Practitioner report: *SHINE*

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PRACTITIONER REPORT:

SHINE

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On 7 November 2015 in the Byre Theatre, St Andrews, astronomer Dr Anne-Marie Weijmans, composer Eddie McGuire, conductor Bede Williams and artist Tim Fitzpatick collaborated on the project *Shine*. The project was held as part of the International Year of Light, an initiative of the UN General Assembly:

> In proclaiming an International Year focusing on the topic of light science and its applications, the UN has recognized the importance of raising global awareness about how light-based technologies promote sustainable development and provide solutions to global challenges in energy, education, agriculture and health. Light plays a vital role in our daily lives and is an imperative cross-cutting discipline of science in the 21st century. It has revolutionized medicine, opened up international communication via the Internet, and continues to be central to linking cultural, economic and political aspects of the global society.[1]

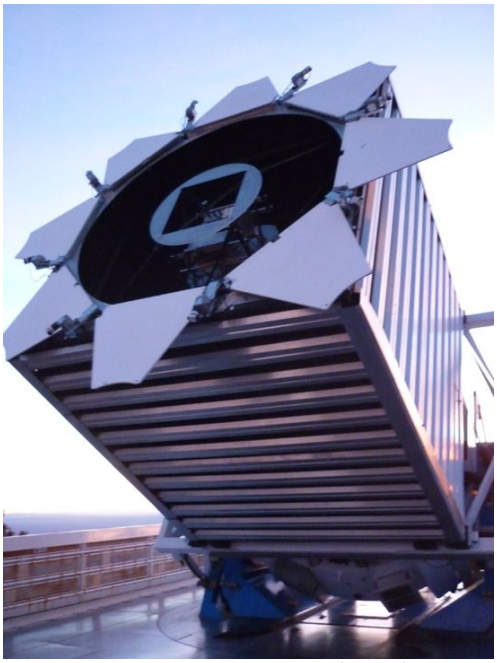
Shine was an interdisciplinary exploration of the *Mapping Nearby Galaxies at Apache Point Observatory* (MaNGA) survey[2], for which Anne-Marie Weijmans is the lead observer. The MaNGA survey focuses on mapping the internal structures of nearby galaxies. *Shine* aimed to raise awareness of the MaNGA survey and its use of *spectroscopy* to study galaxies. *Shine* strove to explain some of the scientific concepts behind the MaNGA survey to a wide audience, to show how with spectroscopy we can unravel light and use its emission spectra to find out which elements are present in galaxies, and how these elements are distributed. This helps us to paint a picture of the ways galaxies form and evolve over time.

More than 350 visitors passed through the Byre Theatre on the day, about half of them first-time science festival visitors. By bringing together science, art and music the authors hoped that audiences attracted to one specific discipline would inadvertently experience another. Before the project commenced, the *Shine* team considered the commonly held view of science and new music being two areas the general public may find challenging, and that the art installation, with its visual immediacy, may be best placed to play the role of Hermes. By using the MaNGA observing plate[3] as a centrepiece the art installation spoke directly of the MaNGA

survey and spectroscopy. The music then took concepts of the MaNGA survey and distilled them into sound.

Astronomer Anne-Marie explained her research for the project as follows:

> Galaxies are located millions, if not billions of light years away from Earth. The only way that we can learn about what is going on in these systems, is by studying their light. We catch their light in our telescopes, lead their light on to spectrographs, and unravel their light into spectra. Different elements in the stars and gas in galaxies give rise to different absorption and emission lines, and by studying these lines we therefore learn about the contents of these galaxies. Movements of stars and gas in galaxies introduce small Doppler shifts to these lines, and so we learn about the dynamical state of galaxies: are they quietly rotating around the centre of the galaxy, or are they perturbed, maybe because of a recent merger? And the movements of stars and gas also give away the presence of an otherwise invisible dark matter halo.



