**Institution:** Queen Mary University of London (QMUL)

**Unit of Assessment:** Physics B9

**Title of case study:** String Theory and Particle Physics Reach a Contemporary Art Audience

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

Few scientists in the UK have done as much as Dr David Berman and Dr Ben Still to bring the latest ideas and results from string theory and particle physics research into the contemporary art world. In 2010, Berman established an artist-in-residence post at QMUL's Centre for Research in String Theory, with Turner Prize winner Grenville Davey the first artist to take up the residency. This collaboration led to Davey creating sculptural responses to the Centre's work on generalized geometry and the role of duality, which have been exhibited widely. Berman has also collaborated with conceptual artist Jordan Wolfson for a work at the Frieze Arts Fair, which won the prestigious Cartier Award in 2009. He has given talks at the Institute for Contemporary Art, the Royal College of Art, Tate Modern and the Core Gallery, and will be curating further exhibitions in 2014. Still has initiated award-winning collaborations with artists, creating diverse artworks that draw-on QMUL's experimental research on neutrino physics, which have been exhibited at numerous venues. This work has transformed the practice of artists and brought complex theories and conceptual ideas to audiences that may not have had much previous knowledge or interest in these areas. Attracting widespread media coverage in both the arts and science press, the work has encouraged greater public discourse around string theory and particle physics.

**2. Underpinning research** (indicative maximum 500 words)

String theory has proven to be an extremely rich and fertile ground for producing concepts and ideas far from our usual experience. One of string theory's central ideas is the concept of "duality". This is a hidden symmetry of the theory that relates different spacetime geometries (recall how in Einstein's theory of general relativity, space and time combine into a single curved space – the curvature of the space relates to the gravitational field). Because of this duality symmetry, space-times that appear naively different may in fact be physically equivalent.

Between 2008 and 2013, Dr David Berman's research [1-4] has focussed on reformulating string theory to make the duality symmetries a manifest property of a new formalism to describe string theory. There are many reasons to do this. Symmetry is at the heart of theoretical physics and any formalism should attempt to make manifest the symmetries present in a physical theory.

The key idea in allowing duality to become manifest has been to extend the number of dimensions of spacetime and have what we think of as the physical spacetime emerge as a projection [3,4]. Different projections then correspond to what we think of as different spacetime geometries when, in fact, in this formulation they are just different projections of a single extended spacetime [3,4]. Importantly, once this reformulation has been achieved it also suggests new and exciting physical backgrounds for string theory such as so-called "non-geometric backgrounds", which are space-times that cannot be described within general relativity, but can with the new duality manifest formulation. These non-geometric backgrounds exist because they are perfectly well behaved geometries from the extended point of view, but the projection onto a single ordinary spacetime cannot be achieved due to topological restrictions. These backgrounds appear to have crucial phenomenological properties that have yet to be fully explored.

In addition to this work on making hidden symmetries manifest, Berman has studied how objects in string theory such as strings and membranes interact [1,2]. The link to the reformulation of string theory comes from the physical constraint that these objects must see the extended space and the projected space in the same way, and their interactions must work the same in both spaces.

Research in QMUL's Particle Physics Research Centre (PPRC) is concerned with understanding the fundamental constituents of the universe and their forces of interaction. Dr Still and other PPRC colleagues play a central role in the T2K experiment in Japan, where a long baseline neutrino beam is aimed at the Super-Kamiokande detector in an attempt to understand the interactions and strange oscillation behaviour of neutrino particles. Oscillations, in which one type of neutrino may change into one of the two other types over a journey of many kilometres, are key

indicators of underlying fundamental physics. Recent breakthroughs in understanding have come from landmark research to which Dr Still and colleagues have made significant contributions [5].

Our research in fundamental physics has inspired artists who are drawn to the focus on geometry; the idea of spacetime itself being a projection or shadow from a larger extended space; the hidden duality symmetry being a consequence of different projections or perspectives. A key motivation has been the desire to find innovative ways of representing QMUL's research into complex subatomic processes; to explore areas where the language of physics has entered the common lexicon but the underlying concepts remain abstract and mysterious.

**3. References to the research** (indicative maximum of six references)

[1] 'M-theory Branes and their interactions', D.S. Berman *Physics Reports* 456 (2008) 89-126.
[2] 'Aspects of multiple membranes', D.S. Berman, L. Tadrowski and S. Thompson, *Nuclear Physics B* 795 (2008) 201.
[3] 'M-theory and Generalized Geometry', D.S. Berman, M.J. Perry, *JHEP,* 1106 (2011) 074.
[4] 'The Local symmetries of M-theory and their formulation in generalised geometry', D. S. Berman, H. Godazgar, M. Godazgar, M. J. Perry, *JHEP* 1201 (2012) 012.
[5] 'Indication of Electron Neutrino Appearance from an Accelerator-Produced Off-Axis Muon Neutrino Beam', K. Abe et al. (T2K Collaboration), *Physical Review Letters* 107 041801 (2011)

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

From da Vinci's *The Vitruvian Man* through to the experimental writing of modernists such as Virginia Wolf and James Joyce, scientific ideas have long informed artistic works. The collaborative work of Berman and Still with contemporary artists ensures this tradition survives today.

