Institution: Queen's University Belfast (QUB)

Unit of Assessment: 9 (Physics)

a. Context

a1. Main Non-Academic User Groups: The main non-academic users of research performed within the School of Mathematics and Physics (hereafter 'the School') fall into the following categories:
(i) high-technology manufacturing industries (such as Seagate Technology, Intel, Andor Technology, IBM, Kyocera / AVX Ltd);
(ii) finance and software-focused companies (such as First Derivatives Ltd, Numerical Algorithms Group Ltd and Hughes Insurance Ltd);
(iii) central large-scale national and international computer facilities and their hardware suppliers;
(iv) the general public, particularly schoolchildren.

a2. Main Types of Impact and How These Relate to Research Centres: The types of impact realized in the School vary across the research centres: ARC (Astrophysics Research Centre), CPP (Centre for Plasma Physics) and CNM (Centre for Nanostructured Media) have strong interactions with manufacturing industry, which should be considered as "economic impact". CTAMOP (Centre for Theoretical, Atomic, Molecular and Optical Physics) interacts strongly with companies in which software and finance are key business elements; this should also be considered as "economic impact". However, in addition, CTAMOP has had an influence on the provision of national public services, creating the HELIUM code that has been used, as a performance-benchmarking tool, to ensure that upgrades to the HECToR UK National Supercomputing Service have been fit for purpose. In terms of "societal impact", all centres engage enthusiastically in outreach and in the development of the public understanding of physics through a number of events coordinated by the School Outreach Committees, with ARC being particularly active in this respect.

b. Approach to impact

b1. Staff Interactions with Non-Academic Beneficiaries: Members of staff in the School are acutely aware of the benefits of positive interactions with non-academic research users and of the increasing importance of the 'Impact Agenda'. Indeed, from 2011, contribution to impact is now monitored as a distinct element in evaluating staff performance in appraisals and promotions. Within the REF period, interaction is best illustrated and discussed under three major headings: 'Direct Engagement with Companies' (b.1.1); 'Engagement through Contact with Economic Development Agencies' (b.1.2) and 'Outreach and Media Engagement' (b.1.3).

b1.1 Direct Engagement with Companies:

b.1.1.1 Andor Technology plc. This globally-leading high-tech imaging, spectroscopy and microscopy company is a spin-out activity from the School (started in 1989). Aided by research in ARC and CPP over the last two decades, Andor has grown into a company that now employs over 300 people in 16 locations worldwide. It distributes its products to ~10,000 customers in 55 countries, has an annual turnover of over £50M (making profits of the order of £6M-10M) [1] and has a share price that has increased by a factor of over 5 over the last 5 years, despite the global economic climate. In recognition of Andor's global success, the principal founders, Drs Donal Denvir and Hugh Cormican (graduates of the School), were awarded the Institute of Physics 'Paterson Medal' (2000) and 'Swan Gold Medal' (2008) [2]. The company was also shortlisted as a finalist (one of three) for The Royal Society of Engineering MacRoberts Award (2012). Staff within ARC and CPP have interacted strongly with Andor since its inception. By collaboratively developing imaging solutions to augment cutting-edge research in the School, Andor realize that they can create new high-performance products that can be subsequently sold in a wider market. This established relationship has continued throughout the REF period.

b.1.1.2 Seagate Technology and ANSIN. Seagate is a global leader in magnetic storage technology. In 1993, they established a manufacturing plant for read-write heads in Springtown (Derry / Londonderry), and since then have maintained close R&D links with the School. Seagate has benefited from collaborative research and also from the QUB research-trained graduates that they have subsequently employed. Around 20 QUB PDRAs and PhDs have been directly funded by Seagate in the last 15 years; QUB has also directed investment to support this collaboration. A step change in the nature of the Seagate-QUB interaction occurred during this REF period: a new

materials research facility (ANSIN) was created in 2010 with direct funding and equipment donation from Seagate [3]. The total investment amounts to ~£9M and the funded research programmes have involved all of the established academic staff within CNM (commitment levels ranging from 10% to 50% of full-time over 4 years). A key remit of ANSIN is to engage with other high-tech industry. Thus, academic staff have been proactive in widening commercial participation: sponsorship from FEI has been negotiated, at Senior Vice-President level, to fund a permanent new microscopy lecturer (Dr Arredondo; appointed in 2012); Intel Ireland have agreed an access agreement for ANSIN microscopy use when needed; IBM (Watson) has embedded a visiting research fellow to work on metal-insulator transition materials (Dr Saad, who arrived in 2012); Cirdan Imaging, a recent medical imaging start-up company, is also a partner in ANSIN, and has already engaged in a Knowledge Transfer Partnership (KTP) to develop novel imaging chips.

