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Sublime frequencies: The construction of sublime listening experiences in the sonification of scientific data

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Abstract

In the past two decades, the sonification of scientific data – an auditory equivalent of data visualization in which data are turned into sounds – has become increasingly widespread, particularly as an artistic practice and as a means of popularizing science. Sonification is thus part of the recent trend, discussed in public understanding of science literature, towards increased emphasis on 'interactivity' and 'crossovers' between science and art as a response to the perceived crisis in the relationship between the sciences and their publics. However, sonification can also be understood as the latest iteration in a long tradition of theorizing the relations between nature, science and human experience. This article analyses the recent public fascination with sonification and argues that sonification grips public imaginations through the promise of sublime experiences. I show how the 'auditory sublime' is constructed through varying combinations of technological, musical and rhetorical strategies. Rather than maintain a singular conception of the auditory sublime, practitioners draw on many scientific and artistic repertoires. However, sound is often situated as an immersive and emotional medium in contrast to the supposedly more detached sense of vision. The public sonification discourse leaves intact this dichotomy, reinforcing the idea that sound has no place in specialist science.

Keywords

art–science, public understanding of science, sonification, sound, sublime, visual culture

During a 'Music and the Brain' event at the 2008 *Wien Modern* festival for contemporary classical music, the researchers Gerold Baier and Thomas Hermann took the stage to

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present their method for the *sonification* of a human electroencephalogram (EEG), the representation of brainwaves as an acoustic signal. After an introduction to their approach – which the presenters insisted was driven mostly by 'love for information content' rather than 'aesthetic desire' – and a live demonstration with the brainwaves of composer Alvin Lucier, the lights were turned off. For the rest of the performance, the room remained dark as bursts of rhythmic sounds alternated with slides showing keywords, including 'epileptic', 'generalized seizure' and 'slowing of the rhythm', in white letters on a black background. By the time the performance was over, the room had emptied somewhat, but the remaining audience applauded enthusiastically. I overheard conversations describing the performance as 'very oppressive, but also really beautiful at times'. Afterwards, Baier asked me whether I had found the experience 'intense', and was clearly pleased when I answered in the affirmative. The goal, he explained, was to convey an experience from which the listener cannot withdraw, just as an epileptic cannot withdraw from a seizure.[1]

In this article, I discuss sonification in terms of its promise to create *sublime* experiences of science, 'experiences of awe and wonder, often tinged with an element of terror' (Nye, 1994: xvi).[2] Jon Turney (2004) argues that the sublime is a particularly powerful medium for the popularization of science, but his analysis is limited to textual evocations of the sublime in popular science writing. As I suggest here, the sublime can be particularly effective when it is realized in sensory experience, as is done in sonification as well as other domains, such as IMAX shows and interactive exhibits that have become a mainstay of many science centres and museums (Griffiths, 2008; Macdonald, 1998; Ploeger, 2004). The *Wien Modern* performance is an excellent example of such an evocation of the sublime through sonification; the self-professed goal of the evening was not to create beautiful music, but to translate scientific measurements describing dynamic events in the brain into a sensory experience – and a somewhat threatening and oppressive experience at that. As I will show in this article, the fascination with sonification often rests upon such a construction of sublime experiences and fits into broader trends in the relationship between science and its publics, and science and art.

Sonification has been concisely defined as 'the use of nonspeech audio to convey information', and is usually described as an auditory equivalent of scientific visualization (Kramer et al., 1997). It is a relatively young field of scientific and artistic research. Although some precursors exist – such as the Geiger counter and experiments in the 1960s that used sound to discriminate between earthquakes and underground nuclear detonations (Volmar, 2013) – a community systematically dedicated to sonification research only emerged in the early 1990s. It has been meeting annually since at the International Conferences on Auditory Display. This interdisciplinary community is engaged in an ongoing struggle for the scientific acceptance of sonification (Supper, 2012a, 2012b).

The phenomenon of sonification has recently started to attract the interest of scholars in the social sciences and humanities. For example, Jonathan Sterne and Mitchell Akiyama (2012) claim that 'despite the prevalence of visualization, we are also living in an age of unprecedented sonification' (p. 557), and the cultural history of sonification is explored in a German-language edited volume (Schoon and Volmar, 2012). Several papers in that volume address why sonification has received increasing attention from

media and funding agencies, and conclude that the widespread availability of media technologies that allow for the easy generation of sound from data are an important factor (Harenberg and Weissberg, 2012; Rumori, 2012). The contribution by Martin Rumori (2012) finds an additional explanation in fashion trends in the art world, as sonification profits from the 'exoticism of the medium of sound' and promises to explore 'a new, mysterious world of sound' (p. 237).[3]

In this article, I want to give a more specific and empirically grounded answer to the question of what makes sonification so compelling to the public imagination. Words such as 'exotic' and 'mysterious' capture some of the appeal of sonification, but the philosophical concept of the *sublime* gives a fuller appreciation of how sonification is presented in public discourse. I also want to link the proliferation of sonification to broader trends in the relationships between the sciences and their publics and between science and art, as described by Science and Technology Studies (STS) scholars.

My contribution focuses on the public life of sonification, rather than its existence as an academic niche. The two researchers described at the beginning of this article have a long-standing academic interest in the exploration of sonification; they present papers regularly at International Conferences on Auditory Display, and one of them is a member of the board of the associated academic community. However, I deliberately refer to a performance at a music festival rather than an academic talk because my interest here is in examples of sonification that occur outside the dedicated research community and are developed for listeners who are neither sonification researchers nor specialists in the domain from which the data are taken. Some of these sonifications are performed in concert settings and others in popular science talks; some are reported on in the science sections of newspapers, others are circulated as music recordings or sound art installations. My analysis is based on semi-structured qualitative interviews, ethnographic field notes taken at various sonification concerts and talks and primary documents, including popular science articles, websites and art journals.

In focusing on examples of sonification in popular science and art, I am not trying to argue that there is an absolute distinction between them and specialist science. As STS scholars have shown, the dividing line between popularization and specialist science is less clear-cut than has traditionally been assumed (Hilgartner, 1990; Wynne, 1995). For instance, because scientists often read popular science publications related to disciplines outside of their own, popular accounts can stimulate cross-disciplinary fertilization and ultimately feed back into the research process (Bunders and Whitley, 1985; Hilgartner, 1990). Indeed, popular science texts often operate as spaces for scientists 'to evaluate, to rethink, and to locate their own work in a larger context' (Paul, 2004: 60). Even the narratives of fictional texts and movies play a role in communication among scientific experts (Kirby, 2003; Mellor, 2007).

Equally blurry is the line that divides sonification as a scientific tool from sonification as a means of artistic expression. Even within the scientific community dedicated to sonification, the boundaries between science and art are continually negotiated (Supper, 2012a, 2012b). My analysis here focuses on examples of sonification in the public sphere, rather than in the world of specialist science, but it does not take the boundaries between the two for granted. Instead, it asks how various sonification projects position themselves in relation to the public, to science and to art. It thus contributes to recent STS

scholarship on the relations, boundaries and intersections of art and science (Born and Barry, 2010; Halpern, 2012).

I will begin my analysis by briefly describing four sonification projects from different scientific domains: astrophysics, the geosciences, particle physics and genetics. Each of the projects positions itself differently in relation to specialist research, popular science and art, and each of them allows me to raise different questions about sonification. These questions, which resonate across many sonification projects, ask after several related themes: the rationale of sonification for science popularization, the artistic motivations for working with sonified data, the role of synaesthetic imaginations and the usage of metaphors to suggest that the sounds are inherent to the phenomena being sonified rather than the outcome of a series of human–technological interventions. After my descriptive accounts, I discuss the different configurations of science and art that they exemplify. I then show what the different examples have in common by analysing how sublime experiences of science are constructed with the help of rhetorical, musical and technological strategies. After sketching out the elements of this *auditory sublime*, I reflect on how sonification fits into broader trends in the relationship between science and public. Finally, in the conclusion, I discuss how the framing of sonification as a source of the auditory sublime affects the ongoing struggle for the academic legitimacy of sonification as a scientific method.

