Institution:	**Cardiff University**
Unit of Assessment:	**9**

a. Context

The Cardiff University School of Physics and Astronomy promotes and achieves impact from its high quality research in two main areas:

Economic impact: companies (e.g., NEC), and non-academic research institutes (e.g., ITER) benefit from commercial availability of technology through a company, QMC Instruments (QMCI), hosted in the School, and through consultancy and contractual arrangements with School staff (e.g., IQE, Oclaro, SEA Ltd.). Recent initiatives in Earth Observing, based on applying and adapting technologies developed for astronomy to remote sensing of the Earth's atmosphere, are also aimed at future impact in the area of the Environment.

Impact on society and culture: substantial PR and outreach programmes, especially related to research in astronomy and gravitational physics, are carried out to influence the general public, educationalists and children, both directly and through the media. Beneficiaries include schoolchildren (through direct contact via talks and visits by School staff, local and national exhibitions), teachers (via training sessions, provision of educational resources, and secondment to the School), and the general public locally, nationally and worldwide (through popular talks and exhibitions, through the web, and through extensive and organised coverage in the mass media).

b. Approach to impact

In keeping with the School's strategic aim to maximise impact from its research, staff are actively supported in generating impact through allowance of time in the School workload model for outreach events, industrial consultancy, provision of travel expenses, and direct funding of outreach events and exhibits. Recent examples of our agile and proactive approach to impact are transfer of new material characterisation techniques to industry, adaptation of astronomical technology to Earth observation and meteorology, public engagement based on astronomy with the *Herschel* Space Observatory, and leverage of EU funding based on our *Herschel*-based schools educational programme. Opportunities are identified and initiatives planned through the work of the School Outreach Committee and the Director of Innovation and Engagement (I&E).

Commercial/economic impact: The School has developed an I&E plan to maximise economic impact from research. Director of I&E Peter Hargrave is responsible for maintaining and implementing the plan, is also active in the Technology Strategy Board (TSB) Sensors & Instrumentation KTN, and promotes the School's R&D activities and expertise via frequent invited talks and participation in national meetings on space technology, security, and Earth observing.

The Astronomy Instrumentation Group (AIG) has a direct route to R&D commercialisation via QMC Instruments (QMCI) (see Case Study 2). AIG staff work closely with is QMCI, often through consultancy contracts (during the REF period, nine AIG staff members had such arrangements with QMCI). AIG research is also being extended to incorporate Earth observing, with potential impact in understanding climate change and meteorology. Current developments include the Chinese Feng-Yun 4 meteorological satellite (to monitor the whole of China on 15-min. timescales for precipitation and storm warning), in which we were invited to participate based on our THz instrumentation expertise and our role in *Herschel*. With industrial partner Thomas Keating Ltd. we are contracted to carry out a design study for a microwave remote sensing receiver, with the prospect of major future contractual involvement in this project. The AIG is also collaborating with SEA Ltd. in a TSB-funded study for a future ice-cloud imaging satellite to constrain variables for global climate models, with a new instrument design, based on technology developed by the AIG.

The Condensed Matter and Photonics (CMP) group works to maximise the connections between researchers and users, including embedding users within research projects. It works directly with industrial partners, such as Element Six, and has external advisory groups for projects; e.g., the advisory group for the EPSRC-funded *Silicon based QD light sources and lasers* project has representatives from IQE (semiconductor wafer manufacturer) and Oclaro (laser and optics company). Workshops are held during projects to advertise outputs to external parties. CASE studentships (two during the REF period) also facilitate collaborations. The group's strong links with industry also build understanding of potential future impact. Examples are service contracts

(totalling £139k) with NLight to characterise material with a technique developed by the group, and to transfer the technique to their facility, with IQE for a Vertical Cavity Surface Emitting Laser test process, and with Samsung for work on quantum dot emitters. The group also engages with potential end users (e.g., attendance at *Physics to Healthcare* STFC events), and is represented at EPSRC III-V Semiconductors and STFC Security and Atmospheric Monitoring events.

The University runs the Cardiff Partnership Fund (CPF) to provide seedcorn funding for proof of concept studies and advice on developing ideas and business plans. The CMP group actively uses this fund: Macdonald was supported by the fund in 2009, leading to an EPSRC Follow-on Fund Grant in 2011 (EP/I006052/1). Langbein received CPF funding leading to follow-on funding from BBSRC, and is now developing a spin-out company using CU-patented technology for a novel microscopic technique with bioscience applications. The CMP has also developed a laser source with QMCI, with University support for a patent application (UK appl. No. 1217514.7).

Outreach and societal impact: We have one of the most professional and well-organised education and public outreach (EPO) programmes amongst UK Universities, which maximises the impact from our research and harnesses the enthusiasm and commitment of our staff, postdocs and students. The School Outreach Committee (chair Haley Gomez), comprising staff from each research group and in-house EPO experts, defines the detailed plans for School EPO activities.

To maximise EPO impact from our research, we have formed strong links with EPO professionals, including hosting them in the School. An award-winning social enterprise, *science made simple* (*sms*) (http://www.sciencemadesimple.co.uk/) assists staff (and vice versa) in devising and running outreach projects based on our research, and provides professional training, advice, and contacts with local schools. Interactions include secondary schools shows *Herschel: Mysteries of the Cold Universe* (see Case Study 3), and *Gravity Beyond the Apple*, developed in 2008 with the Gravitational Physics Group (GPG), and outreach training under an EPSRC nanotechnology and biomedicine programme. Wendy Sadler, *sms* Director and a winner of the prestigious EU Descartes Prize for outreach, was our Schools Liaison Officer until Nov. 2013, was also Chair of WISE in Wales when the Discover Saturday Club for girls was established, and continues to work on projects to attract females into STEM subjects.

