Developing the hertz art-science project to allow inaudible sounds of the Earth and Cosmos to be experienced

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Abstract. The Earth and atmosphere are in constant motion. Volcanoes, Glaciers, Earthquakes, Thunderstorms and even the Aurora produce powerful low frequency sounds known as Infrasound. Infrasound is constantly passing through our atmosphere but contains frequencies below the range of human hearing, effectively an inaudible symphony. Inspired by wanting to allow

10   physical access to this natural phenomenon, a collaboration between the worlds of contemporary art and meteorology has been developed. This led to a project called **hertz,** named after the nineteenth century physicist Henrich Hertz whose surname provides the scientific unit (Hz) for frequency. **hertz** explores the manifestation of the hidden resonances of our own planet and the secret harmonies of our stars. This was principally achieved using furniture adapted to vibrate with infrasonic waves from pre-recorded sources and in real time. The project's motivations are in exploring new methods to experience and re-

15   engage with parts of our planet through this phenomenon. **hertz** has had a UK national tour in which several thousand people interacted with the piece. This paper describes the concepts, creative ideas, technology and science behind the project. It addresses its development, including the steps to make it accessible for all, and examines its impact on those who interacted with the work.

1 Introduction

20   The Earth and atmosphere are constantly shifting due to a range of natural processes such as seismic motion, volcanic explosions and glacial slippage. Atmospheric phenomena such as hurricanes, thunderstorms and tornadoes also contribute. At first-hand, these events can be both majestic and alarming. Increasingly, these are rarely experienced directly, as more of the Earth's population lives in towns and cities, insulated from these and also the less extreme visceral expressions of nature. The acoustic signals of natural terrestrial and atmospheric changes are more and more obscured by the background anthropogenic

25   noise of airports, trains and motorways. Technology further isolates the modern human from the natural environment in which we evolved increasingly being used as a filter through which we view the natural world. Seeking to re-establish links with the natural environment, one of us, the artist Juliet Robson, aimed to create an interactive art work that would re-establish this diminishing link, one that was tangible in a very real sense and that allowed a way in to the important but sometimes inaccessible research done by scientists. This would specifically reinforce the view that "Artists are no longer concerned with

30   creating artwork that reflects or interprets reality; rather, they want to be active agents in creating it, ... That means that artists need to have an even deeper understanding of the mechanics behind science and technology.'' (Williams, 2017). To undertake this, it was apparent that such a project would need to call on science technology engineering and maths (STEM) expertise to create an authentic as possible representation of natural hidden resonances through providing an immersive experience. Robson approached two scientists and a mathematician to explore the possibilities of making hidden resonances of the stars and natural

35   phenomena of our planet heard and felt.

One of those was, co-author, Graeme Marlton, a meteorologist interested in the educational possibilities of such a project who was working on the Atmospheric Research Infrastructure in Europe 2 (ARISE 2) project (Blanc et al. 2018). The ARISE 2 project encompassed examining a multitude of different measurement techniques to measure the dynamical properties of the

40   atmosphere. One such technology that was utilised in this project was infrasound measurements. Infrasound contains sound frequencies which fall below the audible range of human hearing, essentially sound waves below 20 Hz. It is produced naturally, or artificially by large explosions such as that of a nuclear detonation or by mining activity, as well as trains and planes. Natural infrasound is produced by volcanoes, earthquakes, glaciers, ocean swell, thunderstorms, hurricanes and even the aurora borealis (Wilson 1969) see figure 1. The importance of infrasound to the ARISE project was to learn about the state

45   of the atmosphere by learning how infrasonic waves passed through it from a known infrasound source, such as a volcano (Smets et al 2019).

Ultimately, raw infrasound data contains inaudible recordings of our planet and its atmosphere. To provide new access to this information, the raw infrasound data could be processed to provide physical changes which could be sensed, using

50   commercially available transducers. Transducers are devices which shake when a low frequency sound is played through them. They are fitted in 4D cinemas and video gaming chairs to provide a vibrating sensation to the spectator when an explosion or aircraft passes over on screen to make the experience more immersive. The aim here was to enable people to feel their bodies resonating to the inaudible symphony of the planet. Figure 2 shows the initial concept work drawn up for the project. This would become one of the two working strands for Robson's immersive new project.

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The other strand is not discussed at length here, but it worked by taking astronomical measurements of the stars and from the spectral signature derive a sound wave. Sound waves move through sun stars gaseous interior because of temperature changes and the star in turn fluctuates in brightness, satellites like Kepler and transiting exoplanet survey satellite can observe these vibrations. This data was obtained from NASA's Kepler project (Chaplin et al 2010) and then sonified and played through

60   Chladni plates built for the project. Chladni plates consist of a flat sheet of metal, usually circular or square, mounted on a central stalk to a sturdy base. When the plate oscillates at a particular mode of vibration, the nodes and antinodes form complex but symmetrical patterns over its surface. The positions of these nodes and antinodes can be seen by sprinkling sand upon the plates, the sand will vibrate away from the antinodes and gather at the nodes (Stöckmann 2007). As the frequencies of different

stars were played through the plates, the sand sprinkled on the plate formed geometric patterns related to that particular star's
65 frequency.

As the connection between the two strands was that of resonance, and resonance is closely associated with frequency, the
project was named **hertz,** after the standard unit of frequency. Drawing on the premise that everything vibrates, from the
smallest atom to the furthest star, their frequencies surround us and yet leave no imprint, **hertz** would enable people to feel
70 their bodies resonating to the inaudible symphony of our own planet and experience the stars singing and see their sound made
visible. **hertz**'s ultimate goal would aim to reconnect us to our planet and place in the cosmos. Its ancillary aims would also
be to educate about the science behind the project

In this paper we predominantly focus on the infrasound strand of the **hertz** project. In section 2 we will describe the science
75 behind how the installation works and the initial feedback received on the prototype. In section 3 we describe how the feedback
modelled the version prepared for the **hertz** tour around the UK. In section 4 we review the feedback from the public from the
tour. In section 5 we discuss the collaboration from both the artist and the scientist. The project findings are summarised in the
conclusions in section 6.

2 hertz from concept to prototype

In order to create an immersive experience where modified infrasound is played through a transducer, infrasound recordings
which had captured the acoustics of the natural world were needed. In this section we describe how infrasound is measured
and how the infrasonic recordings used in the **hertz** project were acquired. We will then describe the prototype setup and how
the infrasound recordings were processed to create an immersive experience.

