



# The Vibrating Universe: Astronomy for the Deaf

M. A. De Leo-Winkler<sup>1</sup> · G. Wilson<sup>1</sup> · W. Green<sup>2</sup> · L. Chute<sup>2</sup> · E. Henderson<sup>2</sup> · T. Mitchell<sup>2</sup>

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## Abstract

The Deaf have often been overlooked when designing informal STEM education and public outreach activities. Astronomers at UC Riverside and teachers at the California School for the Deaf, Riverside (CSDR), have designed an astronomy workshop aimed specifically for the Deaf using the school's on-site sound lab. We have used astronomy for this workshop because the field has a significant edge over other sciences to act as portal for K-12 engagement in science given the imagery it presents, the answers it offers to grand questions, and its interdisciplinary nature. The workshop is an unconventional activity that excites the students and provides a positive experience in astronomy, based on knowledge that they already acquired beforehand in the classroom. Our workshop uses electromagnetic emissions, enhanced sounds and sonification processes of cosmic phenomena that have low frequencies and sufficiently distinguishable patterns which are delivered to students through a specialized designed sound lab for the Deaf. Storytelling paired with videos and images are used to give understandable meaning to the sounds of the Universe. Positive feedback was collected from over 80 students who participated in our workshop. Our activity can be reproduced elsewhere to further engage the Deaf community in science.

**Keywords** Education · Astronomy · Deaf · Disability

## Introduction

The Deaf have often been overlooked when designing informal STEM education and public outreach activities. Strides have been made by astronomy communicators and educators during the past decade. We have developed an astronomy-themed workshop, given that the field has been proven to be a gateway to get the public interested in STEM (De Leo-Winkler et al. 2016). The workshop was delivered through vibrations on a specially designed sound lab, dozens of which exist worldwide. We believe the activity can be successfully and easily reproduced elsewhere.

Some efforts in astronomy have been developed with the Deaf community in mind. Sign language (other than fingerspelling) for most astrophysical phenomena is mostly non-existent. Special work groups in the USA, Bulgaria (Zamfirov et al. 2007; Proust et al. 2011; Hintz et al. 2015), and the International Astronomical Union have adopted this

project through the Sign Language Universal Encyclopedic Dictionary<sup>1</sup> (Proust et al. 2011). Although the names of cosmic phenomena can be fingerspelled, the lack of ad hoc signs presents hurdles in settings such as planetariums and museums (Hintz et al. 2013; Mumford et al. 2013). Several problems have been associated with science education to Deaf students, for example: morphological knowledge presents a hurdle in the comprehension of scientific vocabulary (Trussell et al. 2018); the lack of experiences through experiments has also been reported to hinder scientific understanding (Roald 2002).

Astronomy is a gateway into science. The concepts and questions it acknowledges create a sense of grandeur and awe. Its biggest assets are the riveting images produced with the advent of space telescopes, adaptive optics, robotized missions and the communication era, “which inspire us and promise answers to big questions” (Rosenberg et al. 2014, p. 1). These images also “provide a gateway to increase scientific understanding, by clarifying how nature behaves and how the scientific method leads us to develop models of this behavior and then subject these models to rigorous tests” (National Research Council Astronomy and Astrophysics Survey Committee 2000, p. 168).

✉ M. A. De Leo-Winkler  
mariodlw@ucr.edu

<sup>1</sup> University of California, Riverside, 900 University Ave.,  
Riverside, CA 92521, USA

<sup>2</sup> California School for the Deaf, Riverside, 3044 Horace St.,  
Riverside, CA 92506, USA

<sup>1</sup><http://www.astro4dev.org/blog/category/tf3/sign-language-universal-encyclopedic-dictionary/>

According to the World Health Organization, just over 5% of the world's population—around 360 million people—suffer from hearing loss which affects their daily lives, with the majority of these people living in low- and middle-income countries (WHO 2015). Out of 145,176,155 US civilian non-institutionalized population below the age of 35, some 1,058,261 have reported difficulty hearing, a 0.7% of the national population (NSF 2015, Table 1-3).