b.1.1.3 Finance and Software Companies. CTAMOP interacts strongly with finance and software-based companies. In fact, 'Datactics' [4] (a company that provides software to improve the quality of data held by organizations, and counts Royal Philips Electronics, the Bank of Ireland and the NHS amongst its clients) was created by ex-members of academic staff from CTAMOP. Staff expertise has also been used to successfully develop KTPs with financial modelling-based companies (such as First Derivatives Ltd) and software-reliant companies (such as Hughes Insurance Ltd). A recent KTP with Hughes Insurance allowed new advanced analytics technology to be developed and embedded in the company software, leading directly to a 4.5% increase in customer retention figures. This specific project was so successful that the KTP associate (David Sandford) was named as one of only five '*UK Business Leaders of Tomorrow*' at the National KTP2012 Awards [5].

b1.2 Engagement through Contact with Economic Development Agencies:

b.1.2.1 Technology Strategy Board (TSB). Opportunities for engagement with the TSB are highly prized. Within the REF period, the TSB funded 3 KTPs in the School; in addition, staff in CNM recently (2010-13) took part in a major research-led programme (coordinated by the National Physical Laboratory) on Low Carbon Vehicles, in which new dielectric materials were investigated for niche pulse-power applications. Success has already allowed Syfer Ltd (a capacitor manufacturing company) to incorporate completely new dielectric formulations (branded 'Hiteca') into multilayer ceramic capacitor chips; even at an early stage of evaluation, properties appear to be competitive with (and in some ways superior to) standard commercial units [6]. Syfer has definitive plans to progress commercialisation of these new capacitors over the next two years.

b.1.2.2 Invest Northern Ireland (INI). The School has a strong ongoing direct relationship with INI (the local regional development agency still seen to be central to the Regional Innovation Strategy by the N. Ireland Assembly Programme for Government). Our academics sometimes accompany INI officials on trade missions, helping to attract foreign direct investment from a number of multinational companies by showcasing QUB competencies in research and education. Academic staff members have also helped INI to develop infrastructure and graduate training, to support local industrial needs and to help anchor multinational employers to the UK, through specific collaborative research programmes: in 1996 the "Northern Ireland Centre for Advanced Materials (NICAM)" was established; this was followed, in 2002, by "Nanotec NI" [7]. These Centres of Excellence provided ~£5M of capital investment that gave a high quality infrastructural platform that is still of use for both fundamental and commercial research and development.

b1.3 Outreach and Media Engagement: Individuals within the School are often approached to partake in various forms of outreach, from evening lectures (*e.g.* The Science Café) and participation in mock interview panels for schools, to appearances on radio and television for the BBC. The School actively encourages staff to take any opportunity to respond positively to such approaches. All staff are made aware that public engagement is a significant element of the activity portfolio that contributes formally towards academic promotions. ARC academics are particularly active, appearing regularly on radio and television to discuss their work specifically, as well as convey the wider implications of astrophysics research. Appearances have been made in the Sky at Night, Horizon, the One Show, Hitchhikers' Guide to the Universe (part 3 – Exoplanets), BBC Newsline, BBC Breakfast News, BBC News 24 and RTE News. In addition they feature in radio broadcasts, for BBC Radio Ulster and for the BBC Radio 4 programmes 'Today' and 'Material World'.

b2. Specific Support for Enabling Impact The University has well-established centralized units for supporting engagement with end-users (see b2.1 below) and members of staff are encouraged to liaise directly with them. However, School-level support systems are also being generated: staff sabbaticals for impact development are now encouraged and internal 'champions' have been identified to drive specific areas where we see impact growing in the future. For example, the School now has a champion to coordinate activity relating to the interaction of physics with health and life sciences: plasma sterilization and plasmonic excitation in tumour-embedded nanoparticles are already of particular interest to end-users, and we hope that genuine impact will develop in these areas. In outreach, the School has appointed a temporary position, funded by the philanthropy of Michael West, with the specific remit of developing public awareness and interest in astrophysics.

b2.1 School's Use of Institutional Resource: The University offers significant levels of advice and practical help for exploitation / knowledge transfer through both the Research & Enterprise Directorate (R&E) and QUBIS (www.qubis.co.uk), the University's wholly owned company that supports commercialization of research and innovation. Institutional support is developed to the extent that QUB was named as the Times Higher Education (THE) Entrepreneurial University of the Year in 2009/10. This environment has been extremely useful to the School. For example, on the basis of recent research (Kabashin *et al.* 2009 Nature Materials, **8**, 11, 867; McPhillips *et al.* 2010 ACS Nano, **4**, 2210) and lodged patents in the area, staff approached R&E to help explore the potential exploitation of nanowire and nanotube arrays in biosensing applications. With R&E support, a KTP was established with Cirdan Imaging, ~£100K 'Proof of Concept' funding was leveraged from INI and a R&E-inspired collaboration between CNM and academics in Biochemistry was established, to allow the biosensing efficacy of the new arrays to be benchmarked against commercially-available products. Angel investment and support from QUBIS resulted in a new spin-out, Causeway Sensors Ltd., being formed in 2013.

