Institution: University of Birmingham

Unit of Assessment: UoA 09 – Physics

Title of case study: Engaging the public with Physics: scientists for tomorrow's world

1. Summary of the impact

The power of physics, from the largest to smallest scale, to capture the imagination is unrivalled. This has been used as a vehicle for engagement and education in a wide-ranging series of public-engagement activities over the period 2008-2013. These activities (over 130 outreach events per year) are closely linked to the full spectrum of the School's research. Here the focus is Astrophysics, Nuclear Physics and Particle Physics and is built around live events, hands-on demonstrations, educational software development, and media work. The activities have engaged young people through schools and family groups, with a broader cross section of the general public also reached. Birmingham's leadership is evidenced through its major role at each of the Royal Society Summer Exhibitions since 2011, the delivery of extensive national and regional activities supported by the IoP and the STFC, its extensive schools' programme and wide media exposure. The activities have communicated the significance of recent discoveries in physics and astronomy, showing how research, including by Birmingham scientists, has led to these.

2. Underpinning research

The ability of fundamental physics, at the extremes of length scales, to capture the public imagination is remarkable. Our research covers several frontier topics with the highest popularity. The impact described in this case study is underpinned by the University of Birmingham's cutting-edge research in Astrophysics, Nuclear Physics and Particle Physics. The corresponding research highlights are summarised below.

Particle Physics: The behaviour of the Universe at the smallest distance scales is described by a set of theories known as the Standard Model of Particle Physics. Members of Birmingham's Particle Physics group have a long history of leading roles in experiments (e.g. UA1, OPAL, ATLAS) which have been central to the establishment of the Standard Model, notably through the discoveries of the W, Z (led by Prof. Dowell) and Higgs bosons. As of March 2013, Prof. Charlton is the spokesperson of the ATLAS experiment at the Large Hadron Collider (LHC). Group members designed and constructed essential parts of the ATLAS detector and in its exploitation phase are central to the Higgs search programme [1], to studies of top and other heavy quarks and to strong interaction physics. In the LHCb and NA62 experiments, group members perform precise measurements of decays that are ultra-rare in the Standard Model, but can be enhanced by the influence of processes only allowed in Standard-Model extensions [2]. [including: Charlton 1996-2013; Lazzeroni 2006-2013; Newman 1996-2013, Nikolopoulos 2011-2013; A. Watson, M. Watson 2008-2013; N. Watson 2011-2013; Watkins, Wilson, Hawkes 1998-2013; Goudzovski 2008-2013]

Nuclear Physics: Under extreme conditions of density and temperature, nuclear matter undergoes a phase transition into a state of matter known as a quark-gluon plasma. This state is thought to have existed in the first ten microseconds after the formation of the Universe, and is recreated in heavy-ion collisions in ALICE at the LHC. Members of the Nuclear Physics group have leading roles in studies of the properties of the quark-gluon plasma, and the production of specific particle species in this medium [3]. These studies provide new information on the strong interaction, and improve understanding of the early Universe. [Staff: Evans, Lazzeroni, Jones 1995-2013]

Astronomy: Research activities in astronomy at Birmingham cover several frontier topics: (a) Most of the mass in the Universe is actually "dark". Our gravitational lensing programme directly probes the dark matter that dominates galaxy clusters [4], and also helps to constrain "dark energy". The best-known dark objects are black holes. Birmingham researchers use the world's most powerful low frequency radiotelescope, GMRT, to study the enormous jets ejected at relativistic speeds from the supermassive black holes at the centres of large galaxies as they swallow material from their surroundings [5]. [Staff: Ponman, Raychaudhury 2000-2013; Smith 2005-2013] (b) Closer to home, the research frontier is the search for Earth-like planets. Researchers are playing a leading role in this search by studying the properties of the stars that host them, using the technique of asteroseismology first developed at Birmingham. Much of the most exciting data comes from NASA's Kepler Mission, and Birmingham asteroseismology results [6] are key to determining whether newly discovered planets are potentially habitable and how common such systems might be. [Staff: Chaplin 1999-2013, Elsworth, Miglio 2011-2013] (c) A whole new branch of astronomy is due to open in the next five years, with the possible discovery of gravitational waves - the ripples in space-time predicted by General Relativity. Birmingham researchers are working to decode