Approximately 30% of the science and engineering workforce report the onset of some disability before the age of 19 (NSF 2015, p. 13). Of the undergraduate students with a disability that continued into STEM, 4.3% chose engineering, 0.9% physical sciences, and 0.3% mathematics as a career option (NSF 2015, Table 2-7), all slightly smaller percentages than students without a disability in the same fields (5.1%, 1.0%, and 0.5%, respectively). Of 35,360 doctoral degrees awarded in the field of science and engineering in the USA in 2012, 326 recipients had lost hearing (NSF 2015, Table 7-5).

While there is a surplus of citizens holding a Ph.D. degree for jobs in academia in most STEM fields, there is a strong demand in big data, engineering, and programming (to mention a few) for individuals with technical to Ph.D. degrees in government agencies and the private sector (Xue 2014). However, equal employment opportunities for people with a disability is still a major hurdle. Scientists and engineers with a disability report a much higher unemployment or out-of-the-labor-force rate (~ 37%) compared to their counterparts without a disability (~ 15%) (NSF 2015, p. 14). Additionally, the median annual salary of scientists and engineers with a disability employed full time in the area or in related occupations, on average, is reported to be 7.5% lower than their counterparts without a disability (NSF 2015, Table 9-18).

History records only a handful of professional astronomers who were born or developed deafness/hardness-of-hearing at a young age: Robert Aitken (1864–1951, binary stars, Lick Observatory), Annie Jump Cannon (1863–1941, stellar classification, Harvard College Observatory), John Goodricke (1764–1786, variable stars, Warrington Academy), Henrietta Swan Leavitt (1868–1921, luminosity–periodicity relationship of Cepheid stars, Harvard College Observatory). We believe it is necessary to increase this number. Fortunately, some professional efforts have been created to provide astronomy tools for the Deaf community, such as *xSonify* by Diaz-Merced et al. (2012) and Drs. Garry Foran and Jeffrey Cooke's *StarSound*.

Our novel STEM education activity uses vibrations as the medium to transmit the sounds produced by cosmic phenomena, following a series of medical papers that suggest the brain of deaf individuals undergoes neural reorganization to process vibrations in the absence of sound (Karns et al. 2012). The phenomenon known as cross-modal

neuroplasticity enables the region of the brain associated with hearing to process vibrotactile information (Levänen et al. 1998; Shibata and Kwok 2006). Additionally, the studies point at deaf individuals as being more sensitive than hearing people to minute changes in vibration frequencies, a subject we address in the “Workshop” and “Results” sections.

We propose that direct contact with astronomy is a positive gateway to enhance knowledge in STEM-related fields, or entice students to pursue higher education in natural sciences, within the Deaf community. As there is very little material especially designed for this specific goal for Deaf education, we produced an innovative and unconventional experience that excites students and provides them with a positive exposure to astronomy, with the only pre-requirement being their own everyday experience and the knowledge that they had acquired in advance within the classroom. This experience is a supplementary educational tool that transmits radio emissions, enhanced sounds, or sonified data from cosmic phenomena through vibrations.

Throughout this paper, as sound is produced by vibration, the terms will be used without distinction.

## Methodology

### Media

We engaged students from elementary and middle schools at CSDR that are Deaf—some of whom might also display a different learning hurdle—with an activity based on vibrations which is paired with an oral presentation, accompanied by images and video, and a telescope viewing event.

We used sounds related to the Universe, and classified them in three different categories:

- natural sounds: within the standard human hearing range (20 Hz–20 kHz), recorded directly from the source, without the need to manipulate or interpret them. For example: the sound of a rocket launch;
- enhanced sounds: energy produced within the electromagnetic spectrum other than the standard human hearing range, requiring manipulation to bring it within this range. For example: low-frequency radio emissions from the Sun, high-frequency ultraviolet emissions from stars;
- sonified data: data converted into sounds through parameters specified by the user (a process known as *sonification*). For example: temperature variations in the cosmic microwave background (remnants of the Big Bang).

The availability of sounds from different cosmic phenomena is the only restriction to the scope of the workshop.