We host the office of Edward Gomez, Education Director of Las Cumbres Observatory Global Telescope Network (LCOGT), a non-profit company building and operating telescopes worldwide, allowing us to give the public and schools access to research-class robotic telescopes and to publicise School research. He is an Honorary Lecturer in the School, and supports us by leading University I&E grants, as well as external STFC and EC grants (~£115K in the REF period).

Since 2008, School EPO activities have reached a global audience of over 14 million, including 16,750 UK schoolchildren. We maintain a list of all outreach activities, with over 300 events since Jan. 2008, including more than 90 hours of public talks, over 40 radio shows, 360 teachers trained and a 10 million-strong audience watching School staff on TV (details of our engagement activities are available at https://www.astro.cf.ac.uk/community/). £588k from external bodies was awarded to School staff for EPO projects during the REF period. Substantial School funds (£126k) were also used to support EPO, and a further £52k from the University's I&E fund was also awarded. EPO activity is taken into account in the academic workload model and staff appraisals. The School also makes extensive use of the University's Public Relations team in publicising its research achievements through press releases.

The School, with *sms* support, runs a substantial programme of activities for local schools (http://www.astro.cf.ac.uk/forteachersandschools/), including an annual sixth-form conference, typically attended by 400 pupils and their teachers. Staff, postdocs and students support this event with talks and demonstrations on their research. An annual Institute of Physics Christmas Lecture is given for GCSE-level pupils, and a range of schools talks by our staff, most based on their own research, is available (http://www.astro.cf.ac.uk/forteachersandschools/?page=freeschooltalks).

The GPG develops research-based educational tools using audio-visual material, videos, interviews, and on-line games, presents its work at exhibitions, museums and roadshows, and gives public and schools talks. As part of a 2008 Royal Society Summer Exhibition *Can you hear black holes collide?*, the GPG developed, with UK collaborators, a web-based game, *Black Hole Hunter* (http://www.blackholehunter.org/; over 43,000 unique visitors to date). The CMP Group also

supports outreach events, talks and exhibitions. Smowton is a member of the IEEE Photonics Society Board of Governors, which supports and oversees public outreach and education. The Astronomy and AIG Groups are very active in outreach, with *Herschel* as a particular focus (Case Study 3). Other recent projects include Haley Gomez's science clubs for girls (age 12-14) in which she showed not only a change in the girls' views, but also in their parents' (100% of parents said that the course showed them that their daughters could have a career in science).

c. Strategy and plan

Our main strategic aims for the future are (i) to sustain and enhance our strong activity in outreach and educational impact; (ii) to develop further the application of AIG THz technology to Earth observation; and (iii) to create further economic impact, especially from research by the recently enlarged CMP group which has doubled in size since 2010. This expansion has targeted areas with high potential for future impact: diamond growth and devices, magnetic materials, photonics, and advanced semiconductor devices.

In keeping with these aims, we already defined the following specific objectives:

(i) following counsel from the School External Advisory Panel, the CMP group will develop close partnerships with four external companies (IQE, Element Six, Renishaw, TWI);

(ii) we will continue outreach programmes based on Astronomy and AIG research, with a focus on externally-funded large-scale projects (for example, Haley Gomez is the UK PI of an EC project (*Inspiring Science Education, 2013-16*) to produce innovative *eLearning* tools and enhance science learning in 5,000 schools in 15 countries);

(iii) we will maximise outreach from potential future space projects such as the EChO and SPICA astronomy satellites, and the Feng-Yun 4 meteorological satellite;

(iv) we will develop an outreach programme associated with early science from gravitational wave detection (expected on a 5-yr timescale) with an approach similar to the one adopted for *Herschel*;

(v) we will expand Earth-observing research and associated societal impact, realising the promise for atmospheric sensing of much of the technology developed for astronomy (e.g., we will engage with the European Earth observation community through the SPACEKIDS EU FP-7 programme to develop kinetic inductance detectors for space EO applications, which we coordinate);

(vi) we will further enhance commercial impact via QMCI through development of new products and potentially a new spin-out company for THz imaging.

These objectives are being actively addressed via the School I&E Strategy, group-level initiatives, initiation of programmes by the School Outreach Committee, and the motivation and dedication of our staff. Awards of School research funds will be made to staff who achieve significant impact, and it will continue to be given significant weight in appraisals and promotion cases.

d. Relationship to case studies

1. Antikythera Mechanism: This research, and the considerable international public attention that it received, derived originally from the academic freedom accorded to staff in the School to pursue their own high-quality research. Prof. Edmunds and his colleagues had the encouragement and assistance of the School from the start in what was an unusual endeavour for the School.

2. THz detection: QMCI and the School have a mutually beneficial arrangement. QMCI's business is largely derived from AIG research and facilities. We provide a favourable environment for QMCI – lab space, reasonable rent, and a good deal on profit sharing – amply rewarded by the volume of business and corresponding income to support research, the opportunities for commercialisation, and the national/international contacts, and opportunities for joint technology development with both commercial and academic use. There will be future opportunities to extend this to commercialisation of CMP group technology, and to establish separate spin-outs.

3. *Herschel* Outreach: Cardiff leadership of the *Herschel*-SPIRE instrument, combined with strong scientific involvement, made it natural for us to lead a UK-wide *Herschel* outreach programme. School support for this has been very strong (partial support for the outreach officer post and purchase of satellite models, an infrared camera, and outreach consumables), and the professional expertise and participation of the *sms* and LCOGT teams has been invaluable. We also benefitted from successful bids to the Cardiff University I&E fund. Based on the success of this programme the School will match its involvement in future large projects with similar programmes.