Sloan Telescope used in MaNGA survey.
Image courtesy of Anne-Marie Weijmans

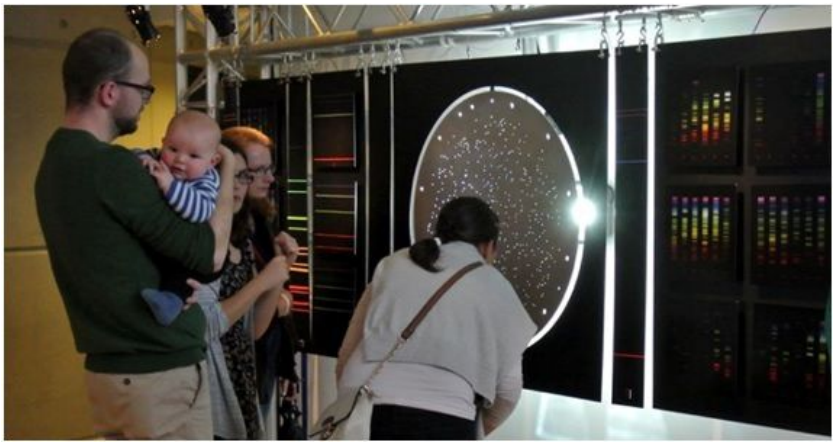
MaNGA is a spectroscopic survey of galaxies, which uses the 2.5-metre Sloan Telescope in New Mexico, USA. MaNGA uses hexagonal fibre bundles to collect the light of galaxies, and record their spectra. MaNGA is part of the fourth generation of Sloan Digital Sky Surveys (SDSS-IV), with previous generations having imaged the northern sky and measured the cosmic expansion rate, amongst others. So far, MaNGA has observed more than 1,400 galaxies, and over its six-year survey period will record the spectra of 10,000 galaxies, the biggest galaxy survey of its kind.

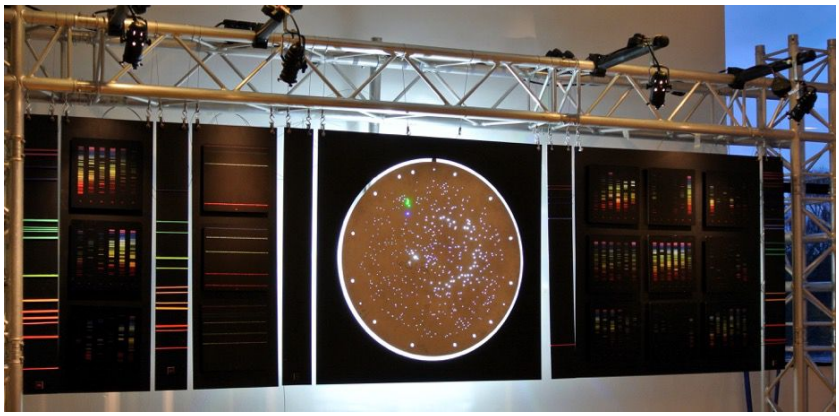
Tim Fitzpatrick's artistic response to the project is called *Code for Everything*. Engaging directly with spectroscopy, he wrote:

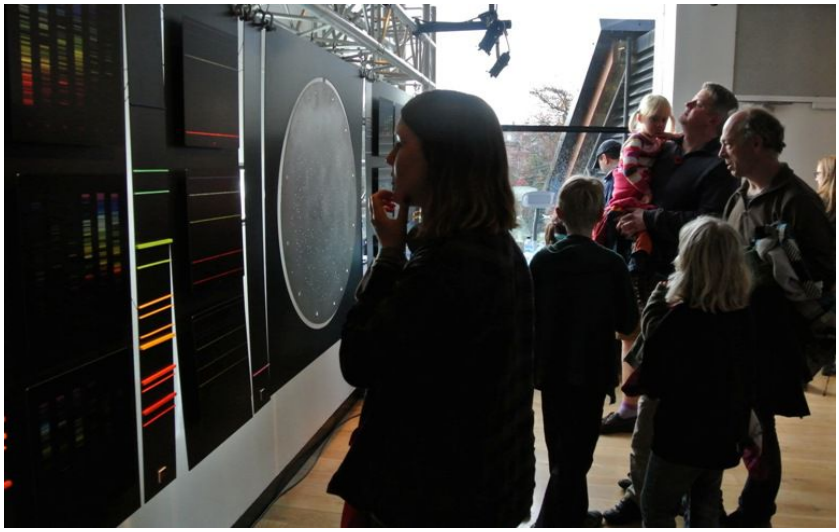
> An important part of Anne-Marie's work is as the lead observer with MaNGA—mapping nearby galaxies at Apache Point Observatory in New Mexico. The work involves studying the very particular properties of light from stars and galaxies, and the detail gathered from the studies —spectroscopy—tells us a great deal about those stars' or galaxies' composition and characteristics.
>
> Fundamental to spectroscopy is the fact that each of the elements that make up our universe have their own characteristic spectral lines, or emission lines: distinct wavelengths of light that are a product of the behaviour of the elements' atoms. So when the spectrum of a star or galaxy is analysed, we are able to find the characteristic spectral lines of individual elements that may be present and these can tell us so much about the composition and characteristics of that star or galaxy. With these colour-coded 'fingerprints' we have the tools to identify the atomic and molecular components of stars: reading the light of the universe as contained in a beautiful series of codes.

> In the making of *Shine* I became fascinated by the existence of these coded spectral lines. Behind the seemingly random distribution of lines of colour in the individual spectra are the codes of colour that describe our Universe: the four pure lines of Hydrogen, the explosive riot of Europium, the starkness of the single green line of Thalium to the reassuring uniformity of Oxygen. An unmistakable code of light for all that we know; code for past, present and future, code to infinite horizons and code for everything.

The pictures below are of Tim Fitzpatrick's *Code for Everything* installation for *Shine*:







In addition to the art installation there were science demonstrations, as shown in the following pictures:

Make your own spectrograph! In this demo visitors could make their own spectrographs using old CDs as gratings to unravel the light. Visitors could then test their spectrographs by aiming them at special gas lamps, and compare the emission line spectra they saw with our printed versions. Images courtesy of T. Fitzpatrick.

Visitors could listen to radio emission, of which a tiny fraction was generated in the Big Bang and recorded in the cosmic microwave background (top). Visitors were also challenged to make a spectrogram of their own voice, and learn how sound could be made visible. (bottom). Images courtesy of T. Fitzpatrick.

Overview picture of the foyer of the Byre Theatre, where many of our science demos were located. Image courtesy of T. Fitzpatrick.

After audience members had moved around the art installation and science demonstrations, they entered the main auditorium of the Byre Theatre and listened to a public lecture from Dr Tom Brown of the School of Physics and Astronomy, titled 'Waves and Particles—Light's Confusing Nature':

> In this lecture we will look briefly at the history of understanding light and see how its behaviour has been understood by both waves and particles. More recently the advent of the quantum universe in the early twentieth century has caused us to think of light being simultaneously (and somewhat confusingly) both a wave and a particle. In fact this wave / particle behaviour has given rise to many of the twentieth century's innovations from the low-power LED lights that are gradually being used more and more in your home, to the way the information you look up on the internet is carried around the world.

After Tom's lecture, the St Andrews New Music Ensemble performed Matthew Hindson's *Light is both a particle and a wave*. Eddie McGuire then introduced his new work, *Symphonies of Galaxies*. His unscripted presentation is presented here verbatim.