Several space agencies and researchers have made all three types of sounds publicly available. The National Aeronautical and Space Agency (NASA) and the European Space Agency (ESA) have a wide repertoire of recorded rocket launches and enhanced sounds from their missions to the Sun or the Solar System. Researchers such as Paul Francis<sup>2</sup> (Australian National University), John G. Cramer<sup>3</sup> (University of Washington), Robert Alexander<sup>4</sup> (University of Michigan), and Travis Metcalfe<sup>5</sup> (Space Science Institute) have produced sonifications based on asteroseismology, the cosmic microwave background, solar storms, or supernovae. Computer-rendered animations or videos are also publicly available from the same sources.

### Multi-sensory Sound Lab

California School for the Deaf, Riverside, has a multi-sensory sound lab built by the Oval Window Audio company. It is a specially designed room that converts sound into other mediums that can be experienced by deaf individuals, such as vibrations and lights. The original use of the lab is for music appreciation and speech therapy. There are approximately two dozen labs installed in the USA for institutions with similar educational needs, and several others installed worldwide (Oval Window Audio, *private communication*, 2016).

The lab consists of eight interlocking floor panels on top of foam blocks that vibrate when sound is transmitted through the system. Loudspeakers amplify sounds, in this laboratory they are directly pointing at the interlocking floor panels to transmit the vibrations produced by sound. Students can sit or stand on the floorboards to feel such vibrations. A light tower, laser, speech analyzer, and television screen are some of the visual displays to show the loudness, pitch, quality, and rhythm of sound. The room is also equipped with a CD player, microphones, and musical instruments, as well as audio jacks to plug in with various technological devices (MP3 players, computers, phones, etc.).

### Sample

Co-authors De Leo-Winkler and Wilson, both astronomers, made an initial selection of 25 sounds. During our first testing session, without students (from now on  $\mathbb{W}_0$ ),

co-authors Green, Chute, Henderson, and Mitchell (education specialists from CSDR) selected the final list of sounds. Criteria for selection were:

- undetectable: high-frequency sounds that produce few or no vibrations were discarded;
- bothersome: sounds which are either too highly pitched for students using a cochlear implant (CI), or which require excessive power to produce vibrations, were discarded;
- uniqueness: the vibrations should be completely distinguishable one from another. For example, those produced by small stars tend to be very similar, but the research group decided to test them to see if students were able to differentiate between them.

The final list of samples consisted of 19 sounds. The team proceeded to develop the full audio–visual presentation.

We presented the workshop to students in two different versions. The first (from now on  $\mathbb{W}_1$ ) acted as a test run to evaluate how students reacted to the activity: which vibrations were liked the most and the least, which required additional work to make them comfortable or entertaining, and to gather comments from the students and teachers (see Evaluation Sheet in the “Evaluation” section). Several weeks later, a second version (from now on  $\mathbb{W}_2$ ) was presented, which incorporated all input from  $\mathbb{W}_1$ .

After assessment of the science curricula for each school grade level, students from third to eighth grades were given priority to attend the workshop, as they had already been taught themes related to space in the classroom. Students were divided into two groups: the first was composed of students for whom deafness was the primary disability, some had a secondary disability as well; the second was made up of students for whom the deafness created an additional educational hurdle beyond their primary disability. We repeated the workshop for each grade, to avoid mixing age groups.

Upon the request of the teachers, we presented the workshop to both groups without distinction. This presented several challenges: we needed a brief presentation to maintain student interest; we needed ideas to be presented clearly without technical jargon, linking as many physical phenomena as possible with everyday examples; the workshop had to be simple enough for all groups; and our evaluation method had to be designed with simplicity and clarity to be answered by all groups.

$\mathbb{W}_1$  was delivered in two sessions to the following students: the first to 12 third grade students, the second to 14 eighth graders, and 4 special-needs eighth graders.  $\mathbb{W}_2$  was delivered in three sessions: the first to 14 sixth graders, the second to 9 special-needs sixth graders, and the third to 30 seventh graders. A total of 83 students attended both versions of the workshop.