We do not do science that way: public outreach in asteroseismology

The tradition of thinking about the 'music of the spheres', or the serene music created by the movements of celestial bodies, has been an important theme in Western science and culture for centuries (James, 1993) and continues to be a resource for science popularization (Edford, 2007). In the last few years, it has become especially popular among scientists in the astrophysical specialization of asteroseismology. In this field, which is dedicated to the study of the internal structure of stars through the interpretation of their pulsation periods, sonifications are often played with the promise of 'listening to stars'.[4]

These sound examples are usually framed as tools for communication with non-specialist audiences; they function primarily as metaphors that are meant to convey that oscillations propagating at the surface of a star contain information about the composition and size of its core. Essentially, the comparison goes, these frequency spectra are like sound waves, and we can distinguish different kinds of stars by their frequency spectra in the same way that we can tell a piccolo from a large flute based on its sound. Accordingly, public presentations often illustrate the principles of asteroseismology by playing sonifications of different stars side by side.[5]

Indeed, it is mostly during public talks or media appearances that asteroseismologists communicate with the help of sonification. Sometimes, they also do so during university lectures or professional talks, but they usually do not play these sounds for an audience of specialist peers. Sonification examples are used only 'if it's not a conference in my own field'.[6] If they are played for a scientific audience, they are framed as an 'amusement'.[7] A recent asteroseismology textbook warns, 'While it is possible

to use our observations of pulsating stars to generate sound files for the stars, and listen to them, we do not do science that way' (Aerts et al., 2010: 6). Sonification, it is stressed, is not one of the standard procedures of data analysis. In denying the significance of the auditory representations, the scientists reinforce a categorical distinction between 'real' and 'popular' science; sound, it is suggested, is only appropriate for popular science.[8]

While these asteroseismologists draw a clear boundary between real and popular science, they consistently talk of popularization as something to which they are genuinely committed.[9] They describe it as an enjoyable activity in its own right, as well as a means to an end, such as getting 'smart students for astronomy' (Kolláth, 2006: 421) or acquiring public funding. Indeed, in a scientific discipline that is heavily dependent on expensive telescopes and space missions, the need to communicate to lay taxpayers is perceived as an important imperative.[10] As one of my interviewees facetiously remarks, sonification can be used to justify the funding for such research with the argument that the kids like to dance to it: 'Well, we can use the world's biggest telescopes, they cost more than a hundred thousand Euros a night to use them, and we can make disco music with them'.[11] This argument is put forth with a certain amount of irony, and indeed, is aimed more at warding off particularly aggressive challenges to the usefulness of astrophysical research than at convincing anyone of its enormous societal and economic value. Nonetheless, it hints at an important function of these sonifications, which do in fact help to legitimize asteroseismological research by affording audiences a better understanding of the research as well as an emotional connection to it.

The sound files that are used in public demonstrations of asteroseismology often circulate among peers or on the Internet. When asked how these sounds were made, the scientists do not necessarily know or feel the need to know the answer.[12] The same is true for other scientific fields where sonification is used in similar ways. For example, an astrophysicist who likes to entertain audiences with the sound of the universe just after the big bang resents it if the listeners ask too many questions about the sounds themselves.[13] On the contrary, an infrasound researcher who entertains general audiences as well as his peers with the sounds of volcanoes takes great pleasure in talking about how he made those sounds, but he freely admits to 'massaging' the sounds to make the results sound more musical. Such massaging of the data is unproblematic for him, as it does not interfere with the scientific message he wants to convey about volcano activity.[14] In these stories of sonification as a tool for popularization, sonification is framed as a form of entertainment of marginal scientific value, rather than as an accurate representation of scientific data.

Music driven by the forces of nature: John Luther Adams' *The Place Where You Go to Listen*

Intriguingly, being 'true to the data'[15] is often more important for artists who work with sonification than it is for the scientists quoted above. This phenomenon is evident in a 2006 sound and light installation, *The Place Where You Go to Listen*, at the Museum of the North in Fairbanks, Alaska. The music critic Kyle Gann (2006) described the experience of visiting the installation:

> You walk in, separate yourself from the world directly outside, sit on the bench, and slip into the red-and-violet, or blue-and-yellow, moods of the five glass panels in front of you. A continual hum greets you, and after a moment you begin to sort out the strands of the complex tapestry that the hum turns out to be. There are sustained chords, an intermittent rattle of deep bells overhead, and an irregular boom of extremely low frequencies that you have to focus on to remain aware of.

Composer John Luther Adams created the installation in collaboration with a programmer and several scientists advising him on seismological and meteorological matters. Each of the visual and auditory events is driven by real-time scientific measurements of natural phenomena. Coloured glass panels change their hue according to time of day and season, sustained chords track the current position of the sun, a single band of filtered noise changes according to the lunar phases, deep rumbling sounds are controlled by seismic activities and bell sounds are used to present fluctuations of the magnetic field that correspond to aurora activities.

In a book about the genesis of the piece, Adams (2009) describes it as 'a self-contained sound world in which the inaudible becomes audible' (p. 139) and as an expression of his 'personal mythology of the North' (p. 102).[16] He concisely explains his artistic motivations:

> The music of *The Place* is produced by natural phenomena. But this is not a scientific demonstration of natural phenomena. It is a work of art. The essence of this work is the sounding of natural forces interacting with the consciousness of the listener. This is not a simulated experience of the natural world. It is a heightened form of experience itself. […] Despite my desire to remove myself and invite the listener to occupy the central position, *The Place* is still a musical composition. Although I tried to minimize the evidence of my hand, I remain the composer. (Adams, 2009: 8)

Although Adams rejects the interpretation as a scientific demonstration, he emphasizes that not all artistic decisions were made by him, as he trusted the 'forces of nature' with some of the decisions traditionally made by the composer (Adams, 2009: 115).

With Adams' efforts to minimize the evidence of his hand, *The Place* can be understood as part of a larger musical tradition in the 20th and 21st centuries of a 'self-denying tendency on the part of many composers' who are compelled by 'the possibility of removing the individual from the act of composition' (Willcock, 2006: 226). Indeed, the shift from conceptions of music that stress its individuality, subjectivity and expression towards a more materialist and objective one that emphasizes detachment and restraint has been portrayed as one of the defining characteristics of 20th-century music (Morgan, 1998); 'the resolute elimination of the artist's ego or personality from the artistic product' has been presented as the common denominator of otherwise radically different avant-garde scenes in Europe and North America (Taruskin, 2005: 55). Sonification, as a way of ostensibly handing over some compositional decisions to scientific data rather than an individual artist, fits this tendency perfectly. For Adams (2009), as for many other composers of his generation, sonification constitutes a way to escape the 'overindulgences of artistic romanticism' (p. 9).

On this basis, it is not surprising that meddling with or massaging the data is often more frowned upon among artists working with sonification than among scientists using it for the purposes of popular outreach: deliberately manipulating the sounds resulting from the sonifications, or picking only those sounds that are especially beautiful, goes against the very concept that sonification embodies for such artists. For the artists, it is of utmost importance to avoid manipulations of the data and to '[remain] quite straightforward in this regard',[17] as remarked by the German composer Marcus Schmickler, whose piece *Bonner Durchmusterung* consists of 10 movements each based on a sonification of a different astronomical dataset. By contrast, editing sounds during the sonification process would constitute cheating. In the words of composer Alvin Lucier, who pioneered sonification-based music with his 1975 piece *Music for Solo Performer (For Enormously Amplified Brainwaves and Percussion)*, it would mean doing 'an imitation of a thing and not the thing itself'.[18]

Sensory perceptions of abstract entities: the *LHCsound* project

In the previous two sections, I first described sonifications made and used by scientists and then discussed examples of sonification that were primarily the work of artists. For the next two sections, I focus on projects based on extensive collaborations between scientists *and* artists. The *LHCsound*[19] project is such an example. In order to sonify particle physics data generated at CERN's Large Hadron Collider (LHC), the physicist Lily Asquith collaborated with musicians, including Richard Dobson and Archer Endrich. Like much of the research at the LHC, the project prominently featured the Higgs boson, an elementary particle that was predicted by the standard model of particle physics but remained elusive to experimental verification for a long time. The Higgs boson was reported found at last in the summer of 2012; most activities of the *LHCsound* team, however, date from before this moment.[20] The project started in 2010 and gathered an unexpected amount of media attention almost immediately – enough to crash the project's web server, which was not prepared for the sudden publicity.[21]

Most media reports about the project emphasize the usefulness of sonification for scientific specialists. Ostensibly, sonification 'provide[s] particle physicists with a new analysis tool' (Ghosh, 2010), which 'help[s] scientists listen out for a Higgs boson if and when it is successfully produced' (Taylor, 2010).