**Collaborating with artists and informing their work**
Research carried out at Queen Mary's Centre for Research in String Theory (CRST) and in the Particle Physics Research Centre (PPRC) has proved a rich source of inspiration for numerous artists including Grenville Davey, Jordan Wolfson, Flow Motion, Nelly Ben Hayoun, Lyndall Phelps and twenty-five artist-participants in Still's *Jiggling Atoms* collaboration. The artists worked directly with researchers and sought to understand the latest developments in string theory and neutrino physics, before going on to explore these ideas in a number of artworks. These collaborations between artists and CRST and PPRC researchers led to a significant change in practice for the artists involved, and reached new and diverse audiences at galleries and art and science fairs. Secondary impacts include widespread media coverage, encouraging greater public discourse about contemporary physics and the latest developments in string theory and particle physics.

**Bringing an artist in residence to the CRST**
In 2010, Berman initiated an innovative artist-in-residence post within the CRST. Grenville Davey (Turner Prize Winner in 1992 and exhibitor in the Royal Academy's high-profile Modern British Sculpture exhibition in 2011) was supported by a grant from the Westfield Trust and the Henry Moore Foundation with the purpose to produce work based on the research of CRST. Davey's work over a period of years had been concerned with symmetries and families of related objects and as such he had a natural interest in Berman's work on manifesting duality geometrically.

Commenting on his time at CRST and his sculptural responses to the work on generalized geometry and the role of duality, Davey said: *"The work at Queen Mary on dualities and generalised geometry provides a new challenging way of seeing… This is the sort of thing artists search for and are desperate to find in their work. My art practice and indeed specific sculptures have now been directly influenced through interaction with Dr Berman and the idea of dualities made manifest"* [1]. These works have been shown or will appear at:

- Testbed1 (a gallery linked with the Royal College of Art) as part of the "Our autonomous nature" exhibition (May 2012) in the Chelsea fringe festival, (with audiences of around 1,000);
- Isaac Newton Institute exhibition at Cambridge University Library (June 2012) as part of an art-science talk (audience of 100);
- Financial Services Authority, Canary Wharf (summer 2012);
- The Arts Club, a private members club in Mayfair, (October 2013);
- Chelsea Space Gallery (April 2014) and Ruskin Gallery in Cambridge (May 2014).

**Award-winning collaboration with Jordan Wolfson at the Frieze Arts Fair**

In 2009, Berman collaborated with conceptual artist Jordan Wolfson to produce a work for the Frieze Arts Fair, one of the world's leading art events attracting over 60,000 visitors each year. The resulting artwork won that year's prestigious Cartier Award and consisted of several parts, including a series of one-to-one tours of the fair by CRST string theorists (Dr Berman, D Thompson, A Low, J Bedford, M McGaurie). These tours, described as "nomadic seminars on string theory", introduced over 300 influential artists, art journalists, curators and gallery owners to the conceptual aspects of string theory research at the CRST. A further 300 people watched the tours take place and the conversations were recorded, edited and used by the artist as a script for a live performance. This led to a further commission (worth £10,000) for Wolfson, which led him to make "Your Napoleon: an intervention based on the string theory of physics" [2,3].

**The resulting impact on public discourse via media coverage**

The project at the Frieze Arts Fair attracted attention not only from the 60,000 attendees but also in the widespread arts media coverage in the *Guardian*, *New York Times*, *Wired Magazine*, and *The Arts Magazine* [8]. The presence of science-inspired stories in the arts media (and of arts-inspired stories in the lay-science media) clearly demonstrates the impact the work has had in building an awareness of science/art collaborations. This awareness has manifested in an invited article about the collaboration in *New Scientist* [9]. Berman's work with Davey has also received attention internationally with an invited talk and subsequent article about the collaboration for the Korean Institute for Advanced Study (September 2012) and for the Japanese popular science magazine *Parity* (autumn 2013). A talk and exhibition of the Davey collaboration at the private members club The Arts Club in London took place in October 2013.

One of the *Guardian*'s cultural critics Sam Wollaston wrote of his experience at the Frieze Arts Fair: *"Part of a project devised by US artist Jordan Wolfson, the strolling chat with Dr Berman quickly gets beyond three dimensions to four, which I'm just about OK with (the fourth is time), but then he's suddenly talking about 10 of them. Ten dimensions! It works mathematically, apparently. And these dimensions are really small and tightly rolled up – Berman demonstrates this with my notebook……. it sounds beautiful."* (*Guardian*, 15 October 2009.)

**Other CRST work with artists**

CRST research on dualities has also influenced the sound artists Flow Motion [4], who created a piece called "Exploring eleven dimensions". This artwork was produced in direct response to extensive discussions with Dr Berman and Dr James Sparks (Oxford) regarding ideas in M-theory. Performed to audiences of 250 at the Science Museum's Dana Centre and at Queen Mary in November 2011, it was funded by an EPSRC pathways to impact grant. Dr Berman has also given talks on his research, and its role in his arts-collaborations, at the Institute for Contemporary Art, Tate Modern, the Royal College of Art, and the Core Gallery, with audience numbers being around 100 for each event. After listening to one of Berman's talks artist Lia Perjovski said: *"M-theory does what art should do: it challenges our view of the world and challenges what I mean [by] art."* Berman will be curating an exhibition at the Ruskin and Chelsea Space Galleries in 2014, and has previously curated an exhibition at Clare Hall, Cambridge in 2008.

