*). We also show how our research in curiosity-driven basic science can spark the imagination of adults and children through high quality engagement activity, and inform wider ethical debates about mankind's place in the Universe (*Astronomy Outreach*).