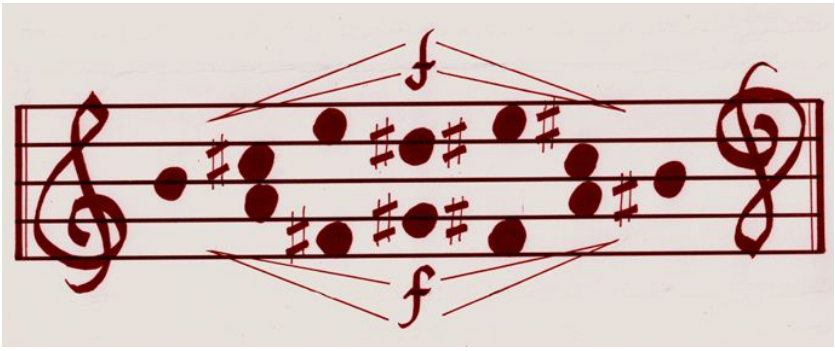
Well, the title of the piece is Symphonies of Galaxies, and I'm using that word 'symphonies' just to tell you that everything is sounding together, and a bit like Stravinsky who uses the word in his Symphonies of Wind Instruments. So I'm bringing together all the imaginary sounds of the galaxies into a piece of music. All that music can do is give you a hint of the ideas involved; you can't really paint a picture directly of reality using music. I'm just going to spark your imagination, that's all I can do. By letting you hear some beautiful sounds then you can imagine: you've got to do the work of imagining that universe out there. So we're all part of something much bigger. In fact this project is part of something that the United Nations sparked off; the general assembly of the United Nations voted in 2013 to make this year, 2015, the year of light, so the piece of music you're going to hear is a bit of a celebration of that. We hear about the universe accelerating in its expansion, if you wait patiently until the end of the piece you'll hear the music becoming more excited and faster, symbolising that expansion. And that's what music can do: symbolise things, and spark off some ideas.

The piece is a celebration of the work that Anne-Marie and her colleagues are doing at the University of St Andrews in which they are mapping ten thousand nearby galaxies. It's not like your local neighbourhood or local streets: these are galaxies out there. Amazingly the light from those galaxies takes millions of years to reach us here.

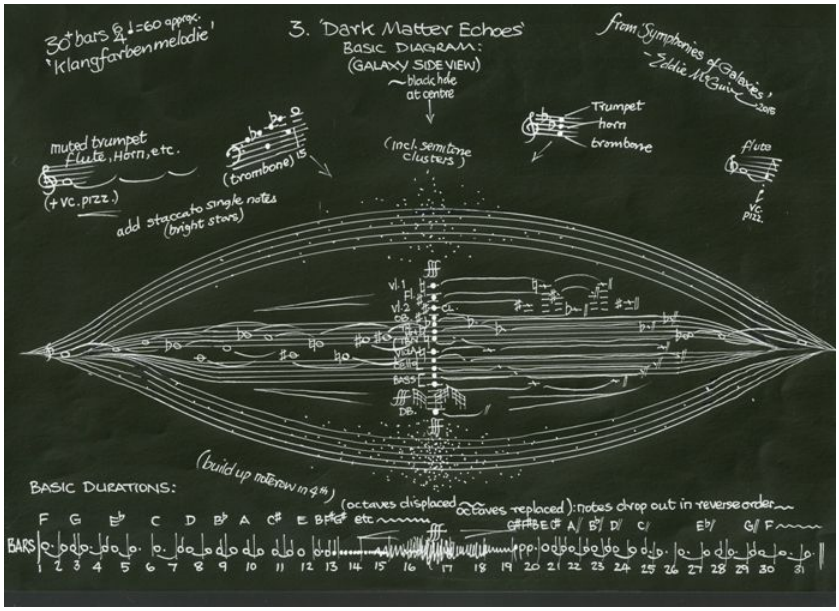
I was also thinking during the earlier lecture [by Dr Tom Brown] that I was feeling a bit sad for poor Albert Einstein: he didn't get a Nobel Prize for his greatest work —the Theory of Relativity[4] . I think we should dedicate the piece and this performance to him, I hope he is listening —maybe he's listening in some type of time warp. We'll

dedicate this performance and piece to him instead of getting the Nobel Prize, I hope he's happy with that. But it's actually one hundred years since he launched his general theory of relativity, and that has led to the insight that we can say that the Universe is expanding[5], and as the previous speaker said, that the colours of the light tell us how fast the galaxies are receding. And I tried to copy that, I tried to give a hint of that in my piece of music: the piece accelerates to the end, it gets more excitable. You'll hear in the piece that it is quite a romantic expression, because it's the human element, the researchers that are doing all this work—it's Albert Einstein, it's Newton, it's Anne-Marie and her colleagues who are looking into the universe and finding out much more about it.

