Institution:	**Cardiff University**
Unit of Assessment:	**9**
Title of case study:	**The *Herschel* Space Observatory: scientific and technical outreach**

1. Summary of the impact (indicative maximum 100 words)

We have formulated and executed an extensive public engagement and outreach programme based on our leading technical and scientific involvement in the *Herschel* Space Observatory, a €1 billion astronomical satellite which was launched in 2009 and operated until April 2013. *Herschel* observed the Universe at far-infrared and submillimetre wavelengths with three scientific instruments, one of which (SPIRE) was built by an international team led by the Cardiff Astronomy Instrumentation Group, and Cardiff astronomers have been at the forefront in scientific use of *Herschel* and SPIRE. The beneficiaries of our PR and outreach programme include schoolchildren teachers, the media and the general public. The programme has achieved high exposure and impact locally, nationally and internationally. It provides inspirational personal contact and up-to-date material and information which has stimulated widespread and continuing interest in *Herschel* and also helped to raise the profile of STEM subjects, ultimately benefiting the economy.

2. Underpinning research (indicative maximum 500 words)

SPIRE is a large multinational project (18 institutes in eight countries, including six in the UK), with a total budget of around €90M. The project started in 1998 following approval by the European Space Agency (ESA) of the instrument proposal. It is led by the Principal Investigator (PI) Griffin. (The PI is responsible to ESA for all aspects of the design, construction, testing and delivery of the instrument, and for in-flight calibration, data processing software, and operations support). SPIRE work started in Cardiff in June 2001, when the Queen Mary, London, Instrumentation Group, led by Profs. Ade and Griffin, relocated to Cardiff. Thenceforth the Cardiff Astronomy Instrumentation Group led the project to construct and operate SPIRE.

Elements of the SPIRE instrument were built by Cardiff University and various participating institutes, and the instrument was assembled and tested at the Rutherford Appleton Laboratory prior to delivery, in April 2007, for installation in the *Herschel* spacecraft. To date, *Herschel* has produced over 700 refereed scientific papers, about 40% of which use SPIRE instrument data.

UK funding support for *Herschel* has been provided successively by PPARC, STFC, and UKSA. *Herschel* technical work at Cardiff has been supported by a series of grants totalling ~£3.2M from those agencies from 2001-2015, covering SPIRE instrument leadership, construction, operations and data processing, and post-operations. Following the end of the operational phase, we are now embarking upon a three-year post-operations programme designed to finalise the data-processing software, and to re-process all the SPIRE data for permanent archiving. Additional funding for science exploitation at Cardiff has been provided by STFC Rolling and Consolidated grants (£7.1M since 2009 – not all *Herschel*, but *Herschel* research has been the main focus of the group's research grant during that period, constituting about 50% of the grant support).

From 2001, in parallel with the Cardiff-led manufacture of the instrument, Cardiff academics were prominent in defining and then carrying out *Herschel*'s science programmes. Griffin coordinates the SPIRE Science Team (over 300 members), responsible for the consortium's science programme (10% of mission time). Cardiff staff lead several of the large *Herschel* Key Projects. Prof. Gear is joint coordinator of the SPIRE Nearby Galaxies team, and Prof. Eales leads one of its survey programmes; Griffin is prominent in the team studying star formation in the Milky Way. Eales and Griffin are members of the SPIRE High-Redshift Galaxies team. Eales also co-leads the *Herschel*-ATLAS extragalactic survey, the second-largest open time Key Project, in which Dr. Gomez is also involved. Note that all of the Cardiff staff mentioned above have been REF-eligible Cardiff University employees since 2001 or before except Gomez (appointed lecturer in 2005).

Twelve *Herschel*-based papers by Cardiff staff are submitted to the REF. In addition to the SPIRE instrument paper [3.1], REF-submitted research highlights led by Cardiff or with strong Cardiff involvement include: determining how the luminosities of galaxies have evolved over the last five billion years [3.2, 3.3], a detailed study of global star formation in our nearest neighbour spiral galaxy, Andromeda [3.4], demonstration that Type Ia supernovae produce little or no dust, in contrast to core-collapse supernovae [3.5], and clear evidence that star formation in the Milky Way

is mediated by complex filamentary structure in molecular clouds [3.6].