2.1 Infrasound recordings

Infrasound cannot be detected using normal audio recording equipment. Instead, a microbarometer, a very sensitive pressure
sensor, can be used to detect the subtle pressure variations generated by infrasound. Globally, networks of microbarometers
are maintained by meteorological and seismological organisations. The largest network is maintained by the Comprehensive
Nuclear-Test-Ban Treaty Organization CTBTO, who have 60 infrasound stations across the globe (Christie and Campus 2010).
90 The main purpose of this microbarometer network is for detection of a nuclear detonation. However, as these stations monitor
constantly, they mainly detect infrasound generated by the atmosphere and other man-made disturbances. A US based
company, InfilTech, manufactures a small portable, low-cost infrasound detector, the INFRA20, for $350 which can be logged
via a USB port of a standard PC. An INFRA20 was used to gather infrasound recordings for the project. It was initially
deployed in the suburbs of Reading during July 2017 where it measured infrasound from several thunderstorms that had formed
95 over northern France and had moved northwards over the English Channel and into southern England on the 18th July 2017.

Figure 3 shows a spectrogram - an image that displays the detected infrasonic frequencies - for these events. The spectrogram has a horizontal time axis, and frequency on the vertical axis, using colour to indicate the amplitude of the signal. From the recordings made that night, as each thunderstorm approached infrasound frequencies in the 0.1Hz to 1 Hz range were generated. The most intense frequencies were detected from the thunderstorms at 3 LT. From 7LT to 9LT there are different

100   low amplitude infrasonic waves detected in the 0.5 to 1 Hz range, likely to be associated with the morning rush hour. To contextualise this, the infrasonic waves observed here oscillate once over a period of 10 seconds whereas the sound from a subwoofer will oscillate over a period of a hundredth of a second.

The INFRA20 was also used to record the infrasonic signal from Aurora Borealis at Pallas, Northern Finland in September

105   2017. The infrasound there had a distinct signature at the 1 Hz band as shown in figure 4 and in agreement with (Wilson 1969). The infrasonic signals produced by the Reading thunderstorms and the infrasonic signal from the aurora is 4 times smaller. This shows that different phenomena produce have different infrasound signatures. In addition to the recordings made directly with the INFRA20, infrasound data clips were also provided by ARISE project members. These included infrasonic recordings of Mount Etna, and an F16 jet aircraft accelerating to speeds greater than that of sound.

110   **2.2 Hertz prototype test rig**

Figure 1 showed a concept picture for the infrasound setup. For prototyping, a large subwoofer loudspeaker (250 Watt) and an ADX maximus transducer were used. The transducer had a clamp allowing it to be attached to a chair or wheelchair which was the choice for the prototype. Robson had a spare metal wheelchair made of metal that were good at transferring vibrations. There were also a variety of possible places where the transducer could be attached. In addition, it was easy to move to different

115   areas of the studio in order to experience and experiment with different spatial configurations. Both the transducer and subwoofer were connected to the soundcard of a computer meaning the same processed infrasound signal could be played through both simultaneously. The reasons for adding a subwoofer that could play low frequency sound was added to increase the immersive experience, so that audiences could be attracted to the installation from a distance. This also stimulated another sense, hearing, by providing loud deep sounds complementing the resonance provided by the transducer that provided access

120   through physical sensations in the body. The transducer was designed to only play audio signals between 120 Hz and 40 Hz. Given the power delivered through the subwoofer and transducer, the opening track of Pink Floyd's *Dark side of the Moon* (Pink Floyd 1973) led to tremendous shaking of the modified chair and studio in which it was placed. As part of the development process some of the initial testing was documented by smart phone. However as discussed earlier, low frequencies can't be detected through conventional sound recording equipment. Thus, on playback through mobile phone or computer, the

125   modulated infrasound was inaudible and only the vocal reactions and the rattling of loose objects on tables were audible. A video example from the development phase can be found here (doi link will be provided to data repository once paper accepted)

2.3 Infrasound processing method

The next part of the project was to turn the infrasonic recordings described in section 2.1 into something that could be played
130 through the transducer and large subwoofer. In their current state they would be inaudible and would not register on the
transducer or subwoofer. In addition to this background noise, for example from wind passing over the sensor, also needed to
be filtered out. To achieve this a digital bandpass filter was applied over the raw infrasound data. A bandpass filter is a physical
or software device which allows a frequency between two given frequencies to pass, whilst frequencies outside of this range
are removed. The spectrograms in figures 2 and 3 were used to define the upper and lower limits of the band pass filter, by
135 establishing the frequency range in which the infrasonic signatures were largest.

The first approach was to use the amplitude of the bandpass filtered infrasound signal to modulate a tone at a range of low
frequencies between 60 and 100 Hz. This gave mixed results. At first it gave an unworldly noise, with the rig making a zooming
noise as the shaking and rumbling changed intensity at random speeds, sounding like a sci fi effect. A single tone was successful
140 in yielding an interpretation of infrasound. However, we felt that it didn't encapsulate what infrasound might sound like if we
could hear it. One thing which was lacking was a depth, which was largely due to the monochromatic tone used and it was felt
that a mix of frequencies would amount to a larger sense of resonant layers and feeling of being immersed in the infrasound.
Hence, an alternative was to create a deep polyphonic tone. The method to achieve this was to firstly create pink noise. Noise
is sometimes described by likening its spectrum to the optical spectrum of colours. White noise is the hiss noticeable on radios
145 tuned away from a radio station, and its spectral power is constant over all frequency bands. Pink noise's spectral power is
inversely proportional to the audio frequency. This gives an effect where low frequency noise is more dominant than higher
frequency noise, giving a rumbling sensation that surrounds and is felt bodily like sitting on an airplane or being close to bass
speakers at a Rock concert.

150 The bandpass filtered infrasound signal was then used to modulate the amplitude of synthetic generated pink noise. to ensure
a deep rumbling was experienced through the prototype rig a further low pass filter, a filter similar to the band pass filter but
only removing high frequency sounds was then applied. This produced a low rumbling noise to be played through both the
subwoofer and transducer, the rumbling changing in amplitude as determined by the raw infrasonic signal. This produced an
effect that we felt was relatable to infrasound if we could hear it, while keeping translatable authenticity, something that was
155 important to **hertz**'s ethos. The polyphonic processed infrasound recordings now had more depth and character, which began
conveying an emotion and sense of majesty about our planet that the project had yearned to create. For example, the sound of
Mount Etna seemed to have a dark feel to it with unpredictable and at times violent 'outburst' of sound. The Aurora felt it had
a more soothing rhythmic feel with less extreme changes in volume and intensity. The sound was too low in frequency to be
recorded on a device like a laptop or a phone. This meant you had to physically be present in order to sense the frequencies,
160 making it an immersive and experiential artwork.