The piece has a bit of a parallel with the new techniques that they've invented. They've fabricated bundles of fibres that can look at not just one spot in a galaxy and expand it —they can look at the entire galaxy by multiple fibres that are fitted into a hexagonal shape to receive the information through all the different wavelengths of light that you heard about in the previous talk. The theme that you'll hear at the very beginning is a theme that starts on one note and expands into a hexagonal shape:



> It starts on one note, expands to two notes, expands wider, comes together again and comes back to one note at the end. You can turn it upside down and see the same thing again, and that matches the bundle of fibres that are reaching out to those distant galaxies to collect the light and tell us if they going away or are they coming towards us. I was alarmed to hear that there is a galaxy heading straight for us, and it's going to crash right into us; but don't worry—it's not for about ten billion years, so it's not for quite some time. But what I also learnt was that these galaxies are held in place by dark matter. So there's a lot to be found out from this research, and it's that kind of thing that I symbolise in the music. In the third movement you will hear it starts with one note and expands, and it goes in that manner into the very shape of a galaxy, this is my rough sketch that I did when I woke up one night and had the idea to make the third movement into the shape of a galaxy:



Starting with one note, getting wider and wider and denser and denser, until it has all twelve notes. Luckily there are twelve instruments in the orchestra, and twelve notes in the note row I'm using (there are only twelve semitones that people use), so all the notes are heard at the middle point, the densest point of this musical galaxy. Then it fades out again, gets less and less and comes together on one note. So it's a bit like looking side on at a massive spiral galaxy; the third movement is a painting in sound of a spiral galaxy.

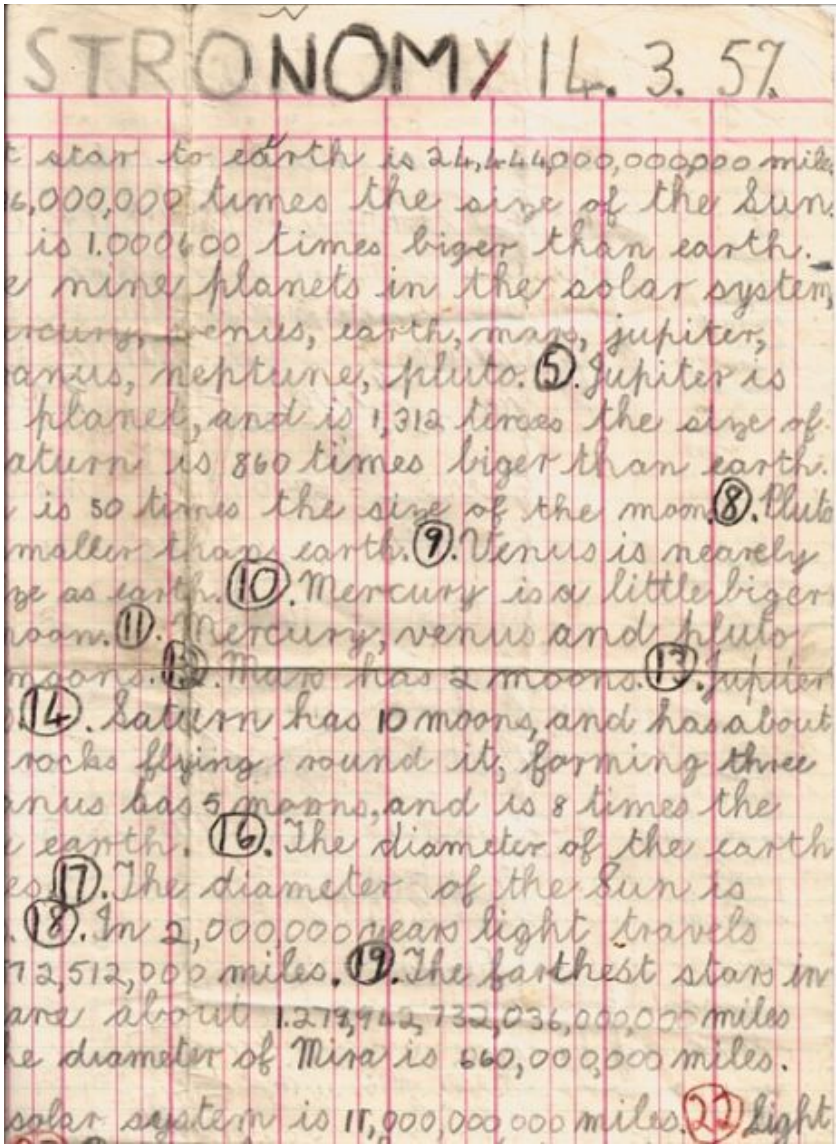
All through the piece follows the hexagonal kind of pattern, it's a symmetrical pattern that goes up a tone, up a minor third, down a tone and reverses that; the same is a reflection in the bass—it's harmonies and melody going in the opposite direction. So that was my thinking on constructing the piece—getting the little bits of melody in the piece to match the ideas. Another idea is that sometimes the sound is a bit diffuse: a lot of tremolos and sounds cover up the melody. That's because a lot of research is being done into how to look through the veils of dust that covers, say, the centre of our galaxy—you can't really see it with your own eyes because it's totally covered with dust, no hoover could hoover it up. What you can do is look at different wavelengths of light, you saw in the diagram from the previous speaker.