3. References to the research (citation numbers from ADS, Oct. 29 2013)

3.1 **Griffin**, M. et al. (183 authors inc. **Ade**, **Gear**), The *Herschel*-SPIRE Instrument and its In-flight performance, A&A, 518, L3, 2010 [10.1051/0004-6361/201014519] [Griffin-1; 563 citations]

3.2 **Dye**, S., et al. (68 authors inc. **Eales**, **Gomez**), *Herschel*-ATLAS: Evolution of the 250 μm luminosity function out to z = 0.5, A&A, 518, L10, 2010 [10.1051/0004-6361/201014614] [Eales-2; 36 citations]; Dye was a postdoc at Cardiff at the time.

3.3 Dunne, L. al (41 authors inc. **Eales**, **Gomez**), *Herschel*-ATLAS: rapid evolution of dust in galaxies over the last 5 billion years, MNRAS 417, 1510, 2012 [10.1111/j.1365-2966.2011.19363.x] [Gomez-1; 57 citations]

3.4 **Ford**, G. P. et al. (20 authors inc. **Gear**, **Gomez**), *Herschel* exploitation of local galaxy Andromeda (HELGA) III: the star formation law in M31, Ap. J. 769, 55, 2013 [10.1088/0004-637X/769/1/55] [Gear-4; 1 citation]

3.5 **Gomez**, H. L. et al. (16 authors inc. **Gear**), Dust in historical Galactic Type Ia supernova remnants with *Herschel*, MNRAS 420, 3557, 2012 [10.1111/j.1365-2966.2011.20272.x] [Gomez-3; 15 citations]

3.6 André, Ph. et al, [57 authors inc. **Ade**, **Griffin**], From filamentary clouds to prestellar cores to the stellar IMF: Initial highlights from the *Herschel* Gould Belt survey, A&A 518, L02, 2010 [10.1051/0004-6361/201014666] [Griffin-4; 216 citations]

4. Details of the impact (indicative maximum 750 words)

At the beginning of 2008 (15 months before the *Herschel* launch) the UK *Herschel* Outreach Group (HOG), chaired by Griffin, was formed to coordinate a national outreach and PR programme. It includes members from all UK SPIRE institutes (Cardiff, Imperial College, UCL-MSSL, UKATC, STFC-RAL, Sussex), several other UK institutes involved in *Herschel* science, and the STFC *Science in Society* team. Funding was secured via two STFC *Science in Society* grants (£135k; ST/H000453/1 and ST/J000248/1), covering 2009-2013, including a Cardiff-based half-time *Herschel* Outreach Officer (HOO), Dr. Chris North, in post from Oct. 2009, and additional funding under the Cardiff SPIRE project grants (~£15k) for outreach expenses. A state-of-the art infrared camera and two scale models, 1:10 and 1:4, of the *Herschel* spacecraft were procured using £30k from School of Physics and Astronomy internal funds (a 50% contribution to the 1:4 model was also made by RAL). These have proved to be major draws at talks, events and exhibitions. HOO tasks include acting as HOG secretary, executing the PR and outreach plans formulated by the group, preparing press releases in consultation with UKSA, STFC, ESA, and scientists in over 20 UK institutes, and developing and maintaining the UK *Herschel* Outreach website. A national network of scientists and engineers from Cardiff and other UK *Herschel* institutes was also established to assist with events (schools visits, public talks, exhibitions, etc.), several of whom have undergone media and communications training.

The *Herschel* outreach programme is led by Cardiff but is a national activity. In this case study we focus explicitly on impact derived from Cardiff-specific activity on the SPIRE instrument and science programme.

Media exposure: During the REF period, 95 items of media coverage have publicised the technical and scientific work of the Cardiff team. This includes articles, referring specifically to Cardiff's involvement, in UK and foreign newspapers including *The Independent, The Sunday Times, The Daily Telegraph, The Calgary Herald, Asian News International, The Qatar News Agency,* and many more. *Herschel* was designated number 7 in *Time Magazine's* Inventions of the Year in 2009 (http://www.time.com/time/specials/packages/completelist/0,29569,1934027,00.html). Cardiff staff have made many appearances on BBC TV and radio including the *Today Programme*, *Science in Action* and Radio 5 Live. A two-part Radio-4 documentary, *The Herschel Space Telescope* was first broadcast in 2009 and followed Matt Griffin and the UK SPIRE team before and after the launch (http://www.bbc.co.uk/programmes/b00nvt8r). It has reached over 1.5 million listeners, and was featured as radio pick of the day by *The Guardian*, *The Daily Telegraph*, and *The Times* [5.1]. There have been at least 24 BBC News website articles, by BBC Science Correspondent Jonathan Amos and others, highlighting the technology and science results (many