b2.2 Outreach Committees: The School has run an extensive outreach programme for many years to raise public awareness of the wider technological and cultural importance of both physics and mathematics. To support this activity, the School topslices ~£20K from its annual operations budget. Outreach programmes are managed and organised by 'Outreach Committees' (one each for physics and mathematics), composed of a cross-section of academic staff from all of the research centres in the School. While many activities aimed at secondary schools have an integrated recruitment aspect, encouraging the uptake of science in third-level education, all programmes are focused on sharing the scientific excitement and interest associated with our fields of research. We run an annual 2-day lecture series for 5th and 6th-form schoolchildren from across Northern Ireland ('Horizons in Physics'). Using a combination of dramatic demonstrations with invited speakers, and more academically-challenging talks from our own staff, we explain basic physical principles alongside some of our most recent research. Audiences average 400 individuals each year. We hold annual competitions for schools in physics and mathematics for 13-17 year olds. In addition, we support local teachers by running an annual one-day Physics Teachers' Conference, in association with the Institute of Physics, providing new teaching resources, guest speakers and a forum for discussing good practice and future requirements. A recent outcome of this was a request from 6th-form teachers for more support on particle physics; this has led to the establishment of an STFC-sponsored one-day particle physics workshop for schools commencing in 2012. Associated with this is a free evening lecture for the general public, which we plan to hold each year along with the Michael West Public Lecture Series in Astronomy [8].

References:

[1] Andor Technology plc, Half-yearly report 2013
(http://www.andorplc.com/pdfs/Andor_Interim_Report_FY13.pdf)
[2] http://www.iop.org/about/awards/career/paterson/medallists/page_38669.html
https://www.iop.org/about/awards/gold/swan/medallists/page_38461.html
[3] http://www.ansin.eu/#home; [4] www.datactics.com
[5] http://www.ktponline.org.uk/best-2012-blt

[6] http://www.electronicsweekly.com/news/research/materials-rd/novel-dielectric-leads-to-200c-automotive-capacitors-2013-08/; M. McMillen *et al.*, Appl. Phys. Lett., **101**, 242909 (2012)
[7] http://www.nanotecni.co.uk/. [8] http://archive.irishastro.org.uk/index1107.html

c. Strategy and plans

c1. Impact Facilitation Board (IFB) To develop greater coherence in our approach to impact, we intend to establish an Impact Facilitation Board (IFB). A Director of Impact (DI) will be appointed from amongst the permanent academic staff, will sit on the School Management Board (SMB) and report directly to the Head of School (HoS). The DI's responsibility will be to monitor, develop and support impact with the aid of the IFB, which will meet twice per year and will be composed of: 3 representatives from our existing user base (e.g. Andor, Seagate, First Derivatives Ltd. etc), a representative from W5 (or other UK interactive science discovery centre), the University Business Alliance Manager (from R&E), the Director of Knowledge Transfer Partnerships (from R&E), a representative from INI and several representatives from other relevant Knowledge Transfer Networks (to allow us to gain input from, and generate profile in, other parts of the UK). Directors of Research (DRs) and the Chair of the Outreach and Recruitment Committee shall also attend, as shall the HoS when appropriate. The IFB will have a steering, monitoring and evaluation role and make recommendations to the HoS for specific actions to help progress the impact agenda.

c2. Specific Actions While actions to be taken are the responsibility of the DI, with approval from the HoS, we envisage the following examples of specific activity:
(i) creating a centralized database of all current impact-related activity and of the specific "pathways to impact" plans associated with externally-funded RCUK research programmes;
(ii) instigating a monitoring process to assess the extent to which impact plans on other externally-funded grants are developing and to suggest specific support actions;
(iii) developing and monitoring an increased engagement with end users, economic development agencies and the media;
(iv) overseeing and monitoring an increase in direct investment from industry, sponsored PhDs, consultancy and industry / end-user influenced research activity;
(v) increasing and monitoring the recognition of staff effort and success in impact, and developing incentives for the uptake of industry-academic fellowships and sabbaticals specifically to develop spin-out opportunities or similar impact-related activities.

d. Relationship to case studies

We have identified five distinct case studies to illustrate the success of our approach towards impact:
(i) *Andor:* this case study outlines the manner in which research activity in ARC has pushed Andor to further develop high-performance imaging systems that have subsequently been sold to other users worldwide, helping them with their imaging problems and generating commercial turnover and profit for Andor Technology;
(ii) *Failure in Multilayer Ceramic Capacitors (MLCC's) for AVX Ltd:* illustrates how expertise in ferroelectrics microscopy and in capacitor-related research within CNM helped to solve a manufacturing problem for AVX Ltd; this saved a major contract for the company worth $600K and helped maintain a key relationship with one of their important automotive-related customers;
(iii) *Seagate Technology R&D Investment Strategy:* illustrates how the quality and nature of research over the last decade in CNM directly influenced Seagate to increase their investment in Northern Ireland, creating ~85 new research & development positions;
(iv) *Outreach and the Public Understanding of Physics:* this case study illustrates how ARC in particular has contributed towards the public understanding of science, especially amongst schoolchildren;
(v) *HELIUM:* this case study demonstrates how a computer code, generated within CTAMOP, has been used as a testing benchmark to ensure that pre-agreed performance levels were reached following installation of nationally strategic computational infrastructure (the HECToR UK National Supercomputing Service).