Towards the right side of the diagram was very sharp radiation that is gamma rays, X-rays—these can cut through dust. If you look at them you'll find out a lot of information about the centre of our galaxy, which is presumed to be the massive pulling power of a black hole. So that's the ideas I'm trying to get across in the piece, we're looking through that dust, and you'll hear the dustiness in the music, but you'll also hear little

explosions of bright chords, dense chords, colliding sounds, and little bits of melody that break through into the light.

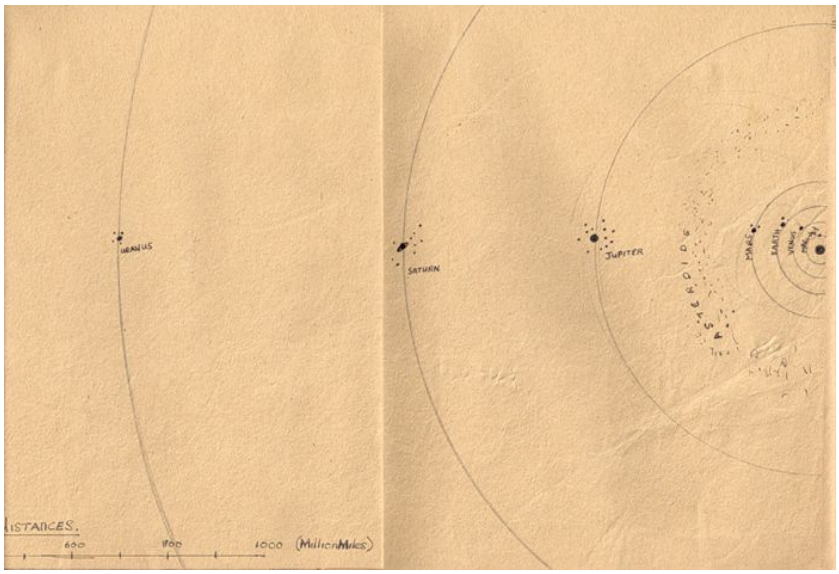
There are four movements; it starts with 'Dust veiled starlight'. The second part is about the idea of the galaxies coming towards us; it's about the galaxies dancing together. If you look at some of the computer simulations of galaxies colliding it creates very beautiful [images], probably horrific if you're in the centre of it. But galaxies colliding are almost dancing with each other. So the second movement is a bit of a waltz, you can imagine galaxies waltzing together as they merge; they almost create Celtic knot work when they're doing that, Celtic spirals. So 'Embrace, Waltz and Merge' is the name of the second movement. The third movement is the one I mentioned before, in which I paint a picture of a galaxy starting at zero and expanding into a dense centre point. And then the fourth movement is what I mentioned earlier: that the universe is accelerating. Of course one day, we might all come to a rest in entropy, a kind of silent universe, but in the meantime the Universe is expanding and the pace of that increases. It starts off as a jig, six beats in the bar. Later you'll hear the instruments in an energetic moment of seven beats in the bar, and then it becomes eight beats in the bar—a kind of reel dance, but it ends up with nine beats in the bar in a slip jig. So the last movement is a bit of a dance movement going through this kind of expansion and getting faster.