As far as the official project is concerned, this is not quite accurate. Funding was acquired through a scheme for public engagement, and promises were made for the development of 'ringtones and an LHC sound iPhone application' rather than for analysis tools for physicists.[22] However, the project team indeed positions the work quite differently from the asteroseismologists discussed above; for the team, the sonifications should be useful not only for the public at large but also for the scientists doing research at CERN. The project therefore entails an interesting balancing act between popular outreach work and developing research tools for scientists. Asquith, who contributes regularly to the 'Science' section of the *Guardian* website,[23] says that while she 'really enjoy[s] doing communication work', it is the idea of making the sonification useful for herself and other physicists that is 'probably the most exciting part of it'.[24] However, this

is also the part that it is most difficult for her to find time for, especially as she feels that putting too much emphasis on it might be dangerous for her fragile career as a recent PhD graduate. After all, many of her peers are very sceptical of the idea of sonification, especially if it is presented as anything *other* than public outreach:

> It's not something I want to be making a big fuss about, because I want people to take me seriously as a physicist. [Laughs.] I'm at the beginning of my career, and I don't want to be famous for being mad.[25]

At least for the time being, then, *LHCsound* exists primarily as a form of public outreach, even if articles written about it mention (often in rather vague terms) its potential as a tool for scientists. The project sets out to make complex and abstract scientific research more accessible for laypeople. For Asquith, sonification constitutes a way to make the excitement of working with collisions at LHC palpable to outsiders without involving them in the difficult calculations that the research is based on.

The project accomplishes this by giving sensory qualities to particles that do not have a known physical manifestation. At the very core of the project lies a synaesthetic imagination of the particles as possessing different colours, textures and sounds. *LHCsound* was first conceived when Asquith tried to impersonate different particles for a musician friend, which led to the idea of taking a more systematic approach. Asquith found that many physicists, herself included, had strong associations of particular particles with colours or sounds. For instance, Asquith reports, her colleagues imagine hadronic activity to sound 'like opening a difficult bag of potato chips' or 'like a man carrying twelve pints on a tray falling down a long flight of stairs – including the swearing' (Asquith, 2010). In the project, these imagined sensory impressions are made audible. In doing so, the entities studied in particle physics, which are notoriously abstract and intangible, are given a palpable and concrete audible form.

3.8 billion years of genetic music: the *Life Music* project

The *Life Music* project rests upon a similar promise of making abstract scientific knowledge audible. In this collaboration between the artist John Dunn and the biologist Mary Anne Clark, protein sequences were turned into music according to their primary and secondary folding structures.[26] However, in their essay describing the rationale of the project from the perspective of the artist as well as the scientist involved, it becomes clear that the goal of the sonification is not only to make biological research more accessible; Dunn emphasizes how sonification can help to make *electronic music* more accessible (Dunn and Clark, 1999). According to Dunn, traditional classical music is steeped in a sense of 'deep structure', which keeps the listeners interested and which is mostly lacking in electronic music. Working with scientific data seems to be a way out of this impasse by giving electronic music a sense of deep structure to which listeners can relate. Dunn posits that not all data are equally able to do this; in particular, he thinks that DNA 'would resonate with the inner maps of humans, who are built upon this code' (Dunn and Clark, 1999: 27).

While Clark's perspective differs, she shares the idea that the sonification of genetic data is particularly fascinating because it represents some essence of life. Clark describes her walks through the music building at her university and imagining what it would sound like to listen to cells instead of practising students:

> Through the doors of the practice rooms, I can hear fragments of 1000 years of written music, played or sung by the current generation of music students–some with finesse, some with hesitation, some with wild improvisation. I think that if somehow I could walk into a living cell, I would hear something similar – the ribosomes ticking away at the synthesis of proteins, playing out their amino acid sequences, note by note, according to a genetic score that is reproduced sometimes with utter fidelity, sometimes with a few unscheduled substitutions, and sometimes with stunningly inventive flourishes. Every generation of cells in every living organism plays the genetic score of its species. However, while the history of music as we know it goes back some 1000 years, the history of genetic music has been at least 3.8 billion years in the making. (Dunn and Clark, 1999: 25)

Clark's musings on the musicality of the genes are variations on a popular theme in the sonification discourse. In proposing that 'the history of genetic music is at least 3.8 billion years in the making', Clark suggests that the genes made music long before she and Dunn came along to transform genetic data into sound. That is, she suggests that music is inherent in genes. Therefore, the goal of the project is not so much to *create* music out of protein structures, but rather to *discover* the music already embedded within them. By framing sonification in this way, the many aesthetic decisions and technical interventions that have to be made for the data to become audible are concealed.

Media discussions of sonification projects in a large variety of different scientific fields share this assumption of an inherent musicality of the phenomena under study. As in the article by Dunn and Clark, metaphors that ascribe sound or music to the phenomena themselves often play an important role. For instance, stars as well as volcanoes are often described as possessing a voice (McGourty, 2003; Mayne, 2006) with which they sing (Branton, 2006; Pendick, 1999). The description of these objects of scientific research as possessing voices endows them, as Sophia Roosth points out in her work on cellular vibrations, with an 'agency to utter sounds that convey information' (Roosth, 2009: 336). The objects make an effort to communicate, while researchers undertake the task of learning to understand what is being communicated. In this way, sonification is framed not as a way of transforming data into sound, but as deciphering the music (or language) of the phenomena under study.

Sonification, science and art

The projects discussed so far involve a variety of different relationships between science, art and the public. Before reflecting on what connects these different examples – a connection that, I will suggest, is created by an evocation of the sublime – I briefly want to take stock of the different ways in which science and art are entangled with each other in these examples. Projects explicitly based on collaborations between artists and scientists have become increasingly popular and common in the last decade, not only in sonification (Halpern, 2012). This burgeoning field of 'art–science' has been analysed by

Georgina Born and Andrew Barry (sometimes with Gisa Weszkalnys) in the context of their research on interdisciplinarity (Barry et al., 2008; Born and Barry, 2010). As Born and Barry (2010) argue, the heterogeneity of such art–science work is often underappreciated. With this, they refer not only to the different forms of collaboration but also to the different logics according to which interdisciplinary work operates. They distinguish three such logics: the logic of accountability, which aims to make science more accountable to the public; the logic of innovation, which is directed at stimulating technical innovation and economic growth; and finally, the often disregarded logic of ontology, which is oriented 'towards effecting ontological change in both the object(s) of research, and the relations between research subjects and objects' (Born and Barry, 2010: 105). As I will show, sonification projects display a similar heterogeneity, with the logics of accountability and ontology both playing a prominent role.

Under the umbrella of the logic of accountability, Born and Barry (2010) argue that art–science initiatives frequently involve a strategy of 'enlisting artists to foster the public's relationship with science' in the hope of reaching new audiences, who 'might develop not only cognitive, but interactive and affective involvements with science' (pp. 108–9). Art and art–science initiatives are thus used to legitimize scientific research.

A similar logic of accountability is present in many sonification examples discussed here; the usage of sonifications to justify public funding for asteroseismological research is a case in point. However, such legitimization is not always a one-way street. Born and Barry's logic of accountability assumes that art legitimizes science, but the *Life Music* collaboration between the biologist Clark and the composer Dunn shows that it can go both ways; references to art seek to make scientific research more accessible, but at the same time, references to a biological subject-matter are also hoped to increase the appeal of electronic music by imbuing it with what Dunn calls a sense of 'deep structure'. Rather than art making science more accountable to the public, art and science are involved in an act of 'legitimacy exchange'. This notion was coined by STS scholars working on the history of cybernetics, who observed that 'an isolated scientific worker making an outlandish claim could gain rhetorical legitimacy by pointing to support from another field – which in turn referenced the first worker's field to support its claims' (Bowker, 1993: 116). While Bowker (1993) refers to the legitimacy exchange between scientific disciplines, Fred Turner (2006) has more recently used the concept to include artists and entrepreneurs. Similarly, the example of *Life Music* shows that the interaction between science and art in sonification does not operate according to a one-sided logic of accountability, in which art is enlisted to legitimize science, but rather involves a two-sided exchange of legitimacy.

However, not all sonification projects can be subsumed under this logic of accountability or legitimacy exchange; others are more concerned with 'altering existing ways of thinking about the nature of art and science, as well as with transforming the relations between artists and scientists and their objects and publics' (Born and Barry, 2010: 105). They thus operate according to what Born and Barry (2010) name the 'logic of ontology'. A particularly poignant example is the composition *Bonner Durchmusterung* by Marcus Schmickler. Although the piece was commissioned for the International Year of Astronomy, the contents of the programme booklet make clear that the intention was not simply to educate about or celebrate astronomical research.[27] Next to a brief explanation

of the ten astronomical phenomena that were set to music (among them eruptions of the sun, rotation profiles of pulsars and gamma ray bursts), the programme notes feature an essay – co-written by the involved artists and their primary astronomical collaborator – that promises 'an epistemological exchange between astronomy and music'. Starting out from the statement that even raw astronomical data are 'deeply dependent on a theoretical model of the world, upon which the measurement process is based', the authors reflect on the role of mathematical models and visualizations in astronomical research, and call into question 'the relation between data and the reality of the observed objects'. How, for instance, does one get from complex rows of numbers to an understanding of celestial objects, let alone a cosmology? The essay concludes by encouraging artists and scientists to work together on a mutually enriching 'poetic interpretation, representation and contextualization of scientific knowledge'. Indeed, in my interview with the composer, he stressed that he was interested in sonification as a means of triggering interdisciplinary reflexivity.[28]

As these examples show, sonification is a diverse and heterogeneous field. While it often involves crossover between science and art, it does so through diverse forms of collaboration, operating according to different logics and leading to different figurations between science, art and the public. In the remainder of this article, I want to discuss what these seemingly disparate instances of sonification have in common. As I will show, they are connected by their evocation of the sublime.