<sup>2</sup><http://www.mso.anu.edu.au/pfrancis/>

<sup>3</sup><http://faculty.washington.edu/jcramer/>

<sup>4</sup><http://isd.engin.umich.edu/degree-programs/design-science/robert-alexander>

<sup>5</sup><http://gemelli.spacescience.org/~trme9702/>

## Workshop

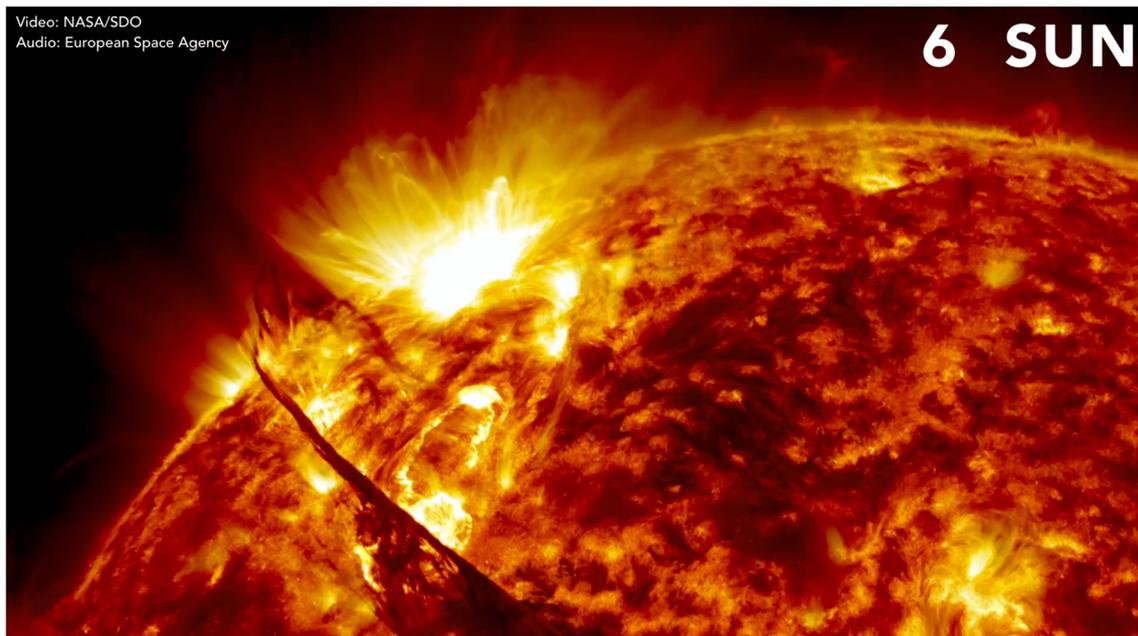
Prior to the workshop, several considerations were made. First, a few days before the workshop took place, teachers reviewed some astronomy-related material and vocabulary with the students. Secondly, the students were informed that a activity would take place at the school’s multi-sensory sound lab, where videos, sounds, vibrations, and a talk on space would be presented. Thirdly, students were allowed to opt-out before the workshop took place; students were also able to leave the sound lab if they found the experience uncomfortable at any given moment. Finally, conversations took place between the presenters and the interpreters; as some astronomy terms and proper names do not exist in American Sign Language (ASL), they had to be fingerspelled and some had to include an additional description. For example, instead of just fingerspelling the word “Jupiter,” interpreters would finger spell “planet Jupiter.”

Students were seated on the interlocking wooden floor, facing a TV screen. The presenter (in our activity, the presenter was a professional astronomer, but narration could easily be performed by a middle-school teacher, as all subjects are taught by them and are part of the school’s science curricula) and an ASL interpreter introduced themselves to the students. Students were made aware that the interpreter will be translating everything the narrator says. Evaluation sheets (see the “[Evaluation](#)” section) were handed out, and instructions on how to fill them were given

out; students with a secondary disability were assisted by a teacher. Special attention had to be taken by the narrator to talk before images, videos, or sounds were transmitted to the students, as they might miss the ASL translation when attention is diverted to the screen or vibrations are transmitted through the floor.