2.4 Outreach activities and reception

Initial development of the prototype rig finished in late 2017. Following this several opportunities arose to demonstrate the prototype rig to the public and experts in both art and science fields. Table 1 shows a list of public outreach events. Figure 6
165   shows two members of the public listening to infrasound in a gallery space in the Attenborough Centre, Leicester, United Kingdom. As mentioned, **hertz** was to be accessible to as many disabled people as possible. **hertz** not only delivered in the practicalities of access needs but also had the ability to be experienced through a number of different senses, auditorily, bodily and visually. The success of this was borne out in Attenborough where the visitors were attending a conference, organised by the disabled artist's commissioning organisation Unlimited, and encompassed a wide range of disabilities.   Responses were
170   sought from those experiencing the artwork, which included:

- 'Epic.' 'Ground-breaking.' 'A whole world around me I couldn't see but felt connected to.'
- 'In this piece, I can time travel and contemplate the geometry of sound into matter – wow. Mind-blowing and poetic.'
175   - 'Incredible vibrations.
- 'Primeval, dramatic, disconcerting and yet thrilling.'

In addition to the feedback received in person, Max Reinhardt of BBC Radio 3's late Junction played excerpts of infrasound from the aurora borealis. The infrasound had been reprocessed, so it was just audible for listening on radio on his show and said what 'What a totally astounding and amazing project'. There was further positive media coverage of the initial prototyping
180   in Disability Arts Online Magazine (Caulfield 2017) and Physics World online blog (Kalaugher 2018)

3 Developing hertz for tour

Following, the running of the prototypes at the venues shown in table 1 and the positive feedback from the public, a tour was commissioned which would see **hertz** being exhibited to the public at three places across the UK. It was realised if the installations were to tour, further development would be needed. The first extensive upgrade was to increase the amount of
185   furniture, with accessibility in mind, that vibrated allowing more people to experience the infrasound vibrations. The second was to upgrade the software that played the infrasound through the subwoofer and transducers. This was to make it (a) stand-alone, meaning minimal operator input, and (b) configuring the software to play infrasound recorded at the locale of installation in real-time. The first part of the work was to replace the wheelchair and attached transducer with more rigid furniture. A steel garden bench and chair which conducted vibrations well were each fitted with a transducer and linked to the existing subwoofer
190   and playback system. The second part, to overhaul the playback system, involved replacing the laptop PC shown in figure 5,

with a small stand-alone computer (a Raspberry Pi) so it could be easily concealed. The INFRA20 infrasound sensor's cable was extended so it could be placed outside whilst being connected to the Raspberry Pi. Further to this the Pi was configured to obtain data from the infrasound sensor, process it, and play back the processed infrasound signal in real time through the subwoofer and transducers. This allowed the real time infrasound of a location to be experienced. As computer peripherals

195 such as a mouse and keyboard would detach from the aesthetics of the installation, the Pi was configured to run in a 'dead head' mode, meaning a graphics user interface was not needed and any settings could be altered solely through keyboard commands. The Pi was also configured to begin the real time acquisition of data on start up further minimizing operator input. Figure 7 shows a photo of the finalised piece.

4 Assessment of feedback during tour

200 The tour of **hertz** occurred between October 2018 and February 2019. The first tour location was at the Oxford Science and Ideas Festival in October 2018. Audience members had the opportunity to engage with the artworks in a hands-on way. They were introduced to the pieces and the science behind it by the co-authors and, astrophysicist, Bill Chaplin. During three bookable sessions, visitors were able to meet the artist and collaborators and interact with the artwork, ask questions, react and explore the concepts and research behind the work, and give feedback. The audience was largely made up of families and those

205 with an interest in science, as shown in figure 8.

Later that month from 18th - 21st October, **hertz** was exhibited at the Tramway art-space at Glasgow, UK as part of the Unlimited, the main funders of **hertz**, festival as shown in figure 7. The equipment was shipped to Glasgow and assembled by the on-site gallery staff. For this tour stop, due to time constraints it was not possible for the co-authors behind the project to

210 promote **hertz** on site. This also yielded an opportunity to see how well **hertz** would thrive as an installation and educational tool in a standalone format. The final stop of the tour was at We the Curious, Bristol between November 2018 and February 2019. Table 2 summarises the tour dates and the numbers of visitors. At all three locations a table was present where visitors could leave feedback and take away postcards with relevant key and interesting facts about the research for further interest. To assist in promoting **hertz** to the public and increase awareness of **hertz** at the tour locations, and the science behind it, **hertz**

215 was promoted through a twitter account and website (https://julietrobson.com/blog/), launched mid-2017. It was also promoted by each venue through their publicity outlets and by Unlimited, the core project funder, on their website and social media. In this section we will discuss the feedback from each of the tour locations and the project's online presence.

4.1 Oxford Science and Idea Festival

Feedback from the public was generally positive with the following comments left by visitors to the event:

220
- "Love how it is very interactive and engaging. It can be as complicated as you like. Brilliant!'
- "Really fun and exciting."

- "Amazing and fascinating. It was wonderful."

A video was also produced commissioned by Oxford contemporary music (https://vimeo.com/306844807) which documents
225   the day and the reactions of the public. During the video one young visitor left a comment on a whiteboard saying "I wasn't
into physics really, until now!". This comment in particular is positive, given that the aims of the project were to build an
informative artwork which would also raise the profile of the physical sciences behind the project. The visitors shown in the
video appear to enjoy **hertz** installation with many of the expressions on their face being of one enjoying themselves and
intrigue. One young visitor was inspired so much that they got back in touch to do work experience week with the co-authors
230   and   spend   a   day   at   the   University   of   Reading's   Department   of   Meteorology.

4.2 Tramway, Glasgow

For the period of the tour at the Tramway the style of feedback differed to that shown discussed in section 4.1 and without the
project leaders present it was hard to gauge what individuals thought. Also, for reasons unknown footfall was not obtained
235   either. However, Tramway's curator was extremely happy with the finished install and said "The install was amazing. I thought
it was simply stunning!!!". Some more general feedback was provided by the venue and unlimited which cited some
improvements which could be worked upon:

- Could be more signage to indicate where works were
- Interpretation information could have been better placed
240   - Some people wanted more specific details about how the infrasound was working, while some were happy to
just experience the work in their own way

The first two points here seem site specific and came about in part due to the project leaders not being present for the installation
to check the layout, information and signage were in the right place. Without a communicator present, these aspects were
especially important. In response to comments, changes were made to the amount of information presented to allow the longest
245   run of the tour to work effectively.

