Institution: The University of Manchester

Unit of Assessment: UoA9

Title of case study: Communicating Physics through the Royal Society

1. Summary of the impact

We demonstrate a sustained record of the highest quality public engagement with physics, evidenced by the selection of our research for the Royal Society Summer Science Exhibition on eight occasions in six successive years (2008 - 2013). Collectively, these exhibits have received more than 94,000 visitors, increasing the knowledge of physics and interest in physics of school pupils and the general public. Each exhibit has produced a lasting legacy of on-going public engagement, influencing, for example, the career choices of an estimated 60,000 students.

2. Underpinning research

The research described below underpinned eight separate exhibits at the Royal Society; where no date is given, named academic staff members were in post at UoM/UMIST 1993 – present.

1. A technique for finding planets orbitting other stars, based on gravitational microlensing, was originally proposed by Mao (while at Princeton University; UoM staff 99-) and was developed at Jodrell Bank Centre for Astrophysics (JBCA), leading to the first detections of planets by this technique in 2004-06 (e.g. [1], work led by Mao and involving Rattenbury (RA 04-09)).
2. JBCA played a central role in the 2009 Planck space mission, which has made the most precise map of the Cosmic Microwave Background Radiation, by building the Planck LFI's 30 and 44 GHz low noise amplifiers [2], which are still the lowest noise receivers ever built at these frequencies. The work was led by Davis (staff, awarded an OBE for this in 2011) whilst Maffei (staff 06-) and Pisano (staff 06-) played key roles in the HFI optics. Early findings included the most precise spectrum of spinning dust emission from the interstellar medium led by C Dickinson (RA 07-09, STFC AF09-).
3. Liquid crystal research from 1995 by Gleeson (staff), Dierking (staff 02-), M Dickinson (staff) and Novoselov, has included understanding novel materials for next-generation fast-switching displays, for example, the first measurement of biaxial order in a nematic liquid crystal [3] and the first physically reasonable model for the origin of polarized vision in vertebrates.
4. The 2004 discovery of graphene by Geim (staff 01-) and Novoselov (staff 06-; RA 01-06) [4] led to the award of the 2010 Nobel Prize in Physics. Many of the unique properties of graphene and its derivatives were discovered and explored in the School. Key among these are the feasibility of working with atomically-thin films [4], the relativistic behaviour of charge carriers, a new kind of Quantum Hall Effect, and the observation of fast spin currents in graphene.
5. Research from 2007 on the photonic and surface properties of quantum dots as light-harvesting elements in next-generation solar cells, and their wider use in the generation of solar fuel, includes the first observation of 'carrier multiplication' (creation of more than one carrier pair per incoming photon) in InP quantum dots [5]. Exploitation offers a significant increase in cell efficiency. Key researchers are: Flavell (staff), Binks (staff 01-), Graham (RA 04-11; EPSRC CAF 11-), Hardman (RA 07-10), Spencer (PG 06-11; RA 11-), and Stubbs (PG 06-10; RA 10).
6. JBCA played an important role in the design and first science of the Atacama Large Millimeter/Sub-Millimeter Array (ALMA). It led the optical design and prototyping of the fibre-optic link technology connecting the ALMA antennas and, since 2009, has hosted the UK Regional Centre, providing support and expertise for astronomers using the ALMA telescope. The first phase of observations started in 2012, with one of the first papers published showed the gravitational collapse of gas around a forming protostar [6]. Key staff: Fuller (staff 1996-) and Avison (PG 07-10, RA 10-).
7. UoM physicists played key roles on the ATLAS experiment at CERN and the D0 experiment at the Tevatron, which led to the discovery of the Higgs boson in 2012. On ATLAS, staff contributed to the construction and operation of the detector (notably Loebinger (staff), Ibbotson (staff -05) and Duerdoth (staff -05)), and to triggering, operation and data analysis (Wengler (staff 05-10), Oh (RS URF 09-), Yang (staff 06-13)) [7]. Several analyses contributing to the Higgs evidence observed at the Tevatron were performed by PhD students, RAs, and staff, notably Soldner-Rembold (staff 03-, D0 coordinator 09-11), Schwanenberger (staff 07-, D0 coordinator 11-12), Peters (RA 05-10) and Petridis (RA 10-12).

3. References to the research

The research was published in international journals where the outputs have received significant numbers of citations. References that best indicate the quality of the research are marked **.