Notions of the sublime

The aesthetical concept of the sublime was first developed in the 18th century, when philosophers such as Edmund Burke (2008 [1757]) and Immanuel Kant (2007 [1790]) used it to describe a sense of awe and terror in the face of the wonders of nature. In contrast to beauty, which is characterized by harmony, the sublime always contains a fundamental contradiction; it is pleasure mixed with pain, terror with delight.

Whereas Burke's treatise discusses the various objects and qualities that are thought to rouse sublime reactions, Kant focuses on the individual perceiving them. As Kant argues, it would be inaccurate to 'term any *object of nature* sublime, although we may with perfect propriety call many such objects beautiful. […] All that we can say is that the object lends itself to the presentation of a sublimity discoverable in the mind' (Kant, 2007 [1790]: 76, original emphasis). Kant's notion of the sublime thus refers to a mental process, and is characterized by 'a discord between imagination and reason, pointing to the superior ability of reason to think infinity' (Van de Vall, 2002: 362). For Kant, the sublime is always elicited by a confrontation with infinity and unimaginable greatness, whether it is in the mode of the mathematically sublime (which begins with the perception of incredible magnitude or complexity) or the dynamically sublime (which begins with the perception of sheer physical power).

While the sublime is often aroused by objects that are physically immensely powerful, it does not hinge upon perceivers finding themselves in mortal danger; indeed, even in the perception of truly dangerous phenomena such as tornadoes or volcanic eruptions, the sublime is usually experienced 'from a safe distance' (Masco, 2004: 351). As Rosalind Williams (1990) posits, the sublime

> depends on the delicate equipoise of conflicting emotions. It is connected with pain and fear, but not too closely; it is defined by nervous tension, but not too much; it depends on danger, but only theoretical danger. Sublimity celebrates ambivalence. (p. 85)

Burke and Kant focus their discussion of the sublime on the perception of natural objects, although they both occasionally foray into the world of art and architecture. More recently, the concept has been applied to phenomena as diverse as mass tourism (Bell and Lyall, 2002), high-fidelity sound (Barry, 2010), popular science writing (Turney, 2004), avant-garde art (Lyotard, 1989 [1984]), planetariums and IMAX (Griffiths, 2008), the underground (Williams, 1990), railroads (Marx, 1964), the nuclear bomb (Masco, 2004) and bridges, dams and skyscrapers (Nye, 1994). However, not all of these scholars agree on which of these phenomena do indeed count as true instances of the sublime. For instance, David Nye (1994) distances his work on the American technological sublime from post-modern work on avant-garde art, implying that the latter is less sublime than the former: 'But the Grand Canyon or a rocket launch, unlike a book or a painting, is apprehended with all five senses. […] A volcano, unlike a painting, can kill the observer' (Nye, 1994: xx). Nye goes on to suggest that the kind of avant-garde art discussed by Lyotard might be better characterized as an 'aesthetic of the strange'.

This objection seems to limit the sublime to what Kant considered the dynamically sublime, which begins with the perception of threateningly powerful objects. However, while works of art rarely pose a physical threat to the observer, they can confront them with overwhelming sensations of awe and unease. Sonification is a case in point, and may provide the missing link between Nye's technological sublime and Lyotard's artistic sublime. Sonification is closely associated with avant-garde and experimental music (Schoon and Dombois, 2009); like the works of visual art discussed by Lyotard, it challenges traditional artistic conventions and ideas of beauty. At the same time, it can be uncomfortable or even physically painful to listen to. And, like Nye's technological sublime, it is thoroughly mediated by technology, and is not confined to a single sense. In the following sections, I will sketch out the contours of the 'auditory sublime' of sonification, and analyse how this sense of the sublime is constructed.

The technoaesthetics and politics of sonification

A sonification project in meteorology by Andrea Polli (2005) provides a telling example of an evocation of the sublime:

> Some meteorologists call themselves 'storm hunters'. They travel far and take considerable physical risk in order to experience a hurricane or tornado. Do they take such risks because the physical and emotional exhilaration enhances their scientific understanding of the storm? Storm hunters would most likely answer in the affirmative. They experience the sound, scale and physical properties of the storm as well as its direct effect on the environment. A storm experienced only through visualization, whether animated or still, does not convey this visceral information. (Polli, 2005: 31)

The storm, here, is described as creating a sublime experience of awe and fright, which has to be experienced first-hand to be understood. Visualizations, argues Polli (2005), are

fundamentally unable to convey the power of the storms. Sonifications, however, are considered capable of bringing some of the thrill, exhilaration and visceral qualities of a storm to the listeners at home. The sense of the sublime offered by the sonification in this instance rests upon its ability to create a mediated, safe version of the sublime that can otherwise only be experienced in the wild, at one's own peril.

Polli's (2005) description of storms as overwhelming physical events is reminiscent of Joseph Masco's (2004) discussion of the experience of nuclear blasts in his article on the changing technoaesthetics of nuclear weapons science. Masco (2004) distinguishes three eras of nuclear weapons research: the eras of above-ground testing, of underground testing and of a comprehensive test ban. While these eras were induced by international political decisions, they had significant implications for how scientists conceptualized the object of their research, the nuclear bomb.

According to Masco (2004), the era of above-ground nuclear testing was characterized by an aesthetic of the nuclear sublime (a specific form of Kant's dynamically sublime), as scientists experienced the detonations as physical events involving all of their senses. With only minimal protective measures, the scientists were able to experience the scale and the effects of a detonation first-hand. Witnessing the detonations reminded the scientists of the destructive qualities of the bomb, and therefore limited their ability 'to experience the bomb as a purely aesthetic or intellectual form' (Masco, 2004: 352). Once the nuclear tests went underground, this first-hand experience of destruction was lost, and the detonations were experienced purely as abstract numbers and graphs. This was still a form of the sublime, Masco argues, but one closer to Kant's mathematically sublime: not a direct sensory experience, but a sense of awe at the intellectual complexity. The technoaesthetics of the nuclear bomb changed once again when nuclear tests were banned altogether and the emphasis shifted from developing and testing new weapons to stockpiling existing bombs; the bombs were no longer conceptualized as powerful and human beings as vulnerable, but instead, the bombs themselves came to be regarded as in need of protection. Sophisticated simulations were developed as substitutes for direct tests. From a special vantage point in virtual spaces (i.e. inside the nuclear explosions), scientists can 'track specific particles, velocities, pressures, and flows through new, technologically mediated, but nonetheless felt senses' (Masco, 2004: 366). In this virtual reality spectacle, argues Masco (2004), the bomb is reinvented 'in ways that free its aesthetic possibility from its destructive potential' (p. 358).

The spectacle described by Masco resembles the experiences provided by sonification. However, in the technoaesthetics of sonification, the threatening or destructive aspects of what is being sonified are often emphasized rather than downplayed; the goal is not to convey a sense of beauty, but one of awe, enthralment and terror.