4.3 We The Curious, Bristol

The exhibition at We The Curious had by far the largest amount of public engagement this is likely due to the 3 month period
it was installed for. We The Curious was able to provide some more in depth analysis and were able to provide such statistics
as: the average amount of time spent at the infrasound exhibit was 8 minutes and 3 minutes for the chladni plates, and that the
250   majority of people sat on both pieces of furniture during their visit, broadening their experience. Further to this 95% of people
who visited engaged with both the infrasound and the chladni plates. We The Curious was also able to poll people's opinions
and they found that 85% of visitors said they felt a stronger connection to the hidden sounds of the earth after this exhibit and

91% said they felt they understood more about infrasound based on their interaction with the piece. A word cloud was also created using words that were used to describe the project by the public, this is shown in figure 9. The main words that featured

255 mostly were: "loud", "interesting", "fun" and "mysterious". This indicates a mainly positive reception which stimulated interest in our environment and the science behind the installation. There were a few negative words such as "annoying" and "scary". This shows us that the installation did not forge as positive a connection with those individuals as it did with others: nevertheless, connections were still made. There were some more extended pieces of feedback, left on the postcards left for feedback, one is shown in figure 10. Here the visitor is very excited about both the infrasound and chladni plates and states at

260 the end it has provoked feelings, which is the sense of grounding back to our environment that the project had set out to achieve.

There were some who found the experience overwhelming. One visitor said: "it's really strange, I suppose I'd never thought about how the world around us has a lot more energy and produces a lot more sound than we actually hear. Not sure I'd like it

265 if my ears could actually interpret all this – it's pretty disorientating.". Further to this, due to the logistics of the installation being at We the Curious for three months, it was not possible to have Q&As with the co-authors. This leads again to some feedback such as: "I'd love to know more about how you actually interpret that sound. Like, have you just fudged it? Or am I genuinely listing to the sounds of Bristol?" and "I think it's a really nice approach –it would be nice to have something actually explain all the science to me –guess you can't just keep a scientist in a box"

270 **4.4 Web and online presence**

Assessing **hertz**'s online presence could be considered as being easier as one can look at the number of visits, views and interactions across twitter and the website. The twitter account that was set up by the end of the **hertz** tour had 153 followers and made 37000 impressions on twitter. During the tour the website received 626 visits and 3262 visits since the website went live a year before the tour. However, one of the problems with social media metrics is that you don't necessarily know the

275 impact you have had on your audience. There were plenty of likes and retweets on the twitter account but not many comments to see what people thought of **hertz.**

5 Reviewing the science-art relationship

hertz is a multi-disciplinary project which required Robson, well versed in the arts, and Marlton, Chaplin and Gibbs, academics

280 with a STEM background to work together. The two backgrounds have very different practices. For the arts, the objectives of a Research and Development project such as the first stage of **hertz** within boundaries can be fluid and allows for blue sky thinking. This freedom is appealing to a scientist who typically works on projects that are constrained to a particular question or are required to produce a very specific outcome. Methodologies used in each discipline initially seem distinctly different.

For example, in an art project the artist may create a small concept piece or drawing and iterate on the piece towards a finished
285 work. Along the creative path, ideas may change or be put aside, different lines of enquiry may open, and the finished piece
may, on the surface bear little resemblance to the initial concept piece. This will be influenced by the nature of the piece and
the artist concerned. On the other hand a scientist will perform and outline an experiment, make detailed recordings of the
outcomes and use mathematical deduction to test the hypothesis, often repeating the same experiment several times and there
is generally little room for subjectivity in the interpretation of the outcome, other than in how the results might be presented.
290 In this respect the methodologies can be quite different, and the disciplines differ, yet, in science, a scientist or team of scientists
will often perform investigations over several years that critically depended on moments of inspiration and creativity. The
outcome from an experiment will often inform the next experiment. For example it may be found that there may be a
relationship between X and Y found in the first experiment, but a further experiment may be undertaken to see how it varies
with Z. Isaac Newton was noted for saying "If I have seen further than others, it is by standing upon the shoulders of giants."
295 meaning that even the greatest scientific breakthroughs are a consequence of experiments done by forerunners. Artworks too,
come about through being influenced by or reacting to art traditions or historical art works . In these extensive iterative and
creative processes, the approaches of both art and science are similar.

When **hertz** began as a research and development process there was a common iterative process which has been shown in
300 sections 2 and 3. However, in order to achieve this, the early stages were spent working on communication, understanding
each other's terminologies, methodologies and describing processes to each other in laymen sense to convey each
collaborator's discipline, expertise and objectives. Robson is no stranger to this and knew historically that Art and Science
haven't always been so distinct, and indeed Robson's father was a plant physiologist and poet who was often a sounding board
for her projects. Hence, Robson sought to promote this in **hertz**, through developing a strong and unique working relationship
305 between the collaborators. At times, however, expectations of artist and scientist inevitably differed. For example, in one of
the first sessions where the infrasound prototype was set up, the speaker and transducer jumped into life playing one of the
infrasound recordings for the first time. Marlton's reaction was "...well at least we know that works, now we should tweak
it...", whereas Robson saw it as a major breakthrough in bringing the concept art in figure 2 to being a reality.

310 In addition to the different methodologies that were melded together, each collaborator brought different aspects together
which would not normally meet. For example, Marlton brought experience and contacts from science and technology and
Robson brought contacts from the world of art such as art curators, commissioners, funders and programmers. **hertz** then
became an art installation in its own right that was packed with loads of underlying science. It was set up for the public to
appreciate it as an experiential interactive artwork, while learning about the underlying science as described in section 4
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As part of the exhibits, Marlton and Robson were interviewed about how their attitudes, perceptions and knowledge about
have changed due to the project. Robson responded:

"This is the first time working with scientists in this way. I would say this project (hertz) as a whole has given me an
320   *understanding of the ways artists and scientists can collaborate, affect each other's work and learn each other's language. There may be different priorities for the artist and the scientist and if attached to an organisation. There are also the funders priorities of the artwork or artist. Juggling and doing justice to the needs and agendas of different people and bodies has been a learning curve and something to take forward in my career. In terms of my practise it has been a very enjoyable process and I will continue to collaborate and work with scientists. Bill (Chaplin) one of the collaborators on hertz has experience in*
325   *collaborating with artists. His approach is a good example of how a collaboration between artists and scientists can work well in terms of mutual needs and respect for each other's work: creating something that is more than an educational tool for the scientist, something that can inspire audiences to find out more about the research the scientists do and has authenticity but that stands alone as as artwork that has meaning in different contexts be that artistic scientific or other. This can only be achieved with a commitment by the artist to meaningfully engage in the scientific research and for the scientist to trust the*
330   *artist and their ability to create something that can reach a wide audience and communicate with them."*