astrophysical signals from the large international laser interferometers that they have helped to build, and are also developing new optical technologies [7] which will allow the next generation of instruments to study exotic phenomena such as the merger of black holes. [Staff: Freise 2005-2013, Mandel 2011-2013, Vecchio 2000-2013].
All individuals mentioned above are Lecturers or Research Fellows in the School of Physics and Astronomy.

3. References to the research

1. *Search for the Standard Model Higgs boson in the decay channel H→ZZ→4ℓ with 4.8 fb^{-1} of pp collision data with ATLAS:* Phys. Lett. B **710** (2012) 383-402 http://dx.doi.org/10.1016/j.physletb.2012.03.005
2. *Test of lepton flavour universality in K+→ℓ+ν decays*. Lazzeroni, C., *et al.* (NA62 Collaboration), Phys. Lett. B **698** (2011) 105 http://dx.doi.org/10.1016/j.physletb.2011.02.064
3. *Suppression of charged particle production at large transverse momentum in central Pb–Pb collisions*. Aamodt, K. *et al.* (ALICE Collaboration), Phys, Lett. B **696** (2011) 30-39 http://dx.doi.org/10.1016/j.physletb.2010.12.020
4. *A comparison of Sunyaev-Zel'Dovich Effect and Gravitational-Lensing Measurements of Galaxy Clusters.* Marrone, D.P., *et al*., ApJ Lett. **701** (2009) L114-L118 http://dx.doi.org/10.1088/0004-637X/701/2/L114
5. *Heating The Hot Atmospheres of Galaxy Groups and Clusters with Cavities*., E, *et al.*, ApJ **735** (2011) 11: http://dx.doi.org/10.1088/0004-637X/735/1/11
6. *Ensemble Asteroseismology of Solar-Type Stars with the NASA Kepler Mission*. Chaplin, W. J., *et al.*, Science **332** (2011) 213: http://dx.doi.org/10.1126/science.1201827
7. *A gravitational wave observatory operating beyond the quantum shot-noise limit*. Freise, A., *et al.*, Nature Physics **7** (2011) 962: http://dx.doi.org/10.1038/nphys2083

Outputs that best indicate the quality of the underpinning research are references 1, 6 and 7,

4. Details of the impact

The search for an understanding of the Universe as a whole (Astrophysics) and of its fundamental constituents (Particle and Nuclear Physics) holds a special fascination for young people and the public at large. This is employed as a vehicle for public engagement and education in an extensive outreach programme, closely linked to the School's research activities in the relevant areas. The unique features of this outreach programme are the size and diversity (both in terms of types of engagement and the subject range).

Engagement is via science exhibitions, development of novel practical and computer based demonstrations through to conveying science through art and theatre – leadership recognized through a STFC Public Engagement Fellowship. Birmingham is in the top two recipients of STFC Small Awards for Public Engagement, with 17 since their inception (1999), demonstrating sustained leadership. Since 2008 there have been 5 awards to Birmingham in particle physics; more than any other UK institution. The School is unique in having led two multi-institute exhibits in the past three years ("Discovering Particles" in 2011 and "Understanding the Higgs boson" in 2013). It was also involved in "Cosmic 100" in 2012. Prof. Watkins represents the whole UK on the International Particle Physics Outreach Group.