based on direct collaboration and contact between the BBC journalists and Cardiff team members, and 11 of which feature quotes from Cardiff staff). They were typically accessed 100,000–200,000 times in the first 24 hours. Jonathan Amos wrote: "As a journalist, I am constantly looking for a strong narrative and compelling imagery. *Herschel* has consistently provided both since launch. . . The SPIRE group has routinely recognised those pieces of research that will reach out best to the general public, and have been able to convey this interest in very engaging terms. The website (http://herschel.cf.ac.uk/), also, is a model for how to present sometimes complex findings. Far infrared pictures are not very easy to negotiate with a lay eye. The website's stepwise approach, using annotation and very clear terms, is a big help in this respect." [5.2]

Outreach web site: The UK *Herschel* outreach website (http://herschel.cf.ac.uk/) maintained at Cardiff by the HOO, contains up-to-date *Herschel* information with images, results, news stories, press releases, and downloadable material. It is one of the most comprehensive websites about *Herschel* in the world. Traffic statistics (on file) show over 100,000 unique visitors since monitoring began (Aug. 2009) with an increasing trend and peaks when press releases are issued. Links from popular sites such as BBC News provide excellent reach. Educational resources, and "fun" activities for the casual visitor can be downloaded, and that section has been visited over 5,000 times. Materials include classroom activities, posters, self-assemble cardboard models, and links to other educational resources. *Chromoscope*, a tool to show the sky at multiple wavelengths including *Herschel's,* was developed by the HOO and others (http://www.chromoscope.net/; hosting funded by Cardiff Physics & Astronomy). *Chromoscope* is one of the most popular astronomy tools online (more than 3 million unique visitors since Nov. 2009), and is used extensively on the *Herschel* UK website to display results.

Schools programme: We have developed and implemented a schools programme with the assistance of teaching professionals. It consists of interactive lesson plans, talks, and demonstrations using *Herschel* to illustrate several subject areas: multi-wavelength astronomy, spacecraft engineering, space dust, cosmology, and the solar system. Resources were initially trialled by several SPIRE team members from Cardiff and RAL at Monkton Combe School in Feb. 2009, when Cardiff staff, post-docs and students, delivered a week-long Scientists in Residence programme at the school. The programme, for pupils in years 7-13, was based on the science and technology of the *Herschel* and *Planck* missions, and covered aspects of astronomy from the Solar System to Cosmology. The entire week was well received, with 90% giving their sessions at least 3 out of 5 in terms of amount learnt, and 65% giving a mark of at least 4. Sam Chilcott, Monkton Combe science teacher, wrote: "One of the most fulfilling weeks of my professional career was when the Cardiff Astronomy team came over to Monkton. To see the enthusiasm engendered in the pupils, not only in that week, but in the months and years afterwards - indeed, they are still talking about it!" [5.3].

The *Herschel Schools Show* was developed by *science made simple*, an outreach company linked to the School, in collaboration with the Cardiff SPIRE team. Aimed at years 7-11 (KS3 and GCSE), It demonstrates aspects of *Herschel* science and technology. First run in 2007, it was updated to include *Herschel* scientific results. The show has been given ~30 times during the REF period, to a total audience of ~4,000. Evaluation questionnaires (on file) showed that 87% of respondents rated the show as very good or excellent. Instructively, only 25% of them had more than a passing interest in astronomy before seeing the show [5.4].

This activity was later developed by the HOO into a package that has been distributed to teachers as part of our teacher Continuing Professional Development (CPD) programme which he organises. A series in 2010 across Wales (Aberystwth, Cardiff, Camarthen, Llantarnum, Wrexham) reached 130 teachers, and sessions at the National Space Centre and Science Learning Centre, Leicester, have reached 90 teachers. Feedback from teachers attending (on file) was excellent with 78% indicating that they would use the resources in their teaching. David Grace, secondary school teacher and PGCE tutor commented that ". . the subject matter is generally very motivating to most pupils across the ability range" [5.5]. With each secondary school teacher reaching ~100 new pupils each year (based on 1000 pupils per school over 5 school years [5.6]), and with 1.6 – 2 physics teachers per school [5.7], the total reach of these sessions is over 20,000 pupils per year. A Cardiff University I&E fund award of £9k was made in Apr. 2012 for further support of a Welsh schools programme, and the HOO has developed close links with the University's Schools