[1] ***Microlens OGLE-2005-BLG-169 implies that cool Neptune-like planets are common*, A Gould *et al.,* 2006, Astrophysical Journal, **644** L37 (2006); **DOI:** 10.1086/505421 (citations: 152 at 11.10.13, WoS)

[2] *Design, development and verification of the 30 and 44 GHz front-end modules for the Planck Low Frequency Instrument*, R J Davis *et al.*, Journal of Instrumentation, **4** T12002 (2009); **DOI:** 10.1088/1748-0221/4/12/T12002 (citations: 14 at 11.10.13, WoS)

[3] *Thermotropic biaxial nematic order parameters and phase transitions deduced by Raman scattering*, C D Southern, P D Brimicombe, S D Siemianowski, S Jaradat, N W Roberts, V Gortz, J W Goodby and H F Gleeson, Europhysics Letters, **82** 56001 (2008); **DOI:** 10.1209/0295-5075/82/56001 (citations: 42 at 11.10.13, WoS)

[4] ***Electric field effect in atomically thin carbon films*, Novoselov KS, Geim AK, Morozov SV, Jiang D, Zhang Y, Dubonos SV, Grigorieva IV, Firsov AA, Science **306** 666 (2004); **DOI:** 10.1126/science.1102896 (citations: 11,698 at 11.10.13, WoS)

[5] *Efficient carrier multiplication in InP nanoparticles*, S K Stubbs, S J O Hardman, D M Graham, B F Spencer, W R Flavell, P Glarvey, O Masala, N L Pickett and D J Binks, Physical Review B **81**, 081303(R) (2010); **DOI**: 10.1103/PhysRevB.81.081303 (citations: 21 at 11.10.13, WoS)

[6] *The first ALMA view of IRAS 16293-2422: direct detection of infall onto source B and high-resolution kinematics of source A*, J E Pineda *et al.,* Astronomy and Astrophysics **544** L7 (2012); **DOI:** 10.1051/0004-6361/201219589 (citations: 11 at 11.10.13, WoS)

[7] ***Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC* the ATLAS collaboration, Physics Letters B **716** 1 (2012); **DOI**: 10.1016/j.physletb.2012.08.020 (citations: 762 at 11.10.13, WoS)

4. Details of the impact

The Exhibitions

The Royal Society's annual Summer Science Exhibition showcases the most exciting cutting-edge science and technology research [A]. It provides a unique opportunity for members of the public to interact with scientists and ask them questions about their work. The Exhibition is the Society's main public event of the year, and is open to members of the general public as well as students and teachers, scientists, policymakers and the media [A]. The exhibitions have taken place annually since 1778, and are widely regarded as the UK's premier public engagement event in science. Our increased participation during the REF period reflects a strategic decision by the UoA to target this event as a vehicle for optimum science communication, drawing systematically on our most exciting and ambitious research. Part of this strategy is to reuse resources produced for the Exhibits building a lasting legacy on the initial development. Since 2008, we have led or played a major (^{3} 50%) role in 4 exhibits:

***AO:* ALMA Observatory – probing our cosmic origins with ALMA** (6 days, 2012) developed in collaboration with Cambridge and led in Manchester by Avison (RA), with UoM providing about half the exhibition team (6 staff, 3 PhD students).
***SF:* Putting sunshine in the tank – using nanotechnology to make solar fuel** (6 days, 2011) led by UoM (PI Flavell, staff), a collaboration with York, Nottingham and East Anglia. UoM provided over half the team of 23 staff, RAs and PhDs.
***GR:* Carbon Flatland – unexpected science in a pencil line** (6 days, 2011) has exhibit team of 30 from various UoM Schools including Physics and Astronomy (including Novoselov, staff).
***LC:* Liquid crystals: living cells and flat screen TVs** (10 days, 2010) was led in Manchester by Dierking (staff) and Gleeson (staff), and in collaboration with Southampton, York and Sheffield Hallam. The exhibit was largely built in Manchester.