In their introduction to a book on the cultural history of sonification, Andi Schoon and Axel Volmar (2012) discuss a particularly salient example where sonification is used to convey a sense of terror. The sound installation *Lungs: Slave Labour* is a memorial to the slave labourers working in Hall A of the Deutsche Waffen- und Munitionsfabriken A.G. in Karlsruhe during World War II, based on a sonification of data describing their lung capacity. According to the mission statement of the installation, its goal is to 'reconnect people with a political atrocity in a very visceral way'.[29] Other sonifications are explicitly used to express concerns about the effects of environmental destruction and climate

change. For example, a recurring theme in John Luther Adams' (2009) writings on *The Place Where You Go to Listen* concerns the changes in the Alaskan environment and climate as a result of 'overpopulation, overconsumption, pollution, deforestation and widespread extinction' (p. 9). And on the album *Sonic Antarctica* by Andrea Polli (2009), musings about climate change have become part of the work of art itself, and that project juxtaposes meteorological sonifications, field recordings and snippets of interviews with climate researchers. One scientist ponders,

> You know, we could completely screw up the Earth, and it would come back. The problem is, it might not come back for a million years. Now, to the earth, a million years, who cares, it's nothing. But in human history, you fucked yourself. (Polli, 2009)

Not all sonifications include such a normative dimension, nor do they all deal with threatening themes. What they share, however, is a sense of being overwhelmed with the vastness and greatness (or, conversely, the inconceivable diminutiveness) of the sonified phenomena.[30] The creators of many sonifications stress that they regard sound as a way of allowing people to emotionally connect with something otherwise incomprehensible. Indeed, in some cases, the connection is not only emotional but also spiritual. For instance, Dunn and Clark (1999) believe that their sonification of proteins gives 'insights into the astounding depth of structure Nature has built into Her art' (p. 30), while composer Archer Endrich of the *LHCsound* project remarks that the sonification of the Higgs boson has made him 'feel closer to the mystery of Nature' (Ghosh, 2010).[31]

References to the sublime are found around a range of sonifications, regardless of the scientific discipline involved: in relation to the wonders of the cosmos, the dangers of the earth, the inconceivability of particles, the powers of genes and the complexity of the brain. Words like 'eerie' or 'otherworldly' are common descriptors of such sonifications (Branton, 2006; Gann, 2006; PhysOrg, 2010). For instance, the sound designer Micah Frank has created a 'chilling aural portrait' of the 2011 earthquake in Japan, which features 'a series of ghostly oscillations, punctuated by disquieting harmonic rhythms' (Gentile, 2011).

The emotions said to be evoked by listening to a sonification are never purely pleasant. As Martin Rumori (2012) has observed, sonification researchers often display 'a certain aversion to beautiful sounds' (p. 239).[32] The EEG sonification discussed at the very beginning of this article, in which a researcher professed to sacrifice aesthetic preferences for information content, is a case in point. Similarly, some of the sonifications of stars produced by asteroseismologists are said to be 'music only the Borg could love', utterly unattractive to human sensibilities (Overbye, 2011). This lack of aesthetic quality seems to be regarded as a point of pride, a marker of authenticity. Like the metaphors discussed above in regard to *Life Music*, the aesthetic abstinence further reinforces the idea that the sounds come directly from the phenomena; it masks the aesthetic decisions that are unavoidably part of the sonification process.

The abstract sublime

Many of the sonification examples discussed in this article fall into one of two extremes. They either treat a subject matter that has a long tradition of being associated with the

sublime, or they concern phenomena so abstract that they allow for no direct sensory engagement. The sonification of stars, earthquakes and volcanoes are examples of the first kind. These phenomena are familiar sources of (usually visual) sublime imagery, and sonification provides an additional sensory channel to the perception. Celestial bodies have a long tradition of eliciting sublime emotions, enough to earn astronomy the nickname of 'the sublime science' (Zimmerman, 2003); volcanoes have always been a favourite source of the sublime, as they seemingly provide 'conduits into the very bowels of the earth' (Williams, 1990: 87), and earthquakes – specifically the Lisbon earthquake of 1755 – have acted as catalysts in the very development of philosophical ideas on the sublime (Ray, 2004; Regier, 2010). The sonifications of such phenomena often attribute the sublime to the phenomena themselves: a sonification of a star or volcano is sublime because the star or volcano itself is sublime.

However, fields such as high-energy physics or genetics deal with phenomena that have hitherto been closed off to sensory perception; elementary particles and genes exist on a scale inaccessible to human perception. In these cases, sonification serves to make phenomena accessible to the senses that do not allow for direct sensory experience. This links up to what Jon Turney (2004) has referred to as 'the abstract sublime'. According to Turney (2004), evocations of the sublime are among the most powerful rhetorical tools available for popular science writing; they can bring abstract scientific theories into the present in a way that impacts the audience. For example, in abstract biology, a sense of sublime can be textually experienced for ideas that have no physical manifestation by drawing upon metaphors from tried-and-true sources of the sublime, such as oceans and mountaintops. In this domain, the sublime 'can be rendered in words, but the words do not describe something which anyone is ever going to encounter in life, or have any direct sensory engagement with' (Turney, 2004: 96). The sonification of elusive particles such as the Higgs boson similarly allows the existence of these particles to be made more concrete and imaginable, and not only, as in Turney's example, by giving a textual reference point, but also by enabling a sensory engagement with an otherwise abstract phenomenon. Whereas Turney's abstract sublime rests upon a rhetorical association of abstract phenomena with tangible ones that carry connotations of the sublime, the sonifications take a different route by making the abstract phenomena themselves tangible and amenable to sensory perception.

Immersed in sound

Sonification often evokes the sublime by promising a particular sense of presence, that of being surrounded or immersed and soaking in sound. In some cases, this happens only rhetorically, as when Clark ponders what it would sound like to 'walk into a living cell' (Dunn and Clark, 1999: 25). In other cases, the sense of immersion is created spatially and technologically. For example, in Willem Boogman's *Sternenrest*, a musical piece based on stellar oscillations, the audience is physically surrounded by the 192 speakers of a Wave Field Synthesis loudspeaker system as well as by musicians playing acoustic instruments, which is intended to allow the audience to 'imagine itself inside the star' (Boogman, n.d.). In Adams' *The Place*, 'when you enter, the fourteen speakers envelop you in sound' (Living on Earth, 2006). In instances such as these, the sense of immersion is created not

only with rhetorical but also with spatial and technological strategies, especially techniques of surround sound. In this regard, sonification is similar to IMAX, which 'employs a host of technological and architectural devices, such as wide screens, large-format projection, digital surround sound, and stadium-style seating, to create a more absorbing and intense sensory experience for viewers' (Recuber, 2007: 316; also see Griffiths, 2008; Ploeger, 2004). As in the IMAX cinema, the sense of immersion of sonification rarely depends on a single sense, but rather on the interplay of the senses; vision and touch are involved alongside sound in many sonifications. Indeed, sound is itself felt as well as heard, tactile as well as auditory; this is particularly true for deep and rumbling sounds. A good example is the sound of a rocket launch, which one of my interviewees described as shaking the ground 'like a giant earthquake, and the sound just rumbles and pounds into your body'.[33]

Adams' *The Place* is one of many examples of sonifications that also work with visual elements. Although the visuals are relatively simple compared to the sounds, the changing hues of light form an important element of the installation. The sonification of EEGs discussed in the introduction features an even more minimalistic design. While sounds were audible, the room was completely dark; while it was silent between sonifications, the only visual stimulus consisted of white letters hovering on a black background to provide a short explanation of the sounds to come. But the darkness and visual simplicity should not be mistaken for neglect of the visual dimension; it may indicate an absence of vision, but it does so in a way that draws attention to the inability to see, resulting in a state where both attention to sound and awareness of darkness are heightened. The sense of aesthetics being conveyed draws not so much on notions of beauty, but on the ability of the combination of (loud) sounds with darkness to elicit a frightening and oppressive atmosphere. Darkness heightens the experience of sublimity.[34]

Sonification and the changing relationship between science and public

In the past few years, sonification has received considerable media attention; sonification concerts, public talks and magazine articles, all promising that sonification will allow listeners to tap into the sublime, have flourished. This popularity is in stark contrast with the contested status of sonification in the sciences, where a small interdisciplinary community is still struggling for scientific acceptance (Supper, 2012a, 2012b). In the remainder of this article, I want to discuss some reasons why the framing of sonification as a source of sublime experiences has been so popular, and explore the possible repercussions of this public fascination with sonification for its academic acceptance as a scientific method.

The popularity of sonification as an auditory sublime does not exist in a vacuum. Rather, it is strongly related to broader changes in the sciences as a whole and, in particular, the changing importance and nature of 'public understanding of science' initiatives. As STS scholars have pointed out, the relationship between science and its publics has become especially challenging in the last few decades. At a time when the costs of scientific research run high and governments are more concerned with whittling down expenses, the idea that 'the pursuit and acquisition of knowledge [is] valuable enough in

itself to justify pouring money into basic research' (Felt, 2000: 7) loses much of the self-evidence it once possessed. This is coupled with 'a sense of widespread crisis of public mistrust of science' (Wynne, 2006: 211), which has been cause for concern in science and policy circles. Science policy accordingly had to search for new approaches. The old model of public understanding of science, in which a passive public was meant to be educated about science, gave way to a commitment 'to encourage and cultivate two-way "public engagement with science" as a means of alleviating this crisis of public mistrust' (Wynne, 2006: 212). As Brian Wynne (2006) argues, this commitment is often quite superficial, but the change in rhetoric nonetheless requires (at least superficially) new means of reaching the public.