Marlton was also interviewed about how the project has changed his attitudes:

"If I told you I'd made a chair that vibrates to the sound of the earth, people might have been, like, so what? But with the use of Juliet's (Robson) experience, hertz has been presented, raised in profile and her creative license and skills have been used
335   *to create an installation that engages and enthrals the public, I couldn't have done that myself."*

"...I'm more interested now in different ways of displaying data. I make a data plot and sometimes, I think we could turn it into something you could feel, or hear and it has opened up new ways of visualising data, especially if it is something quite complex. So I'm more open to when you look at data or something thinking what could I do with this? I guess learning from
340   *Julie, who looks at something and thinks of several quite out the box things that could be done with it. So I guess as a result of hertz I now think a lot more out of the box."*

In summary, both contributors forged a good working relationship. They had their preconceptions changed by their interaction and developed a wider appreciation of each other's activities as a result.

345   **6 Conclusions**

The collaboration between the artist and scientists worked well and is a good model for future art science collaborations. It worked well because the two disciplines, despite their overlying differences nevertheless share some common methodologies in creativity, allowing them to work objectively towards a common goal and because of a willingness to learn about each other's worlds. When working together it was important to articulate ideas clearly and simply and be prepared to explain ideas

350 in a step by step fashion. It was also important to be open and generous when understanding and delivering what each other's needs for the project were according to their own personal and professional agendas. This project reaped the rewards of the different collaborators bringing their experiences together to make an immersive educational piece. Further to this, the long-lasting implications of the project to the individuals are that they have learnt a lot about each other and this has changed their perceptions about how they may conduct their respective works in the future.

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One of the overarching aims of the project was to produce an installation that would allow people to feel grounded with the environment that more than ever people are feeling isolated from. Looking at the feedback and the word cloud in figure 10 where words such as 'atmospheric', 'enlightening', 'relaxing' show that the installations are making people think about the environment around them. Given that our environment is under threat due to climate change and pollution, a piece such as

360 **hertz** acts to remind us all of the imperative to be aware of the natural world around us. Given the importance of drawing attention to our environment, and the success of **hertz** and its potential for flexibility in size and use of infrasound material, the future of further collaborations looks bright. For example, an installation could be set up in an underground station where large sections of the space vibrate and shake. **hertz** also demonstrates that there is considerable potential for outdoor structures and street furniture to have transducers attached to widen opportunities for experiential art.

365 **Acknowledgements**

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375 **Ethical considerations**

All feedback received from members of the public had been anonymised where needed. At events where photos and videos were taken an opt-out policy was adopted where people who did not want to be in the photos or videos were asked to make themselves known or wear a wristband so the photographer knew not to include them in frame. People experiencing the artwork chose to do so at their own will and were free to leave or stop partaking at any point.