Activity and Reach:

The programme has been led by Lazzeroni (STFC Public Engagement Fellow), Evans, Raychaudhury and Freise in conjunction with Lynne Long, the Schools Liaison Officer. The School of Physics and Astronomy runs, on average, **130** outreach events per year which include (all longstanding annual events) an IoP sponsored programme of 8-10 evening lectures for A-level students (typical audiences are 200-300), themed Master classes (particle, nuclear and astronomy), Physics Summer School (50 students), the regional Physics Quiz (300+ Y9 students), Activities/Challenge Days (attended by 300 students from 30 different schools), an “Ideas Day for Teachers and Technicians” and a biannual “Residential Teachers' Conference”. We also train teachers through themed events such as “Discovering the Cosmos Teacher Training Workshop”. This considerable programme, the vast majority of which is linked directly to the three research themes, is coupled to the development of a series of innovative activities for public engagement, which place the emphasis on participation, and helping make Birmingham's cutting-edge research widely accessible. These activities include:

Particle Physics and Nuclear Physics

- Demonstrations of functioning particle detectors, illustrating the principles of operation of detectors developed at Birmingham for experiments at the Large Hadron Collider.
- The Feynman Zoo, where visitors create animals from Feynman diagrams, and learn how these diagrams underlie studies undertaken by Birmingham researchers in their experiments at CERN.
- Understanding W, Z and Higgs events using an adaptation of the ATLAS event visualization software (MINERVA) – used in the experiments at CERN.
- Development of a booklet "Understanding the Higgs Boson" - produced for the 2013 Royal Society Summer Science Exhibition (2000 copies distributed). Birmingham had a central role in the Higgs discovery.

Astronomy

- Use of a small-scale prototype of a seismic-isolation system and of a compact Michelson interferometer to demonstrate techniques for detecting gravitational waves used in our research.
- Converting star oscillations, recorded by the Birmingham solar-oscillation network (BISON), into sound - music of the Sun.
- Development of an online resource for gravitational waves, providing information, games, and real research software tools used for detector design, illustrating principles of our research.

During the period 2008-2013, different combinations of the above activities, plus others, have been successfully used in more than 300 school visits, around 50 public talks, and at major science festivals, including the Royal Society Summer Science Exhibitions of 2010, 2011, 2012 and 2013, the Manchester Science Festival 2011, the Brighton Science Festival 2012, the Big Bang Fair 2012, and Bang Goes the Theory Live 2012. The total numbers of people reached are approximately 10,000 through school visits, 5,000 through public talks and 50,000 through science festivals (sources 1, 2 and 7).

The message of the live events is reinforced by educational material on particle and nuclear physics and astronomy research, made available via the outreach websites of these research groups within the School, which have received more than 10,000 visitors, and through media work.

The quality and strength of the University's physics-related public-engagement work has been recognised through its attraction of funding from the Institute of Physics, the Royal Society, and the Science and Technology Facilities Council. A notable example is **Lazzeroni's leadership of a team involving 18 UK institutes involved in Particle Physics research in proposing, preparing and staffing the `Understanding the Higgs Boson' stand at the 2013 Royal Society Summer Science Exhibition. The exhibit drew an estimated 7000 visitors, including policy makers, school visitors and the general public.**

The media work undertaken includes radio interviews and television appearances and contributions to newspaper articles discussing Birmingham's research results, for example, from ATLAS [Charlton, Newman], from ALICE [Evans] and from the Kepler Mission [Chaplin]. With an average of 30 interviews per year in radio/TV and national/international newspapers and average figures for the audience, the total number of people reached through this work is estimated to be in excess of 30 million worldwide (source 5).

Significance:

The immediate impact of live events has been assessed by asking random samples of visitors to complete feedback forms (~450). Over a range of events, the feedback has been consistent, and overwhelmingly positive. Some example statistics are summarised below (sources 1, 2 and 3):

- Bang Goes the Theory 2012: in responses from visitors in family groups, 97% said that they had learnt something new about particle physics, and 80% said that they were more interested in particle-physics research;
- Birmingham Astrophysics Schools' Outreach Day 2011: in responses from school pupils, 90% said that they were more interested in undertaking further study in physics;
- Birmingham Astrophysics Public Outreach Day 2010: in responses from visitors in family groups, 89% said that they had learnt something new, and 97% said that they would be keen to attend similar events in the future.