In particular, one strategy to deal with the perceived crisis in the relationship between science and the public has been a new emphasis on initiatives that purport to engage laypeople not as passive recipients of (popularized) scientific knowledge, but as active participants. A notable example of this development is the sprouting of so-called interactive exhibits in science museums and science centres.[35] These usually computer-based interactive displays have been critically examined for their neoliberal underpinnings and conceptions of museum visitors as consumers (Barry, 1998; Macdonald, 1998). Nonetheless, their existence suggests a commitment to offering museum visitors a more active and hands-on engagement with the science on display. While these displays do not necessarily spark broad and democratic debates about scientific developments, it is hoped they will get individuals more interested in science by allowing visitors access to more active, personal and memorable experiences than traditional museum displays. Sharon Macdonald (1998) argues that these exhibits provide visitors with 'a sense of the sensory self, an individualized experience' (p. 131).

Alongside increased emphasis on interactivity, museum scholars and designers have also emphasized the importance of sounds in museums, in particular for creating emotional and immersive experiences (Stocker, 1995). For instance, John Stickler (1995) celebrates the fact that the days of the passive spectator are gone and that museums increasingly seek to draw visitors 'into the very heart of an exhibit' by giving them not only something to look at, but surrounding them with sounds and smells (p. 36).

In the same manner as interactive museum exhibits, sonification promises non-scientists a share of the fascination of doing science by tapping into sublime experiences. At a time in which scientists and policymakers worry about dwindling public support for science, they latch onto sonification as a promising new form that might help to acquire this support for science (or specific scientific projects) by offering listeners a memorable, individualized, sublime sensory experience of science.

Conclusion

The public fascination with sonification rests upon its promise of offering a new experience of science, an experience best characterized in terms of the auditory sublime. In these concluding remarks, I want to return to the concept of the auditory sublime and also offer some thoughts on its implications for the acceptance of sonification as a scientific method. As I will show, the public discourse on sonification that rests upon the auditory sublime reinforces traditional ideas about the respective value of sound and vision in

scientific practice. This is in stark contrast to the efforts of the academic community dedicated to sonification that I have analysed elsewhere (Supper, 2012a, 2012b), which attempts to legitimize sonification as a scientific technique by overturning the traditional hierarchy of the senses between sound and vision.

The experience of the auditory sublime is emotionally loaded and visceral, perhaps even mythical and spiritual, and certainly awe-inspiring and enthralling. It is thoroughly aesthetic, and many find it appealing, but it also conveys a sense of threat, disconcertment and dissonance. I have traced how this sense of the auditory sublime is sonically, rhetorically and technologically constructed in the public discourse on sonification. It is created by the sounds of the sonifications themselves, by their interplay with visual and tactile elements, as well as by rhetorical devices such as metaphors and religious innuendos.

The auditory experience offered by sonification is always mediated. The sonification, for instance, of a volcano is different from the sounds that are emitted by the volcano itself. However, certain rhetorical, musical and technological strategies are used to suggest that the sonification represents something about the volcano that might not be immediately visible or audible from the volcano, but from deeper within it. It is not about sounding like a volcano per se, but about being true to the volcano – or rather, about allowing listeners to believe that the sonification is true to the volcano.[36] Indeed, some cases suggest that it is like being *inside* the volcano.

My point here is not that sonification *is* sublime or offers access to sublime experiences by definition; the sublime is not inherent to sonification. As noted by Kant, the sublime is not a characteristic of an object itself, but a mental reaction on the part of the observer, and as noted by Nye (1994), 'both the objects that arouse this feeling and their interpretations are socially constructed' (p. 3). In this article, I have traced how the producers and communicators of sonifications create the expectation that listening to a sonification yields a sublime experience.[37] It helps that the notion of an auditory sublime, its promise of turning detached spectators into engaged listeners, plays into many of the qualities that are traditionally associated with the sense of hearing, which is widely regarded to be good at creating immersive and emotional experiences. Jonathan Sterne (2003) describes these views as an 'audio-visual litany', in which sound is pitted against vision in relation to a number of supposedly trans-historical qualities, among them the notion that 'hearing places us inside an event, seeing gives us a perspective on the event', that 'hearing is about affect, vision is about intellect' and that 'hearing is a sense that immerses us in the world, vision is a sense that removes us from it' (p. 15).

Sterne (2003) is critical of this audio-visual litany and rejects the idea that there are specific properties of sound that hold true for all eras and cultures. Indeed, studies of specific auditory and visual practices in science have shown that it is by no means universally true that sound offers immersive, emotional experiences while vision provides for rational, objectifying insights. For instance, the research of Tom Rice (2008) on stethoscopic listening shows that hearing can generate objectification, distance and disengagement, and the research of Kelly Joyce (2005) on magnetic resonance imaging shows that medical imaging technologies not only offer distancing views, but can also 'evoke a sense of wonder and excitement' about revealing the inner body of the patient (p. 437). Similarly, visual depictions of the foetus influence how parents emotionally experience pregnancy and perceive the unborn child (Rapp, 1997; Verbeek, 2008). It is

therefore too facile to assume that sound will always be immersive and emotional, or that vision will always be rational and objective. Nonetheless, these ideas are very widespread, and the notion that sound offers immersive experiences holds intuitive appeal. The discourse of sonification as a source of sublime experiences benefits from this appeal, as it plays into and reinforces these widespread ideas about the nature of sound and vision.

The public discourse about sonification that I have analysed in this article does not undermine the traditional idea that science is strongly associated with the sense of vision, and that sound is more suited to emotional experiences than scientific insights. It reinforces the notion that sound has no place in science proper and should be relegated to the margins of scientific research, while leaving the traditional boundary between 'real' and 'popular' science largely untouched. This discourse works in favour of the public popularity of sonification, but at the same time undermines sonification's claims to being accepted as a scientific method.

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Notes

1. This description is based on my field notes of the event. The performance took place on 1 November 2008 at the Konzerthaus in Vienna.
2. The title of this article is borrowed from a record label of the same name. The Sublime Frequencies label has not released any sonifications, but is renowned for its, as Marcus Boon (2006) puts it, 'ethnopsychedelic montages' of ambient field recordings, song snippets and radio static from around the world. There is a certain irony in giving credit for the title, as the label itself is notable 'for the lack of credit or documentation' accompanying its releases (Boon, 2006).
3. Translated from German by the author.
4. A collection of asteroseismological sounds can be heard on the World Science website available at: http://www.world-science.net/othernews/060809_spheres.htm (accessed 28 September 2012).
5. Cyrus Mody (2005) discusses a similar function of sound in his ethnographic study of probe microscopy. The 'talk of probe microscopists is saturated with uses of sound as a metaphorical

resource in relating technical information' (Mody, 2005: 192). For instance, one researcher used a gong, which he struck with the soft and the hard end of a mallet, to demonstrate 'the different interactions between a surface and a hard or soft probe' (Mody, 2005: 192).

6. Interview with Conny Aerts, 6 March 2009.
7. Interview with Donald Kurtz, 6 November 2009.
8. Such a disavowal of the scientific significance of representations used in the communication of scientific results is also a common trope in scientific visualization. Scientists working with visualization often insist that the images they work with are merely pretty pictures with no further significance. Science and Technology Studies (STS) scholars studying visualization practices in fields as diverse as geography (Kwa et al., 2009) and neuroscience (Beaulieu, 2002) have shown that this insistence is often too facile, as the visual forms do in fact impinge on the knowledge made in these fields.
9. See interviews with Conny Aerts, Zoltan Kolláth (23 February 2010) and Donald Kurtz.
10. Graham Howard (2004) argues that astronomy is particularly dependent on popularization activities to legitimize the discipline and the huge public expenditures it entails due to a dearth of immediate practical applications of astronomical research.
11. Interview with Kurtz.
12. See interviews with Conny Aerts and Donald Kurtz. The asteroseismologist Zoltan Kolláth is a notable exception to this trend, as he enthusiastically transforms star oscillations into sound and has collaborated with composer Jenõ Keuler to make symphonies based on the sonifications.
13. Interview with John Heise, 10 March 2009.
14. Interview with Milton Garçes, 3 November 2009.
15. Interview with Robert Alexander, 12 June 2010.
16. With this interest in place, and in the environment of Alaska specifically, the piece continues a long-standing theme in Adams' work (Herzogenrath, 2012). As the musicologist Tyler Kinnear (2012) has argued, the installation discussed here 'is perhaps Adams's closest realisation of what the composer has termed "sonic geography", that is, when place is understood as music and music as place' (p. 231).
17. Interview with Marcus Schmickler (translated from German), 15 August 2010.
18. Interview with Alvin Lucier, 1 November 2008.
19. Further information and sound examples are available at: http://lhcsound.hep.ucl.ac.uk/ (accessed 28 September 2012).
20. However, immediately after the discovery of the Higgs boson, a researcher unassociated with the *LHCsound* project announced that 'sonification enables world to hear new Higgs Boson-like particle'. The resulting piano tune can be heard on the GÉANT website available at: http://www.geant.net/Media_Centre/Pages/Higgs-like-Boson-Sonification.aspx (accessed 3 October 2012).
21. Interview with Lily Asquith, 24 October 2010.
22. See *Public Engagement Small Award Winners*, page 130, available at: http://www.stfc.ac.uk/resources/pdf/PrevSmallAwards.pdf (accessed 10 June 2013).
23. See the *Guardian* website available at: http://www.guardian.co.uk/profile/lily-asquith (accessed 28 September 2012).
24. Interview with Asquith.
25. Interview with Asquith.
26. Further information and sound examples are available at: http://algoart.com/music.htm (accessed 28 September 2012).
27. All quotes in this passage are taken from the programme booklet that accompanied the first performance of *Bonner Durchmusterung* in Bonn on 29 May 2009. The quoted essay consists

of three parts, with a colour-coding scheme indicating who was (chiefly) responsible for each part. The four quotes I have selected (and translated from German) are spread across the three parts. The first quote is credited to astronomer Michael Geffert, the second and third to musicians Marcus Schmickler and Alberto de Campo, and the fourth to visual artist Carsten Goertz.