We have also made significant contributions (*ca.* 15-30%) to a further 4 exhibits in the period:

***PL:* Planck: Looking back to the dawn of time** (7 days, 2013). A collaboration with Imperial College, the Cambridge, Oxford and Cardiff. UoM RAs Watson and Peel designed and built part of the stand; 8 UoM staff, RAs and PGs made up 20% of the exhibit team.
***HB:* Higgs Boson – understanding the Higgs Boson** (7 days, 2013). A collaboration of 17 UK

universities and RAL. The UoM team was led by Soldner-Rembold (staff) with 4 PDRAs/PGs; UoM provided prizes (books signed by Cox (staff)), and part of an online booklet.
***HP:* From the oldest light to the youngest stars: the Herschel and Planck Missions'** (5 days, 2009) A collaboration with Cardiff, Cambridge, Imperial College, the Mullard Space Science Laboratory, RAL and UK ATC, with Lowe (RA) leading for UoM.
***NW:* Is there anybody out there? Looking for new worlds** (4 days, 2008) With the Open University, QUB, St Andrews, Hertfordshire, Keele and The Faulkes Telescope Project. Our contribution on microlensing was led by Rattenbury (RA).

Selection and Preparation

Seven of the exhibits were selected by the Royal Society *via* a competitive process – e.g. the solar fuel exhibit (**SF)** was one of 21 exhibits selected from 97 applications. Selection criteria included the quality of the underpinning research, and track record in public engagement. The graphene exhibit (**GR**) was by invitation following the award of the 2010 Nobel Prize in Physics. Significant funds were raised from external bodies to enhance a number of the exhibits, for example **SF** benefitted from a £46k EPSRC 'Pathways to Impact' award, enabling construction of a solar fuel demonstrator. Seven of the exhibits were staged at Carlton House Terrace (**NW**, **HP**, **SF**, **GR**, **AO**, **HB, PL)**. The 2010 exhibit, **LC**, was part of a Festival of Science and Arts, held at London's Southbank Centre in celebration of the Society's 350th anniversary**.**

Impact on Visitors to the Exhibits

In total, the eight exhibits received more than 94,000 visitors. Those at the Royal Society saw between 5,000-14,000 visitors each, while the 2010 anniversary exhibition received almost 50,000 visitors [C]. As a typical breakdown of these visitors, the 2011 exhibition (**SF, GR**) was attended by around 14,000 visitors made up of GCSE and A-level students (1852, from 92 schools and colleges), teachers (224), representatives of the media (45), FRS/VIP guests (1425) and other members of the public (10265). The school visitors were gender balanced, 54% white ethnic and 86% from non-independent schools; 91% agreed they enjoyed talking to the scientists [C].

Captivating and enthralling hands-on demonstrations were developed for all exhibits. As illustrative examples, these included (for **LC**) displays of the beautiful iridescence of chiral liquid crystals in temperature sensing devices and on the backs of bugs, and visitors were amazed to see dramatic changes when viewed with polarizing light. Members of the public made liquid crystals undergo phase transitions and saw their response to electric and magnetic fields. At **SF**, visitors were able to make quantum dots luminesce, operate a solar nanocell, producing hydrogen at the stand, and race solar-fuel-powered model cars against the solar-powered equivalent using our solar-powered Scalextrix. At **GR**, visitors were able to make graphene themselves using sellotape, and their samples were examined by optical microscopy to confirm that graphene had been made – an achievement that resulted in the award of a chocolate Nobel Prize medal and badge. At **PL**, visitors were able to use a telephone to dial up the sound of the Big Bang. Typically 60-75% of student visitors felt that the exhibition had made them more interested in science, and more interested in the possibility of a science-based career [C].

Impact on Virtual Visitors – Web Resources and Media Coverage

Alongside each exhibit, significant web-based resources were developed, all of which have a life after the exhibition. These included the exhibit web sites (which remain live and active [A]) and (for the later exhibits) blogs, handouts/booklets (e.g. **HB** [B]), factsheets (e.g. **HP**, **NW**), materials for teachers (e.g. **LC** [D]), videos and an *Ask the Scientist* question and answer forum, live during the exhibition. As examples, in 2013 (**PL, HB**), the main exhibition website was visited 113,630 times [C] and the 2011 main site (**SF, GR**) has been shared on over 3400 social networking sites.