A brief explanation of the astrophysical phenomena which is about to be presented was first given by the narrator and then interpreted into ASL; this assures that common astronomical concepts are reviewed by the students (for example, brief and simple descriptions of what a star, planet, or galaxy is). When possible, similes between cosmic phenomena and everyday events were made (for example, the way heat travels to a star’s outermost shell—through convection cells—was compared to bubbling boiling water). A sound was then played and transmitted by the sound system onto the floorboard while an animation or video was presented in the screen (Fig. 1). A pause was made and students were asked to grade the vibration on their survey sheet. The presenters then continued to describe the next astrophysical phenomenon. The whole presentation lasted around 20 min.

The multi-sensory presentation was designed to take the students on a cosmic voyage, from the local universe to distant phenomena, with emphasis on the distances to objects, to convey a sense of scale. The trip started on Earth, presenting sounds of thunderstorms, which are common phenomena which students are aware cause sound, light, and vibration. We then proceeded to the first



**Fig. 1** A sample of the audio/visual material shown to the students (in this case solar pulsations). Notice the credits on the top left on the image/video and audio. The number and name for the cosmic

phenomena is prominently displayed for easy identification in the evaluation sheet. Image credit: NASA/SDO

cosmic phenomena, auroras. Within our narrative, we then ‘traveled’ with the students on a rocket and flew to the vicinity of the Sun. In solar orbit, students felt sonified pulsation periods of the Sun (Fig. 1) and sound-enhanced solar storms.

The voyage continued by rocket to Jupiter, followed by enhanced sounds of the Cassini-Huygens spacecraft encountering the planet’s bow shock, where the supersonic solar wind is heated and slowed by the planet’s magnetosphere. Subsequently, Saturn was exemplified by an enhanced sound of Cassini–Huygens being hit by millions of dust particles as it crossed Saturn’s rings.

Students were then whisked away by rocket to one of the closest stars from the Sun: Alpha Centauri A and B, both relatively similar to our star. Every single star in the Universe is different, and they all pulsate in a unique way. Observations of intensity and velocity from ground-based telescopes of the pulsation frequencies of the star are enhanced into the audible range by scaling the frequencies up by a factor of about a million. Students were then guided to more distant stars like GD358 and BPM 37093, both dwarf stars, and their pulsations were also transmitted to our voyagers.

With the excuse of traveling beyond our galaxy, the next stop was the Large Magellanic Cloud, to provide an example of the enhanced sound of an expanding cloud of gas (nebulae) produced by a dead star that exploded (supernova). These past five cosmic events are all related to stars, and are intended to show how a similar celestial object can produce very different vibrations depending on their size, age and temperature. The final sound is a sample sonification of the temperature variations produced by the Big Bang.

The workshop ends with a Q&A session between the students and the presenter.

## Evaluation

As this activity is a supplementary educational tool to previous knowledge acquired within the classroom, we proceeded to evaluate the workshop’s effectiveness in providing a positive, engaging and fun experience, together with other metrics. Pre- and post-evaluations of acquired knowledge of astronomy are beyond the scope of this iteration of the workshop.

We designed an evaluation sheet (Fig. 2) to collect the following metrics from the students:

- the reaction of the students to each of the 19 sounds: if they found it to be fun-pleasant-of their liking, neutral, or scary-uncomfortable-barely perceptible;
- their overall favorite and least favorite vibration;

- an indication if the duration of the whole activity was short, adequate, or too long;
- provide any additional comments.

Extra care was taken to make sure the evaluation sheet was designed to be filled easily, promptly, and clearly (Fig. 2). The evaluation sheet consisted of a table with numbered lines paired with a named cosmological event or object. The number and name were prominently shown on the TV screen when the sound was being transmitted as vibrations to the students. Two columns follow the names, one marked with a happy face and another with a sad face. Students were instructed to make a mark on the happy-faced box if the sound was fun, pleasurable or interesting, and mark the angry-faced box if they felt scared, uncomfortable or if the vibration was barely perceptible. If the student felt neutral about the sound, they could mark the middle space between both boxes. We assigned a score of  $-1$  (sad face),  $0$  (middle), and  $1$  (happy face) to each answer. Students were also asked to circle their favorite vibration and cross out their least favorite. Students who needed additional explanation were assisted by their teachers.

