

Institution: The University of Glasgow
Unit of Assessment: B9: Physics
Title of case study: Revolutionising schools and public engagement with cosmology, relativity and gravitational-wave astronomy
1. Summary of the impact

University of Glasgow researchers have played a pivotal role in enhancing awareness and understanding of cosmology, relativity and gravitational-wave astronomy on the national and international stage.

- The 'Astronomy's New Messengers' public exhibition on gravitational-wave astronomy has been displayed at international events that have attracted a total audience exceeding a million people. A survey conducted at the World Science Festival 2010 indicated that 89% of visitors found the exhibition had increased their interest in science.
- The University of Glasgow has had a crucial influence on the redesign of the Scottish Higher and Advanced Higher Physics syllabus to include significant content on cosmology, relativity and gravitational astrophysics. In 2012 the revised Higher Physics pass rate was approximately 4% greater than that for the non-revised Higher, demonstrating significant impact in terms of pupil engagement and results.

2. Underpinning research

The University of Glasgow's Institute for Gravitational Research (IGR) has more than 30 years of international research experience at the forefront of gravitational-wave astronomy [1]. The group's expertise includes laser interferometry, materials science, astrophysical modelling and data analysis. Several IGR staff hold leadership positions within the LIGO (Laser Interferometer Gravitational-Wave Observatory) Scientific Collaboration: a team of over 900 scientists worldwide, leading the search for direct detection of gravitational waves. Key staff are: James Hough – Lecturer 1972-83, Senior Lecturer 1983-86, Professor 1986-present, Director of IGR 2000-2009; Sheila Rowan – Postdoctoral Research Associate [PDRA] 1994-2002, Research Fellow 2002-03, Reader 2003-2006, Professor Experimental Physics 2006-present, Director of IGR, 2009-present; Ken Strain – PPARC Advanced Fellow 1995-99, Lecturer 1999-2003, Professor 2003-present; Graham Woan – Lecturer 1996-2003, Senior Lecturer 2003-2006, Reader 2006-2010, Professor of Astrophysics, 2010-present; Martin Hendry – PDRA 1996-1998, Lecturer 1998-2003, Senior Lecturer 2003-2011, Professor of Gravitational Astrophysics and Cosmology 2011-present, Head of School of Physics and Astronomy, 2012-present. In particular Martin Hendry is a founding member and European coordinator of the Education and Public Outreach Group of the LIGO Scientific Collaboration (LSC), and in 2012 was appointed Chair of Informal Education activities for the LSC. The research excellence of IGR staff was also recognised in 2008 when their exhibit "Can you hear black holes?" designed in collaboration with 3 other UK institutions and the Albert Einstein Institute in Germany, was selected for the Royal Society Summer Science Exhibition. In particular, the table-top Michelson interferometer for this exhibit was designed and built by IGR staff.

Hendry's primary research interests are in cosmology and gravitational-wave astronomy, and in particular the potential use of compact binary neutron star and black hole gravitational-wave sources (so called 'standard sirens') as cosmological distance indicators. This latter topic extends Hendry's wider cosmology expertise in calibrating the extragalactic distance scale and measuring the Hubble constant, and in developing innovative statistical methods for analysing galaxy surveys [2,3]. It is Hendry's research on the cosmological distance scale that is the linking thread underpinning the two outreach projects detailed in this case study. His work in this field has been internationally recognised for the last 15 years, resulting in invitations to workshops in e.g. Strasbourg (1997), Santa Fe (2004), Barcelona (2006) and Banff (2013). He was also an invited

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co-author of the CUP Monograph *Bayesian Methods in Cosmology* (2010) and an invited speaker at the two most recent Statistical Challenges in Modern Astronomy International Conferences (2006 and 2011). Due to the excellence of Hendry's research and his outstanding talent and enthusiasm for public engagement in science, in 2010 he was awarded a Science and Technology Facilities Council Science in Society Fellowship. In 2011 Hendry was then elected a Fellow of the Royal Society of Edinburgh, in recognition of his contributions to research, teaching and schools and public engagement.

3. References to the research

1. Sathyaprakash, B. et al., 'Scientific Objectives of Einstein Telescope', *Classical and Quantum Gravity*, 29, 124013 (2012) DOI: [10.1088/0264-9381/29/12/124013](https://doi.org/10.1088/0264-9381/29/12/124013).*
2. Goodwin, S.P. et al. 'A new determination of the Hubble Parameter using galaxy linear diameters', *Astronomical Journal*, 114, 2212 (1997) DOI: [10.1086/118641](https://doi.org/10.1086/118641).*
3. Hendry, M.A. et al. 'A robust method for measuring the Hubble parameter', *Monthly Notices of the Royal Astronomical Society*, 324, 717 (2001) DOI: [10.1046/j.1365-8711.2001.04377.x](https://doi.org/10.1046/j.1365-8711.2001.04377.x).*

4. Details of the impact

Public outreach and education: Astronomy's New Messengers

In 2009 the Education and Public Outreach Group of the LSC was awarded \$950,000 by the US National Science Foundation for a project called Astronomy's New Messengers. Hendry was co-Principal Investigator and the only PI from Europe, working with colleagues from Columbia, Florida, Michigan and Mississippi. The team successfully designed and built a 20-metre² touring exhibition on gravitational-wave astronomy, which premiered at the 2009 World Science Festival in New York, together with a 100-metre² version that subsequently premiered at the 2010 World Science Festival. The exhibits combined state-of-the-art multimedia, a working table-top Michelson interferometer and Black Hole Hunter: a 'Citizen Science'-style interactive computer game. The larger exhibit also featured an innovative, interactive light sculpture – created by the award-winning New York lighting designer Leni Schwendinger – that represented the signals from different types of gravitational wave sources. These combined elements aimed to engage informal learners, conveying the enormous scientific potential of opening a new window on the Universe, together with the huge technological challenges addressed by gravitational wave astronomy. Hendry was responsible for the initial design concept for the National Science Foundation exhibit and for key aspects of its construction. Drawing directly upon his cosmology and gravitational astrophysics research expertise, and IGR's experience in building "Can you hear black holes?" for the 2008 Royal Society Exhibition, Hendry wrote text for the exhibition panels (including material on the Big Bang and the scale of the cosmos), assisted with designing the table-top Michelson interferometer, edited and installed the Black Hole Hunter game and helped design the multimedia displays. He also established the partnership with Leni Schwendinger.