28. Interview with Schmickler. During the interview, Schmickler explained that he was disappointed to find that very few of the astronomers he approached were interested in interdisciplinary exchanges that went beyond handing over datasets.
29. See *Lungs: Slave Labour* website available at: http://eprints.gold.ac.uk/947/ (accessed 28 September 2012). *Lungs: Slave Labour* was part of the exhibition *Making Things Public*, curated by Bruno Latour and Peter Weibel at the Center for Art and Media (ZKM) in Karlsruhe.
30. The association of diminutive scales with the sublime also plays an important role in the discourse of nanotechnology (Mody, 2004). The insight that 'as the great extreme of dimension is sublime, so the last extreme of littleness is in some measure sublime likewise' reaches back to Edmund Burke (2008 [1757]: 66).
31. With these religious overtones, the sonification projects touch upon an important element of the sublime, which is intimately connected with finding 'transcendent significance' in a secularized world, dominated by science and reason (Nye, 1994: xiii).
32. Translated from German by the author.
33. Interview with Kurtz.
34. The capability of darkness to rouse sublime emotions has already been remarked upon by Burke (2008 [1757]: 54f., 73f.). Rosalind Williams (1990) shows how essential darkness was to the conception of the underworld as a sublime space; when the underworld transformed into a supremely beautiful place in the course of the 19th century, this shift went hand in hand with thinking of it as no longer dark and obscure, but as 'a magically illuminated artificial paradise' (p. 83).
35. Although these interactive exhibits are often alternately praised and deplored as a brand-new development, Alison Griffiths (2008) shows that heated debates about the promises and perils of interactivity in the museum can look back on a long history, reaching back to the 19th century.
36. This formulation follows Jonathan Sterne's (2003) historical musings on the notion of 'perfect fidelity' in audio technologies. The goal was not to produce a perfectly silent apparatus, but 'an apparatus that listeners could *pretend* was silent' (Sterne, 2003: 259f., original emphasis). Fidelity was thus a 'set of social and sonic relations in which participants could have faith' (Sterne, 2003: 274).
37. Since the focus of this article was on the producers and communicators, rather than the listeners of sonification, I was able to analyse how the promise of sublime experiences is constructed, but not to systematically address to what extent this promise is actually fulfilled for the listeners.

References

Adams JL (2009) *The Place Where You Go to Listen: In Search of an Ecology of Music*. Middletown, CT: Wesleyan University Press.

Aerts C, Christensen-Dalsgaard J and Kurtz DW (2010) *Asteroseismology*. Dordrecht: Springer.

Asquith L (2010) *What Does an Electron Sound Like?* Available at: http://lhcsound.wordpress.com/2010/02/19/what-does-an-electron-sound-like/ (accessed 12 October 2010).

Barry A (1998) On interactivity: Consumers, citizens and culture. In: Macdonald S (ed.) *The Politics of Display: Museums, Science, Culture*. London: Routledge, pp. 98–117.
Barry A, Born G and Weszkalnys G (2008) Logics of interdisciplinarity. *Economy and Society* 37(1): 20–49.
Barry ED (2010) High-fidelity sound as spectacle and sublime, 1950–1961. In: Suisman D and Strasser S (eds) *Sound in the Age of Mechanical Reproduction*. Philadelphia, PA: University of Pennsylvania Press, pp. 115–138.
Beaulieu A (2002) Images are not the (only) truth: Brain mapping, visual knowledge, and iconoclasm. *Science, Technology, & Human Values* 27(1): 53–86.
Bell C and Lyall J (2002) *The Accelerated Sublime: Landscape, Tourism, and Identity*. Westport, CT: Praeger Publishers.
Boogman W (n.d.) *Sternenrest: 'Stars Don't Make Music'*. Available at: http://www.sternenrest.nl/files/music_English.htm (accessed 12 October 2010).
Boon M (2006) Sublime frequencies' ethnopsychedelic montages. *Electronic Book Review*. Available at: http://www.electronicbookreview.com/thread/musicsoundnoise/ethnopsyche (accessed 28 September 2012).
Born G and Barry A (2010) Art-science: From public understanding to public experiment. *Journal of Cultural Economy* 3(1): 103–119.
Bowker G (1993) How to be universal: Some cybernetic strategies, 1943–1970. *Social Studies of Science* 23(1): 107–127.
Branton L (2006) Scientists tell us to tune in to songs of the stars. *Innovations Report*. Available at: http://www.innovations-report.com/html/reports/physics_astronomy/report-68749.html (accessed 12 October 2010).
Bunders J and Whitley R (1985) Popularisation within the sciences: The purposes and consequences of inter-specialist communication. In: Shinn T and Whitley R (eds) *Expository Science: Forms and Functions of Popularisation*. Dordrecht: D. Reidel, pp. 61–77.
Burke E (2008 [1757]) *A Philosophical Enquiry into the Origins of our Ideas of the Sublime and Beautiful*. Oxford: Oxford University Press.
Dunn J and Clark MA (1999) Life music: The sonification of proteins. *Leonardo* 32(1): 25–32.
Edford R (2007) The elegance of *The Elegant Universe*: Unity, beauty, and harmony in Brian Greene's popularization of superstring theory. *Public Understanding of Science* 16(4): 441–454.
Felt U (2000) Why should the public 'understand' science? A historical perspective on aspects of the public understanding of science. In: Dierkes M and von Grote C (eds) *Between Understanding and Trust: The Public, Science and Technology*. Amsterdam: Harwood Academic Publishers, pp. 7–38.
Gann K (2006) Fairbanks: A long ride in a slow machine. *NewMusicBox*. Available at: http://www.newmusicbox.org/article.nmbx?id=4573 (accessed October 12 2010).
Gentile S (2011) A chilling aural portrait of the deadly earthquake near Japan. Available at: http://www.pbs.org/wnet/need-to-know/the-daily-need/a-chilling-aural-portrait-of-the-deadly-earthquake-near-japan/7906/ (accessed 4 July 2012).
Ghosh P (2010) God particle signal is simulated as sound. *BBC News*. Available at: http://www.bbc.co.uk/news/10385675 (accessed 12 October 2010).
Griffiths A (2008) *Shivers Down Your Spine: Cinema, Museums, and the Immersive View*. New York: Columbia University Press.
Halpern MK (2012) *Across the great divide:* Boundaries and boundary objects in art and science. *Public Understanding of Science* 21(8): 922–937.
Harenberg M and Weissberg D (2012) Vorläufige Vorläufer: Vordergründige Bezüge und hintergründige Gegensätze zwischen Komposition und Sonifikation. In: Schoon A and Volmar