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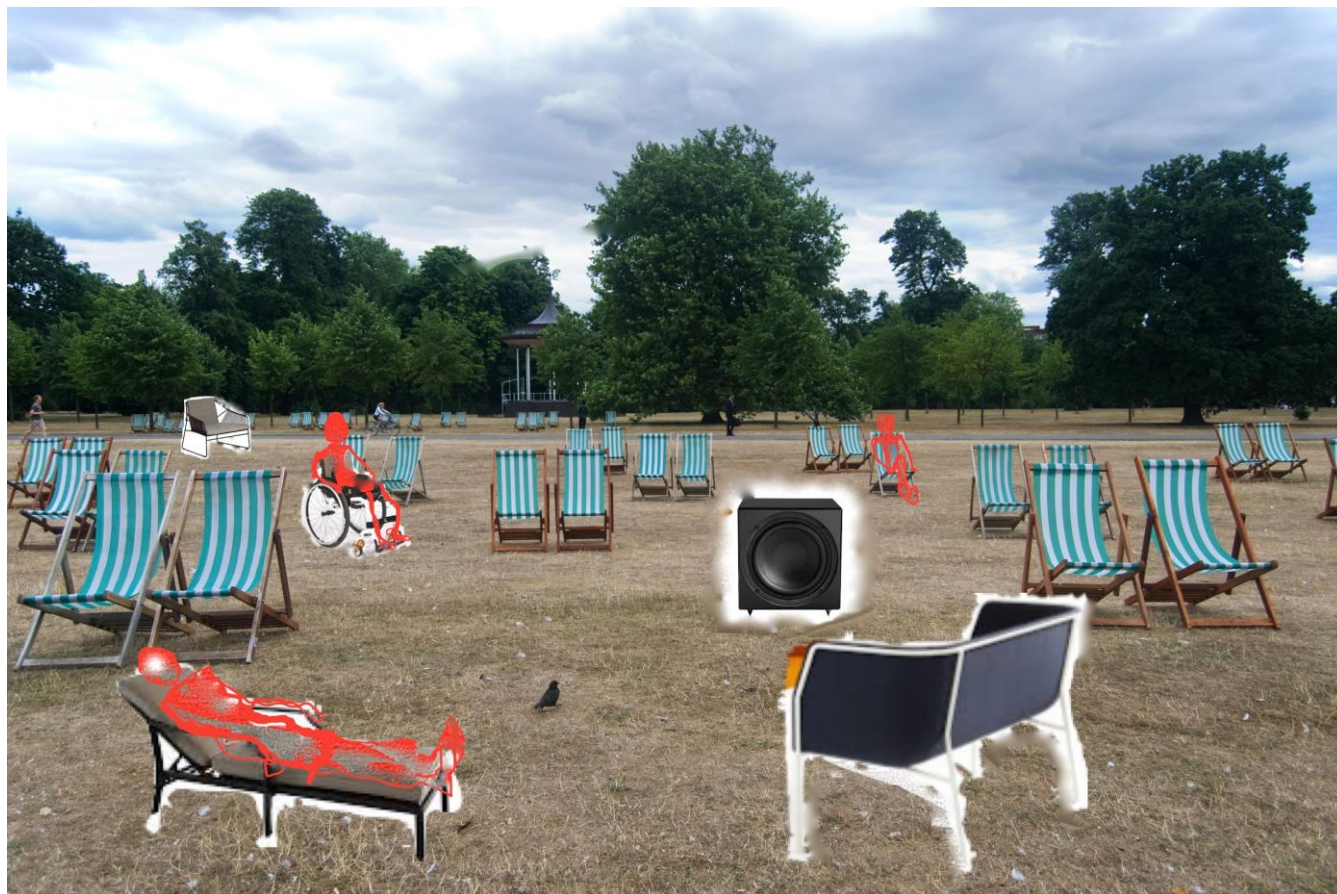
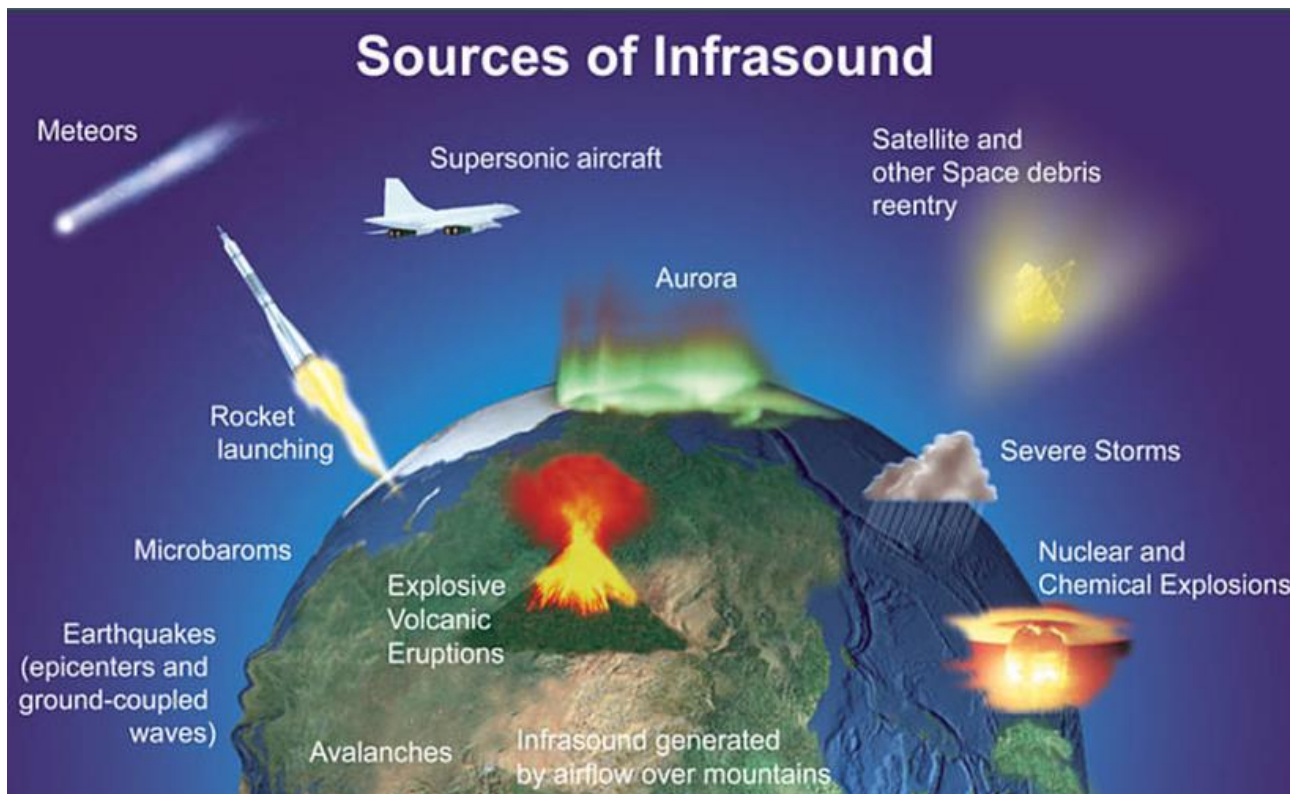

Figures

Figure 1 One of Robson's initial drawings of hertz in an urban park. Blue and white striped deckchairs, other furniture and wheelchair; three people sitting, one in deckchair, one using a wheelchair and one lies on a sun lounger. Figures are drawn in red. Among the furniture is a large subwoofer. The furniture would have transducers attached to vibrate them and the subwoofer would play the sounds of a large ocean wave or storm a long way off the coast.

420 **Figure 2: Sources of infrasound both manmade and naturally occurring from ARISE website (arise-project.eu)**