I was also intrigued, thinking back that when I was six, seven, eight and nine years old I was very fascinated by galaxies. I brought some of my notebooks in which I actually mention galaxies, and how far away they are, and how many billions of stars they had. I wrote out the full length of all the zeros there:


STRONOMY 14. 3. 57.

star to earth is 24,444000,000000 mile
6,000,000 times the size of the Sun.
is 1.000600 times biger than earth.
e nine planets in the solar system,
ercury, venus, earth, mars, jupiter,
anus, neptune, pluto. (5). Jupiter is
planet, and is 1,312 times the size of
aturn is 860 times biger than earth.
is 50 times the size of the moon. (8). Pluto
maller than earth. (9). Venus is nearly
e as earth. (10). Mercury is a little biger
oon. (11). Mercury, venus and pluto
moons. (12). Mars has 2 moons. (13). Jupiter
(14). Saturn has 10 moons, and has about
rocks flying round it, forming three
nus has 5 moons, and is 8 times the
earth. (16). The diameter of the earth
(17). The diameter of the Sun is
(18). In 2,000,000 years light travels
72,512,000 miles. (19). The farthest stars in
are about 1.273,942,732,036,000,00 miles
e diameter of Mira is 660,000,000 miles.
solar system is 11,000,000,000 miles. (22). Light

And I actually drew a map of the solar system; the date is 26 May 1961.



> So I was fascinated by galaxies at that time. I haven't done anything since then, but it's great to come back to it, remember my childhood fascination and try and construct a piece of music which is both listenable and explanatory, pointing out some of the salient facts of the MaNGA project—mapping of the nearby galaxies at the University of St Andrews. I hope it elucidates and informs, is a tribute to the MaNGA project, and let's dedicate it to poor Albert Einstein, who didn't get a Nobel Prize for his Theory of Relativity.

The International Year of Light may have come to an end, but the authors feel that this collaboration between science, art and music has only just started. Tim continues to explore emission line spectra, and has started to plan a short movie that will link his art with Eddie's music. Anne-Marie and Bede are continuing their efforts in linking music and astronomy, with recent Open Nights at the University's Observatory already being enhanced with musical performances inspired by the night sky. The School of Physics and Astronomy at the University of St Andrews has gained a new set of scientific demonstrations suitable for school visits and science fairs. And there has already been a performance of Eddie's Symphonies of Galaxies at an

astronomy assembly in Chile attended by an audience of 800.

Such events will ensure that the legacy of *Shine* will continue far beyond the International Year of Light, and create new opportunities for future communication and collaboration between scientists, artists and musicians.

Live music at St Andrews Observatory Open Night in March 2015.

Notes

1.‹http://www.light2015.org/Home/About.html›

2.‹http://www.sdss.org/surveys/manga/›

3.An observing plate is an aluminum plate mounted underneath a telescope, and has accurately drilled holes in it to allow the light of selected galaxies to travel to the spectrographs. The plates are plugged manually during the day, and observers mount the plates during the night to get observed. On a clear night, 2–3 MaNGA plates can be observed, each yielding spectra for 17 galaxies.

4.Albert Einstein did receive a Nobel Prize in Physics in 1921 for his discovery of the photo-electric effect, but not for formulating the theories of special and general relativity.