Partnership Officer and Community Engagement Team. Our *Herschel* teacher CPD work has helped us to establish a Cardiff role (Gomez Co-I) in *Inspiring Science Education*, a European Union project to develop and deploy science educational resources across Europe. The £158k Cardiff allocation will employ Dr. North when the HOO grant terminates in Nov. 2013, in a role that will continue to use *Herschel*-based material for a European-wide educational programme. In addition, a Welsh Government grant of £73k (Gomez PI) has recently been awarded (Oct. 2013) to bring our astronomy resources, including *Herschel*, into Welsh primary schools.

Public talks, exhibitions and events: During the REF period 75 popular talks on *Herschel* have been given by Cardiff University staff at numerous venues in England and Wales, with total audience numbers in excess of 6,500. Talks have been very well received and we have a substantial collection of very complimentary thank-you e-mails and letters on file. As an example, in an audience evaluation carried out by the organisers of an East of England Engineering Science and Technology Association (EESTA) event in Nov. 2012 at which Matt Griffin spoke, out of 172 responses 136 rated his talk as "excellent" and 32 as "good" [5.8]. Eleven major public events have been organised by the HOO and supported by Cardiff staff. Proposals were successful for the Royal Society Summer Exhibition in both 2009 and 2012. Visitors numbered around 5,000 in 2009, and 14,000 in 2012. Stands at the *Big Bang Fair* were bid for and awarded in four successive years (2010-2013), leading to personal invitations to return each year. Cardiff funds and staff time were used to support these events, and the 1:4 scale model was displayed. Each *Big Bang Fair* was attended by around 35,000 people, mostly secondary school pupils. In Oct.-Nov. 2010, the 1:4 model was provided for a temporary astronomy gallery at the National Museum of Wales, Cardiff - during this period ~20,000 people visited the museum. In Jan. 2012 another NMW exhibition included Cardiff staff and *Herschel*-related activities; 3000 people visited the museum that day. *Herschel*-themed products are given away as freebies at events and exhibitions, bought from a combination of internal Cardiff funds (~50%) and from the Cardiff-based STFC SiS grant (~50%).

In summary, our *Herschel* research and accompanying PR and outreach programme have given the public valuable and exciting insights into science and technology. Importantly, this extends to enhancing educational learning and stimulating engagement with STEM subjects in schools. With many more scientific discoveries to come from *Herschel*'s database of observations, the outreach programme will be sustained, and contacts with educators and the media will be continued.

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 E-mail from the producer of the two-part Radio 4 documentary *The Herschel Space Telescope* confirming the audience numbers and other information about it in Section 4.

5.2 E-mail from the author of many of the BBC News web site articles mentioned in Section 4 confirming readership statistics, our interaction with him, and the statement attributed to him.

5.3 Letter from the Monkton Combe School science teacher mentioned in Section 4 confirming the statement attributed to him and commenting on our dealings with his school.

5.4 A report on the *Herschel* Schools Show, *Herschel and the mysteries of the cold universe*, is at http://www.sciencemadesimple.co.uk/files/herschel_show_report1.pdf and corroborates the statements about it made in Section 4.

5.5 E-mail from the PGCE Physics Tutor, Aberystwyth University, commenting on our *Herschel*-based teaching resources and confirming the statement attributed to him.

5.6 *Secondary School Size: a Systematic Review*, Institute of Education report, October 2004, available at http://eppi.ioe.ac.uk/cms/LinkClick.aspx?fileticket=u9LVD2UJU34= corroborates the statement in Section 4 about the reach of teacher CPD sessions.

5.7 *Physics and Teacher Numbers*, IoP briefing note, Sept. 2010, available at http://www.iop.org/news/10/sep10/file_44832.pdf corroborates the statement in Section 4 about the reach of teacher CPD sessions.

5.8 EESTA-conducted audience evaluation report on EESTA Prestige Seminar *Discovering the Hidden Universe*, held on 14 November 2012, confirming the statements about the reception of Matt Griffin's talk.

Copies of all webpages, documents and testimony are available from the HEI on request.