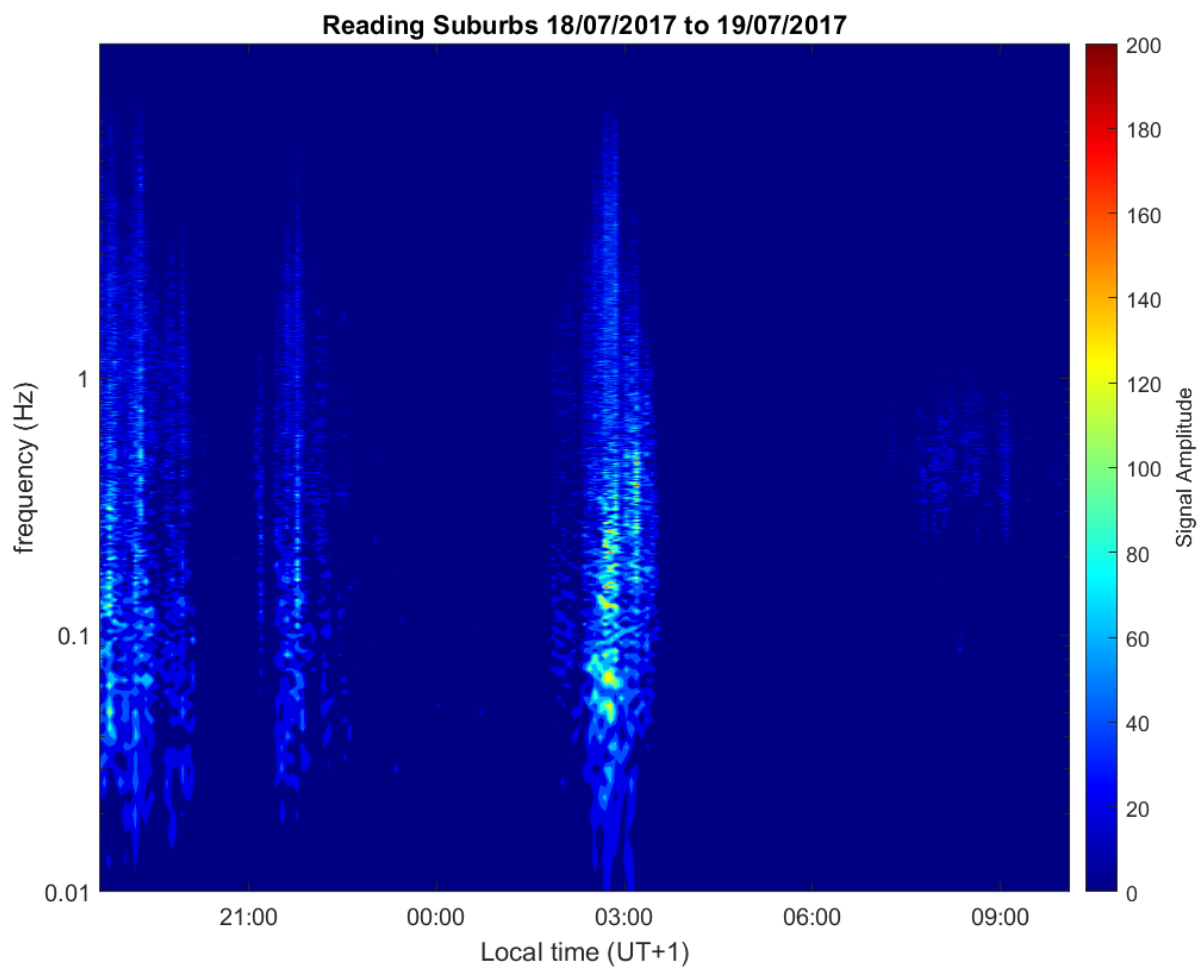



Figure 3: A spectrogram of infrasound data obtained by an INFRA200 sensor placed situated in the SE Reading suburbs from 18th July 2017 to the morning of the 19th July 2017. (On the x-axis is local time in hours on the y-axis is the frequency of the infrasound signals. The colour bar on the right shows the strength of the infrasound signals.)

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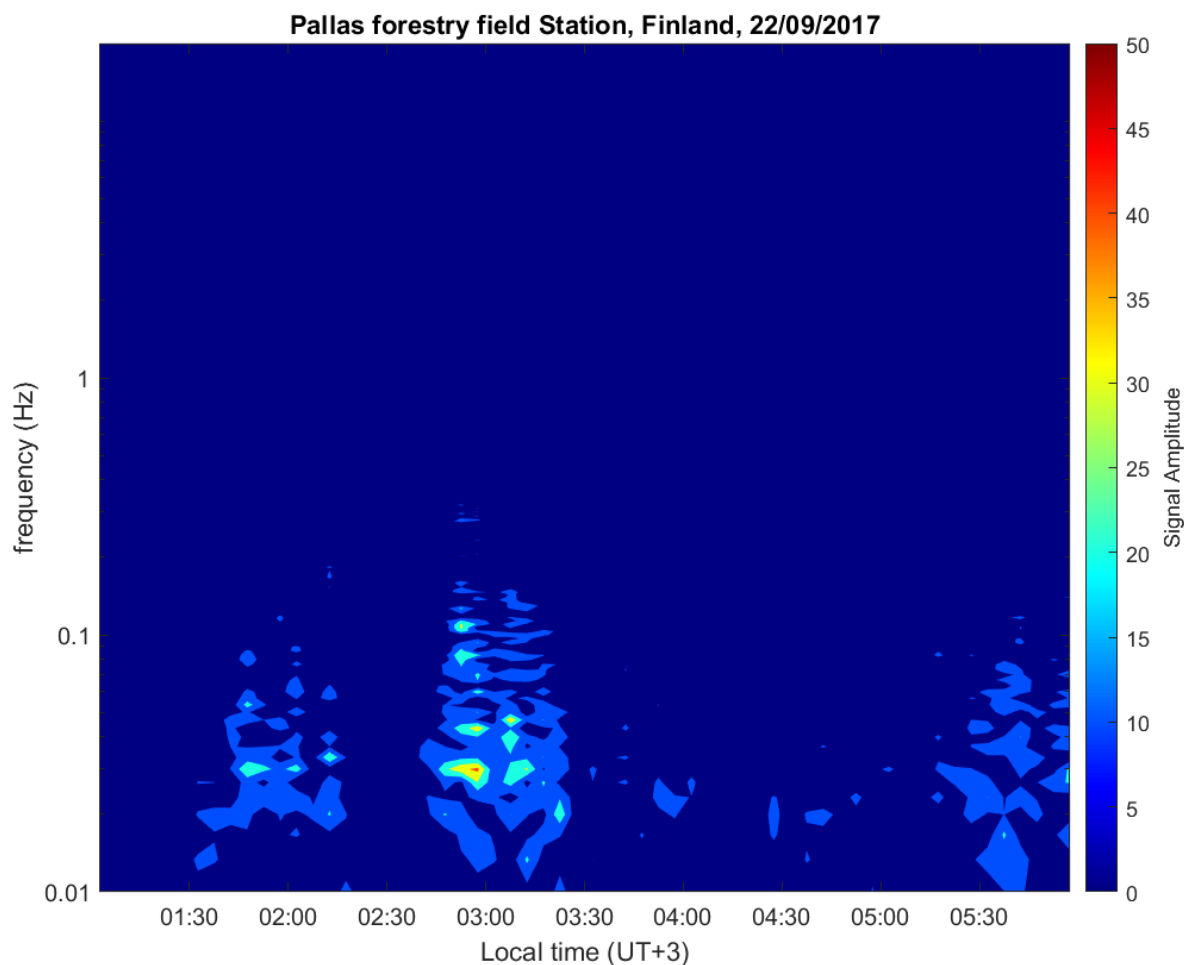
Figure 4: A spectrogram of infrasound data from the infrasound sensor placed situated in Pallas Finland on 22nd September 2019. (On the x-axis is local time in hours on the y-axis is the frequency of the infrasound signals. The colour bar on the right shows the strength of the infrasound signals.)