A (eds) *Das geschulte Ohr: Eine Kulturgeschichte der Sonifikation*. Bielefeld: transcript, pp. 207–222.
Herzogenrath B (ed.) (2012) *The Farthest Place: The Music of John Luther Adams*. Boston, MA: Northeastern University Press.
Hilgartner S (1990) The dominant view of popularization: Conceptual problems, political uses. *Social Studies of Science* 20(3): 519–539.
Howard G (2004) *Legitimating astronomy*. PhD Thesis, University of Wollongong, Wollongong, NSW, Australia.
James J (1993) *The Music of the Spheres: Music, Science, and the Natural Order of the Universe*. New York: Grove Press.
Joyce K (2005) Appealing images: Magnetic resonance imaging and the production of authoritative knowledge. *Social Studies of Science* 35(3): 437–462.
Kant I (2007 [1790]) *Critique of Judgement* (trans. JC Meredith). Oxford: Oxford University Press.).
Kinnear T (2012) Voicing nature in John Luther Adams's *The Place Where You Go to Listen. Organised Sound* 17(3): 230–239.
Kirby DA (2003) Science consultants, fictional films, and scientific practice. *Social Studies of Science* 33(2): 231–268.
Kolláth Z (2006) Public outreach in Asteroseismology. In: Sterken C and Aerts C (eds) *Astrophysics of Variable Stars*. San Francisco, CA: Astronomical Society of the Pacific, pp. 421–433.
Kramer G, Walker B, Bonebright T, Cook P, Flowers J, Miner N, et al. (1997) *Sonification report: Status of the field and research agenda*. Report prepared for the National Science Foundation. Santa Fe, NM: International Community for Auditory Display.
Kwa C, van Hemert M and van der Weij L (2009) Visualising landscapes: Do pictures represent theory or data? In: Scholten HJ, van de Velde R and van Manen N (eds) *Geospatial Technology and the Role of Location within Science*. Dordrecht: Springer, pp. 47–58.
Living on Earth (2006) Listening to Alaska. *National Public Radio*. Available at: http://www.loe.org/shows/segments.htm?programID=06-P13-00016&segmentID=5 (accessed 3 October 2012).
Lyotard J-F (1989 [1984]) The sublime and the avant-garde. In: Benjamin A (ed.) *The Lyotard Reader*. Oxford: Blackwell Publishers, pp. 196–211.
Macdonald S (1998) Supermarket science? Consumers and the 'public understanding of science'. In: Macdonald S (ed.) *The Politics of Display: Museums, Science, Culture*. London: Routledge, pp. 118–138.
McGourty C (2003) Listening to 'Singing Volcanoes'. *BBC News*. Available at: http://news.bbc.co.uk/2/hi/in_depth/sci_tech/2003/denver_2003/2763657.stm (accessed 12 October 2010).
Marx L (1964) *The Machine in the Garden: Technology and the Pastoral Idea in America*. Oxford: Oxford University Press.
Masco J (2004) Nuclear technoaesthetics: Sensory politics from trinity to the virtual bomb in Los Alamos. *American Ethnologist* 31(3): 349–373.
Mayne E (2006) Fed up with pop music? Then listen to some real stars … right here. *MailOnline*. Available at: http://www.mailonsunday.co.uk/news/article-400289/Fed-pop-music-Then-listen-real-stars–right-here.html (accessed 12 October 2010).
Mellor F (2007) Colliding worlds: Asteroid research and the legitimization of war in space. *Social Studies of Science* 37(4): 499–531.
Mody CCM (2004) Small, but determined: Technological determinism in nanoscience. *HYLE: International Journal for Philosophy of Chemistry* 10(2): 99–128.
Mody CCM (2005) The sounds of science: Listening to laboratory practice. *Science, Technology, & Human Values* 30(2): 175–198.

Morgan RP (1998) The twentieth century – Introduction. In: Strunk O and Treitler L (eds) *Source Readings in Music History*. New York: W.W. Norton & Company, pp. 1271–1279.
Nye DE (1994) *American Technological Sublime*. Cambridge, MA: The MIT Press.
Overbye D (2011) Listening to the stars. *The New York Times*. Available at: http://www.nytimes.com/2011/01/31/science/space/31star.html?_r=3&ref=space (accessed 4 July 2012).
Paul D (2004) Spreading chaos: The role of popularizations in the diffusion of scientific ideas. *Written Communication* 21(1): 32–68.
Pendick D (1999) What's this volcano trying to tell us? *New Scientist* 2174: 26–30.
PhysOrg (2010) *Scientists Listen to the Sun in New Sonification Project*. Available at: http://www.physorg.com/news186418364.html (accessed 12 October 2010).
Ploeger J (2004) Techno-scientific spectacle: The rhetoric of IMAX in the contemporary science museum. *Poroi* 3(2): 73–93.
Polli A (2005) Atmospherics/weather works: A spatialized meteorological data sonification project. *Leonardo* 38(1): 31–36.
Polli A (2009) Sonic Antartica, Gruen 064: Gruenrekorder.
Rapp R (1997) Real-time fetus: The role of the sonogram in the age of monitored reproduction. In: Downey GL and Dumit J (eds) *Cyborgs & Citadels: Anthropological Interventions in Emerging Sciences and Technologies*. Santa Fe, NM: School of American Research Press, pp. 31–48.
Ray G (2004) Reading the Lisbon earthquake: Adorno, Lyotard, and the contemporary sublime. *Yale Journal of Criticism* 17(1): 1–18.
Recuber T (2007) Immersion cinema: The rationalization and reenchantment of cinematic space. *Space and Culture* 10(3): 315–330.
Regier A (2010) Foundational ruins: The Lisbon earthquake and the sublime. In: Hell J and Schönle A (eds) *Ruins of Modernity*. Durham, NC: Duke University Press, pp. 357–374.
Rice T (2008) 'Beautiful murmurs': Stethoscopic listening and acoustic objectification. *The Senses & Society* 3(3): 293–306.
Roosth S (2009) Screaming yeast: Sonocytology, cytoplascmic milieus, and cellular subjectivities. *Critical Inquiry* 35(2): 332–350.
Rumori M (2012) Umdeuten: Das Phänomen der Sonifikation zwischen Musikgeschichte, Medientechnik und Markt. In: Schoon A and Volmar A (eds) *Das geschulte Ohr: Eine Kulturgeschichte der Sonifikation*. Bielefeld: transcript, pp. 223–242.
Schoon A and Dombois F (2009) Sonification in music. In: *Proceedings of the 15th international conference on auditory display*, Copenhagen, Denmark, 18-22 May, pp. 76–78.
Schoon A and Volmar A (eds) (2012) *Das geschulte Ohr: Eine Kulturgeschichte der Sonifikation*. Bielefeld: transcript.
Sterne J (2003) *The Audible Past: Cultural Origins of Sound Reproduction*. Durham, NC: Duke University Press.
Sterne J and Akiyama M (2012) The recording that never wanted to be heard and other stories of sonification. In: Pinch T and Bijsterveld K (eds) *The Oxford Handbook of Sound Studies*. Oxford: Oxford University Press, pp. 544–560.
Stickler JC (1995) Total immersion: New technology creates new experiences. *Museum International* 47(1): 36–40.
Stocker M (1995) Exhibit sound design. *Museum International* 47(1): 25–28.
Supper A (2012a) *Lobbying for the ear: The public fascination with and academic legitimacy of the sonification of scientific data*. PhD Thesis, Maastricht University, The Netherlands.
Supper A (2012b) The search for the 'killer application': Drawing the boundaries around the sonification of scientific data. In: Pinch T and Bijsterveld K (eds) *The Oxford Handbook of Sound Studies*. Oxford: Oxford University Press, pp. 249–270.

Taruskin R (2005) *The Oxford History of Western Music. Volume 5: The Late Twentieth Century*. Oxford: Oxford University Press.
Taylor J (2010) What does the 'God Particle' sound like? *The Independent*. Available at: http://www.independent.co.uk/news/science/what-does-the-god-particle-sound-like-2008811.html (accessed 12 October 2010).
Turner F (2006) *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism*. Chicago, IL: The University of Chicago Press.
Turney J (2004) The abstract sublime: Life as information waiting to be written. *Science as Culture* 13(1): 89–103.
Van de Vall R (2002) What consciousness forgets: Lyotard's concept of the sublime. In: Smith P and Wilde C (eds) *A Companion to Art Theory*. Oxford: Blackwell Publishers, pp. 360–369.
Verbeek P-P (2008) Obstretric ultrasound and the technological mediation of morality: A postphenomenological analysis. *Human Studies* 31(1): 11–26.
Volmar A (2013) Listening to the cold war: The nuclear test ban negotiations, seismology, and psychoacoustics, 1958–1963. *Osiris* 28: 80–102.
Willcock I (2006) Composing without composers? Creation, control, and individuality in computer-based algorithmic composition. In: Mahnkopf C- S, Cox F and Schurig W (eds) *Electronics in New Music*. Hofheim: Wolke Verlag, pp. 221–235.
Williams R (1990) *Notes on the Underground: An Essay on Technology, Society, and the Imagination*. Cambridge, MA: The MIT Press.
Wynne B (1995) Public understanding of science. In: Jasanoff S, Markle GE, Petersen JC and Pinch TJ (eds) *Handbook of Science and Technology Studies*. London: SAGE, pp. 361–388.
Wynne B (2006) Public engagement as a means of restoring public trust in science: Hitting the notes, but missing the music? *Community Genetics* 9(3): 211–220.
Zimmerman B (2003) Nineteenth-century American astronomy and the sublime. *Journal of the Royal Astronomical Society of Canada* 97(3): 120–123.

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