The web-based resources developed during each exhibition have contributed significantly to our ongoing public engagement activities. For example, web-based interactive games and quizzes designed for the **SF** exhibit (allowing the player to make enough solar fuel to launch a rocket) have been played over 4,500 times (and reused on the UoM website), while a linked YouTube video has more than 18,500 views. A *graphene virtual microscope* iPhone app (**GR**) has now been downloaded over 10,000 times from Google Play and iTunes. One of the key elements of **HP** was the *Chromoscope* software tool to explore multi-wavelength views of the Universe (lead developer Lowe, RA). This has been used since in exhibitions including the Big Bang Fair Manchester in 2010 (22,000 visitors), and was developed into a web-based application [E] which had around 1.5 million users in its first year. It has also been incorporated into a popular 'touchtable' exhibit that has been in use at Jodrell Bank Discovery Centre (JBDC) since it opened in 2011 [F], receiving more than 235,000 visitors. A major feature of **AO** was the *Pynterferometer*, a piece of interactive software which allowed exhibition-goers to use a touchscreen to drag 'antennas' around and investigate how this affects the output of a telescope. This has led to a publication [G], is available for download, and is being developed further for display at JBDC.

Significant media coverage was generated during and after each exhibit. This included BBC news coverage (TV [H] and website [I]), numerous blogs (such as *Climate Change for Obama*, **SF** [J]) and many specialist magazines including *The Engineer* and *Business Weekly*.

The Legacy – Sustained Public Engagement

Following each exhibit, we have received a substantial number of requests to participate in follow-on activity, in the UK and elsewhere. As an example, the graphene exhibit (**GR**) has been subsequently in action at the Manchester Science Festival (MSF) 2011, 2012 and 2013, during National Science and Engineering Week (NSEW) 2012 and 2013, at *Jodrell Bank Live* (JBL) 2012 and 2013 (a science exhibition/rock concert, 11,000 visitors in 2012), in 3 *Meet the Scientist* events at the Manchester Museum of Science and Industry, and at graphene EU flagship promotion events, such as the Graphene 2012 International Conference in Brussels (10^{th}-13^{th} April 2012). The latter was attended by 600 researchers, industrialists, policymakers and investors. More generally the exhibits have been in demand at large venues such as JBL, MSF, NSEW and Big Bang, London (**LC**, 30,000 visitors) but also in smaller events targeting 'difficult to reach groups', for example, the solar-powered Scalextrix from **SF** was a highlight of *Revolution* – a fun day in Ancoats, an inner city area of Manchester, 2011, part of *Moving Planet: a day to move past fossil fuels* [K]. The exhibitors have collectively given a huge number (we estimate, hundreds) of public engagement talks to e.g. Sci-Bars, Café-Scientifiques, Guilds, professional bodies such as IOP and IChemE, and schools. Feedback from follow-on events suggests that this engagement is as effective as the original exhibitions [e.g. F]; this allows us to estimate (conservatively) that this legacy activity has positively influenced more than 60,000 students towards choosing a science-based career.

5. Sources to corroborate the impact

[A] Corroboration of exhibition descriptions, purpose and role as viewed by the Royal Society: http://royalsociety.org/summer-science/

[B] Example of secondary impact through exhibit booklet (**HB**) 'Understanding the Higgs Boson' http://www.hep.phy.cam.ac.uk/~harrison/understanding-the-higgs-boson/printshop/booklet.pdf

[C] Corroboration of exhibition statistics: Reviews of the Summer Science Exhibition & Soirées 2010, 2011, 2012, 2013, Rachel Francis, Science Communication, The Royal Society.

[D] Secondary Impact through teacher's resources – including 'Science for you to try: Make your own liquid crystal thermometer' (**LC**) http://seefurtherfestival.org/science-you-try-liquid-crystals-living-cells-and-flat-screen-tvs

[E] Example of secondary impact through development of web-based resources (**HP**): The Chromoscope: http://www.chromoscope.net

[F] Statement from Director of Jodrell Bank Discovery Centre detailing corroboration of secondary impact:

[G] Secondary impact through publication in public engagement (**AO**): 'A graphical tool for demonstrating the techniques of radio interferometry', A Avison and S J George 2013 *Eur. J. Phys.* **34** 7 doi:10.1088/0143-0807/34/1/7

[H] Example of ongoing media coverage generated (BBC Northwest Tonight, 13.03.12, **GR**): http://www.youtube.com/watch?feature=player_embedded&v=qwLBwOJBUBQ

[I] Example of media coverage during exhibit (BBC news website, **SF**): http://www.bbc.co.uk/news/uk-england-norfolk-14031585

[J] Example of impact in blogosphere (**SF**): http://climatechangeforobama.blogspot.com/search?q=Wendy+Flavell

[K] Example of secondary impact through ongoing engagement (**SF**) http://www.moving-planet.org/