5.Although at first Albert Einstein did introduce a cosmological constant in his equations to prevent the possibility of an expanding Universe, as in those days a dynamic Universe was unheard of. When later in the 1930s astronomer Edwin Hubble demonstrated that the Universe was not static but instead expanding, Einstein removed this constant, calling it 'his greatest blunder'. The constant did get introduced again at the end of the twentieth century, after the discovery of dark energy and the accelerated expansion of the Universe.

Acknowledgements

We would like to thank the School of Physics and Astronomy of the University of St Andrews, the University of St Andrews Music Centre, and the Byre Theatre for their support. We also thank the sponsor for our main event: the Scottish Universities Physics Alliance (SUPA), and Dr Anne-Marie Weijmans acknowledges the support of a Leverhulme Early Career Fellowship. We also are very grateful to all the volunteers of the School of Physics and Astronomy, who donated their time, expertise and enthusiasm demonstrating the science experiments, and to the musicians of the St Andrews New Music Ensemble for their performance.

About the authors

BEDE WILLIAMS trained as a trumpeter and conductor. For the University of St Andrews Music Centre he directs the New Music Ensemble and teaches chamber music, conducting and performance. He has given the premiere performance of over 60 new works by emerging and established composers. He has a long association with the music of Eddie McGuire, the composer of the specially commissioned piece for *SHINE*.

DR ANNE-MARIE WEIJMANS is a lecturer and Leverhulme Early Career Fellow in the School of Physics and Astronomy at the University of St Andrews. She obtained her PhD in astronomy from Leiden University in the Netherlands, and worked for four years as a Dunlap Fellow at the University of Toronto in Canada, before moving to St Andrews. Her research concentrates on the internal structures of nearby galaxies, as she studies their stars and dark matter haloes. She is the lead observer for the MaNGA galaxy survey. In her spare time, Anne-Marie plays the oboe in the University of St Andrews Chamber Orchestra.

TIM FITZPATRICK is the creative director of the Fife-based community arts project 'The Red Field'. Tim originally trained in photography but over the last 15 years his work has increasingly developed into site specific work often involving combinations of distinctive public spaces, light, music, film, performance and underlying narratives. Recently Tim has created new work as an invited artist for the Pittenweem Arts Festival and has collaborated with composer Michael Nyman and artist Goldie for the Fragments Project—a response to the discovery of a fragment of a twelfth-century manuscript in the Scottish Borders.

EDDIE MCGUIRE was born in Glasgow and studied with James Iliff (RAM 1966-70) and with Ingvar Lidholm in Stockholm. He received a British Composers Award (2003), Creative Scotland Award (2004) and has been featured composer at several international festivals. The BBCSSO Proms performance of Calgacus was selected for BBC Music Magazine's CD The Very Best of the BBC Orchestras (1997). Commissions and broadcasts have included those from St Magnus Festival, Edinburgh International Festival, Lorient Festival, Glasgow Festival Strings, Scottish Chamber Orchestra, Ulster Orchestra and BBC National Orchestra of Wales. Notable successes are his three-act ballet Peter Pan (Scottish Ballet; Hong Kong Ballet), opera The Loving of Etain (with librettist Marianne Carey) and concertos for guitar, trombone, violin, viola and bass. He writes for and plays with The Whistlebinkies and Chinese group Harmony Ensemble. Recent works include Let the Games Begin for Glasgow Chamber Choir, Cowal Colours for Hoot and Dialogue for Philip Sawyer and Andrea Kuypers. In 2015 his Symphonies of Galaxies was premiered at University of St Andrews by its New Music Ensemble—a collaborative venture with its Department of Astronomy and Physics. 2016 sees the premiere of Botanic Gardens for Grimoire (four players at two pianos). Both CD collections of his music (on Delphian Records) have achieved 'Editor's Choice' in Gramophone Magazine—Eddie McGuire: Music for Flute, Guitar and Piano (2006) and Entangled Fortunes (2015, performed by Red Note ensemble).