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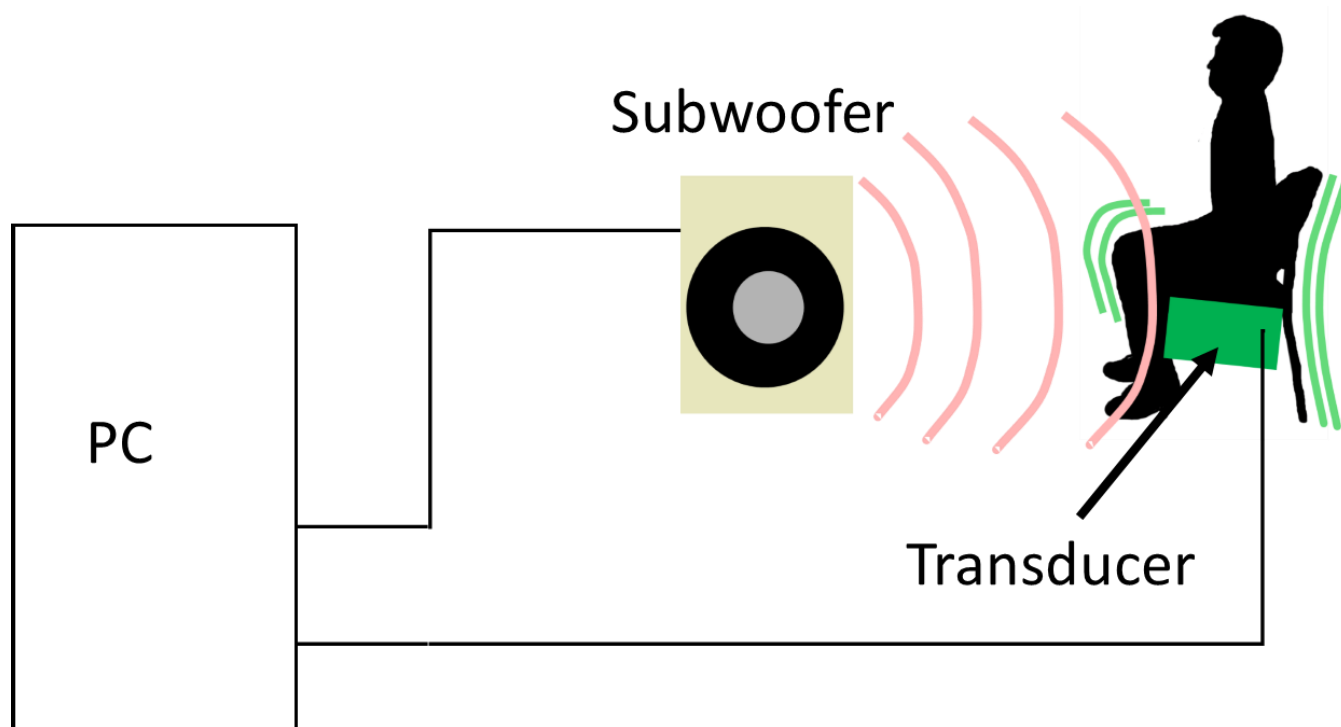
Figure 5: Schematic of hertz prototype rig.

Figure 6: Be There At The start conference. Two people experience the effect of infrasound played through the transducer and large subwoofer in a gallery space. They both face a subwoofer that fills the room with low frequency reverberation of sound.

Figure 7: Finalised version of the hertz infrasound installation at the Tramway, Glasgow. Two members of the public sit on the furniture which has the transducers (blue) clamped underneath. The powerful subwoofer is in the background.

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Figure 8: Left: Juliet Robson introduces hertz to the public at the Oxford Science and Ideas Festival, October 2018. Right: a young member of the audience experiences the reverberations of infrasound from the Oxford locality through one of the metal chairs.

450 **Figure 9: A word cloud summarising the words used to describe the hertz project by the public at we the curious during its exhibition between November 2018 and March 2019.**
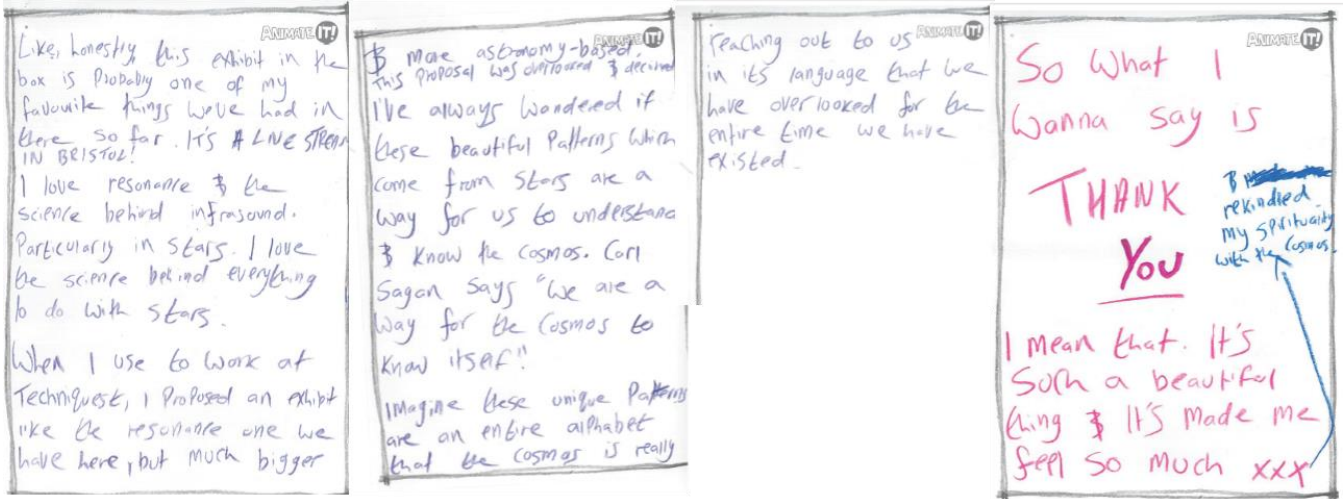
Figure 10: Feedback at we the curious from one visitor to the visit.

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475 **Tables**

Date	Location	People	Audience
November 2017	Wyfold Lane studio, Oxfordshire, UK	11	Funders of R&D, potential hertz supporters and programmers and Scientists.
March 2018	Wyfold Lane studio, Oxfordshire, UK	25	Local families and school children
March 2018	101 outdoor Arts, Newbury, Berkshire, UK	15	Resident artists, Art Commissioners and bbc 3 presenter Max Ernst
March 2018	Be there at the Start Conference, Attenborough Arts Centre, Leicester, UK	100	General Public
April 2018	Session EOS8 – Scientists, artists and the Earth: co-operating for a better planet sustainability, EGU 2018, Vienna, Austria	35	Scientists
April 2018	We the Curious - After Hours Event, Bristol UK	50-70	Artists

Table 1: List of public engagement activities where the hertz prototype were shown

Date	Location	Audience Numbers
15/10/18	Oxford Science and Ideas Festival, Oxford, United Kingdom	55
18/10/18-21/10/18	Tramway art-space, Glasgow, United Kingdom	Unknown
7/11/18-28/3/1	We the Curious, Bristol, United Kingdom	6786

480 **Table 2: Hertz tour locations and audience numbers**