Evelyn Wilson, Director, The Culture Capital Exchange, attested to the value of the CRST working with artists: *"It is the kind of ground-breaking collaborations that are being fostered so carefully at Queen Mary that is paving the way for so many more of us to think afresh about world in which we live."* The CRST's arts engagement strategy is on-going with plans to continue the artist-in-residency programme into 2014/15 accompanying the previously mentioned exhibitions scheduled for 2014.

**PPRC work with artists**

Dr Still has received two IoP awards for his collaborative work with artists [11]. He worked with designer Nelly Ben Hayoun on the *Super K Sonic Boooooum!* installation, an immersive mock-up of the T2K neutrino experiment that was exhibited at a London nightclub in 2009 and at the Manchester Science fair in 2010. More than 1600 visitors experienced an interactive boat ride through the installation accompanied by a PPRC researcher who acted as a tour guide explaining the PPRC's neutrino physics research. An accompanying blog and website describing the research behind the installation had more than 3000 unique visits over the duration of the exhibit. An STFC

Science in Society grant (£8.8K) funded the collaboration. *Jiggling Atoms* was a six-month collaboration between Still and 25 artists that resulted in a strong impact on their artistic practice and enhanced awareness of PPRC's particle physics research [6]. Visual interpretations of complex neutrino physics concepts were created in response to conversations and lectures about the PPRC's research, including illustrations and sculptures depicting neutrino oscillations. These were exhibited at a week long physics festival hosted by a London gallery during October 2012, that also included talks and discussions by Still, and was attended by over 1000 visitors.

More recently, Still was chosen to pioneer the new IoP artist-in-residence programme *Superposition,* in partnership with contemporary artist Lyndall Phelps, which ran for a year from October 2012. This culminated in a sculpture that symbolizes the detection of neutrinos in the T2K experiment and the associated data analysis. This was exhibited at the London Canal Museum during September and October 2013 with over 1900 visitors. An accompanying brochure contains essays by Still and Tom Freshwater, the Contemporary Art Programme Manager at the National Trust that discuss the scientific and artistic significance of the sculpture (http://ph.qmul.ac.uk/sites/default/files/REF/SUPERPOSITION_BOOKLET.pdf). After working on the Superposition project Lyndall Phelps commented *"...I was hooked straight away, especially after seeing images of Super-Kamiokande. My pre-conception that physics might be a tad dry and abstract was shattered, replaced by the promise of poetry and rich sensory experiences"* [5].

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

**Artists collaborated with:**

1. Grenville Davey, Artist, self-employed. Corroborate impact of Dr Berman's research in string theory on his creative practice as an artist.
2. Jordan Wolfson, Artist, self-employed. Corroborate impact of Dr Berman's research in string theory of this creative practice as an artist.
3. Curator, Frieze Art Fair 2009. Corroborate the impact on the Frieze Art Fair audience of the collaboration between Dr Berman & Jordan Wolfson exploring Berman's string theory research.
4. Artists, Flow Motion. Corroborate impact of Dr Berman's research in string theory on their creative practice as artists.
5. Lyndall Phelps, Artist, Self-employed. Corroborate impact of Dr Still's research in experimental neutrino physics on her creative practice as an artist.
6. Selected comments from Jiggling Atoms artist collaborators available here: http://ph.qmul.ac.uk/sites/default/files/REF/JigglingAtomsArtistTestimonials.pdf

**Media coverage:**

7. Report in *Plus Magazine* on Davey and the Queen Mary collaboration – 'String Theory, Duality and Art: how the Higgs boson and Turner Prize collide': http://plus.maths.org/content/string-theory-duality-and-art-how-higgs-boson-and-turner-prize-collide
8. A selection of media coverage describing the Frieze event:

– The *Guardian*, 15 Oct '09 www.guardian.co.uk/artanddesign/2009/oct/15/frieze-special-projects
– Cartier Prize winner 2009 www.friezefoundation.org/cartier/category/year_2009/
- New York Times http://tmagazine.blogs.nytimes.com/2009/12/09/art-theory-jordan-wolfson/?_r=0
– Wired Magazine interview, August edition, 2009

9. New Scientist, 8 May 2010

**Other information**

10. QMUL physics-arts engagement website: www.ph.qmul.ac.uk/engagement/art

**Grants and awards**

11. Henry Moore foundation grant to Grenville Davey 2012.
    EPSRC Pathways to Impact grant
    STFC Science in Society Award for Super K Sonic Boooooum! collaboration (£8.8K)
    IoP awards: http://www.iop.org/news/12/nov/page_58959.html
    http://www.iop.org/activity/groups/subject/hepp/prize/society/page_40790.html