The gravitational-wave astronomy exhibition (both 20-metre² and 100-metre² versions) has been displayed in over 20 locations across 15 US states to date. In addition to the World Science Festivals in New York, they featured in the 2010 and 2012 US National Science and Engineering Expos in Washington DC. Total participation at each World Science Festival and each National Science and Engineering Expo was estimated by their organisers at 150,000 and 500,000 respectively – indicating the scale of the events in which the exhibits have been showcased. Exact numbers of visitors to our exhibit have not been recorded at every venue. For example at the US National Science and Engineering Expos our exhibit was part of an open-plan exhibition space on the National Mall (2010) and the Washington Convention Center (2012). At the 2010 World Science Festival in New York, however, the large exhibit was displayed at its own venue on Wall St where exact audience figures could be recorded. It was visited by nearly 6,000 people. The touring exhibit was estimated to have been seen by around 40,000 people at the Adler Planetarium (Chicago) in 2009, when it was located in the entrance foyer of the Planetarium. A parallel version

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of the exhibit has also been displayed at venues in the UK, including at the 2012 Gravity Fields Festival in Grantham (where Hendry was interviewed by 'The Material World' on Radio 4) and most recently at the flagship BBC Scotland event for 2013 Stargazing Live at Glasgow's Botanical Gardens, attended by 4,500 people.

The aim of Astronomy's New Messengers was to engage adolescents and young adults, increasing their interest in, and understanding of, gravitational-wave astronomy and LIGO science. The effectiveness of the exhibits was evaluated via visitor surveys designed by the Center for Educational Research and Evaluation at the University of Mississippi. Key results include:

- 80% of respondents indicated that the touring exhibit had helped them understand LIGO;
- Over 70% of respondents indicated that the touring exhibit had increased their interest in science, while 89% indicated that the large exhibit had increased their interest in science.

A new physics curriculum in Scottish schools

Combined with the IGR's world-leading reputation in gravitational physics, Hendry's international research reputation in cosmology has positioned the University of Glasgow as a key consultant for the development of the Physics syllabus for the Curriculum for Excellence in Scotland. This role was formalised in 2010 when Hendry was invited by the Royal Society of Edinburgh to join the Physics Qualifications Design Team and the Mathematics Excellence Group – a strategic advisory group set up by the Cabinet Secretary. Through this membership, Hendry has:

- Provided technical advice and scientific oversight for the creation of new astrophysics, cosmology and relativity content for the revised Higher and Advanced Higher Physics courses. Topics now featured in the syllabus include: the Big Bang, Hubble expansion and the CMBR; evidence for dark matter and dark energy; stellar evolution; special and general relativity. Hendry has provided CPD sessions for teachers and edited teacher support materials commissioned by Education Scotland;
- Overseen the introduction of a new 20-hour module on 'Researching Physics' for the Higher, which aims to showcase cutting-edge physics research in Scotland via direct pupil participation in open-ended investigation. Hendry played a key role in developing an exemplar – on gravitational astrophysics and extra-solar planets – for this module, which has been very successful.

Over the next three years, the revised Curriculum for Excellence Higher and Advanced Higher syllabus will be adopted by all Scottish schools. In 2012 and 2013 the first 'early adopter' schools presented pupils for the revised Higher and Advanced Higher respectively. The impact of the new courses has been evaluated by the Scottish Qualifications Authority (SQA) as significant, both in terms of pupil engagement and examination results. In 2012 the revised Higher Physics pass rate was 4% above that for the non-revised Higher. The SQA Qualifications Manager confirmed that these results exceeded their expectations "even allowing for the history of high achievement in many of the centres presenting for the revised Higher Physics course" and stated that "the curriculum support Professor Martin Hendry and colleagues has given to schools has played a significant role in this outcome". Furthermore he reported that during the 2011-12 and 2012-13 sessions "feedback from the early adopter schools indicates that the engagement by pupils with the cosmology and astrophysics content of the revised courses for Higher and Advanced Higher Physics has been very positive".

5. Sources to corroborate the impact

- NSF award details for the 'Astronomy's New Messengers' project http://www.nsf.gov/awardsearch/showAward?AWD_ID=0852870
- Astronomy's New Messengers Exhibition details, University of Mississippi website <http://ligo.phy.olemiss.edu/LIGOexhibit/>
- Final report to the NSF, including the CERE evaluation report (available from HEI)
- 'Can you hear black holes?' at the 2008 Royal Society Summer Science exhibition <http://royalsociety.org/summer-science/2008/hear-black-holes/>

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- Letter from SQA Physics Qualification Manager (available from HEI)
- Education Scotland, NQ Higher Physics – Learning and Teaching Resources
http://www.educationscotland.gov.uk/video/p/video_tcm4664306.asp
- Education Scotland, Teachers' Support notes on Space and Time (available from HEI)
- 2012 SQA results statistics for Higher Physics, including a comparison between the revised Higher and non-revised Higher results (available from HEI).