The impact of the Birmingham outreach activities suggested by the survey results is consistent with that represented in written comments from people and organisations with a strong interest in science promotion. Examples are given below:

- Assistant Producer for Bang Goes the Theory Live 2012: "*They used easily accessible exhibits to show complex scientific processes which were fascinating to the visitors*."
- Science teacher at Holy Trinity School, Kidderminster: "*The students […] were motivated highly by the day and have asked for astronomy to be included in the option choices at GCSE.*"
- Learning and Operations Manager, Birmingham Science Museum (Thinktank): "*We see children becoming the 'teachers' as they explain a particular concept to their parents*"
- Physics World, 2011, reviewing the online resources for gravitational waves: "*This is different from most research-group websites... Kudos to the Birmingham group for doing something more interesting here.*"
- Managing Director at Space Inspired, on the online resources for particle physics: "*The website is a fabulous teaching resource, providing both imaginative and useful resources*."
- Head of Science Faculty, Yardleys School Birmingham: "*There has been a narrowing of the 'gap' in achievement in Physics at Yardleys over the past three years … and there is no doubt in my mind that Dr. Lazzeroni's visits have contributed to this*"

Sustainability:

In addition to having an impact on participants, the outreach programme has led to a variety of follow-up initiatives, providing indicators for longer-term success. For example:

- Online resources on particle physics have been linked to the section of the Royal Society Education website on particle/quantum activities for Key Stage 5.
- Online resources for gravitational waves and for the MINERVA ATLAS event visualisation have continued to attract hundreds of downloads per day (source 3 and 4).
- Information panels on research at the Large Hadron Collider were translated into Welsh for use at the National Eisteddfod of Wales 2012.
- Collaborations between arts and science have been established: Tom Espinor's play *Going Dark* (Warwick Arts Centre, October 2011; Young Vic, March 2012) draws from Birmingham's research on dark matter and dark energy (total audience of 8400). A second run is starting next year - to tour the UK including two weeks at the Science Museum; Caroline Devine's sound collage *5 minute oscillation of the sun* (Milton Keynes International Festival, July 2012) uses data from the Birmingham solar-oscillation network (source 6). An extension of this is funded through an IoP outreach grant to put an art-science installation into Thinktank.

The outreach programme has allowed the School to develop important relations with organisations such as ThinkTank, the Royal Society, and the BBC. This collaboration helps ensure that wide-ranging public engagement, based on current physics research, can be maintained into the future. The School will continue evaluating the popularity and impact of its outreach activities, and to monitor the science-subject intake from the schools engaged through these activities.

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

1) Numbers and surveys for Royal Society Exhibitions, data on RS online resources provided by Royal Society Education Outreach Manager
   http://invigorate.royalsociety.org/ks5/the-best-things-come-in-small-packages.aspx
2) Data provided by organisers (BBC Bang Goes the Theory Roadshow - BBC Learning Assistant Producer; Big Bang Fair, IoP Outreach Coordinator; Manchester Science Festival, Science Communication Officer, MOSI; Thinktank Birmingham Science Museum; Brighton science festival; National Eisteddfod of Wales; Outreach Officers, University of Birmingham).
3) Particle Physics website, with result of surveys and booklet, and activities:
http://www.ep.ph.bham.ac.uk/DiscoveringParticles/
4) Statistics on computer-based resources available at www.gwoptics.org and
https://dcc-llo.ligo.org/cgi-bin/DocDB/ShowDocument?docid=97549
5) Statistics on broadcasting provided by University Communications Team
6) Milton Keynes Gallery and Art Council England, South Cheshire Astro. Society