A second part to the evaluation sheet included questions: (1) Did all vibrations feel different from each other?; (2) Were you excited during the presentation?; (3) Did you learn something about the Universe today?; (4) Was the presentation too long? (was only used in  $W_1$ ). The compendium of the answers to this second part are presented on Table 1; additionally answers to question 4. were reduced to keywords for brevity.

## Results

We collected the evaluation forms and averaged the grades assigned by the students for each cosmic phenomena. We assigned a score of  $-1$  (sad face),  $0$  (middle), and  $1$  (happy face) to each answer and averaged them out for  $W_1$  &  $W_2$ .

There were a total of 26 evaluations collected from  $W_1$  and 55 from  $W_2$ . Results are summarized in Fig. 3 and Table 1.

During  $W_1$  we became aware that students were not sure what to expect of the workshop. When the first sound (auroras) was played, most of them became scared. For  $W_2$  we decided to change the introduction to a commonly known vibration: musical rhythm. We described that vibrations, similar to music, were also created by objects in the Universe and would be transmitted to them. The initial uncertainty was addressed with the inclusion of music, as evidenced in how the grade of the first cosmic sound, auroras improved, from  $0.2 \pm 0.05$  in  $W_1$ , to  $0.78 \pm 0.03$  in  $W_2$ .

**Fig. 2** Sample of the evaluation sheet filled out by the students during the presentation. Students were instructed to make a mark on the happy-faced box if the sound was fun, pleasurable or interesting, and mark the angry-faced box if they felt scared, uncomfortable or if the vibration was barely perceptible. If they felt neutral, they could mark the middle space between both boxes. We assigned a score of -1 (sad face), 0 (middle), and 1 (happy face) to each answer. Students were also asked to circle their favorite vibration and cross out their least favorite



## THE VIBRATING UNIVERSE



**The vibration was:**

<b>0</b>	<b>MUSIC</b>		
<b>1</b>	<b>THUNDERSTORMS</b>		
<b>2</b>	<b>AURORAS</b>		
<b>3</b>	<b>ROCKET 1</b>		
<b>4</b>	<b>ROCKET 2</b>		
<b>5</b>	<b>BUBBLES</b>		
<b>6</b>	<b>SUN</b>		
<b>7</b>	<b>SOLAR EXPLOSION</b>		
<b>8</b>	<b>JUPITER</b>		
<b>9</b>	<b>SATURN</b>		
<b>10</b>	<b>SATURN'S RINGS</b>		
<b>11</b>	<b>ROCKET 3</b>		
<b>12</b>	<b>ALPHA CENTAURI A</b>		
<b>13</b>	<b>ALPHA CENTAURI B</b>		
<b>14</b>	<b>SMALL STAR 1</b>		
<b>15</b>	<b>SMALL STAR 2</b>		
<b>16</b>	<b>ROCKET 4</b>		
<b>17</b>	<b>SUPERNOVA</b>		
<b>18</b>	<b>BIG BANG</b>		

- A. Please put a circle around your absolutely favorite vibration.**
- B. Please cross out your least favorite vibration.**

During  $W_1$ , deaf students with a CI were uncomfortable with sounds that, together with their low-frequency component—which produced the vibration—was accompanied by a high-frequency noise. For  $W_2$ , students were asked to turn off their CI; the discomfort did not present itself again.

During  $W_1$ , we found that the concept of the Sun exhibiting explosions and flares created some confusion between students, they made many questions on the subject. We therefore proceeded to make an analogy with a bubbling liquid, which is similar to how convection cells work. In  $W_2$ , the analogy appeared to have been understood because students did not request clarification.

Despite attempts to make an initial selection of sounds with the assistance of the teachers ( $W_0$ ; ‘Sample’ section),

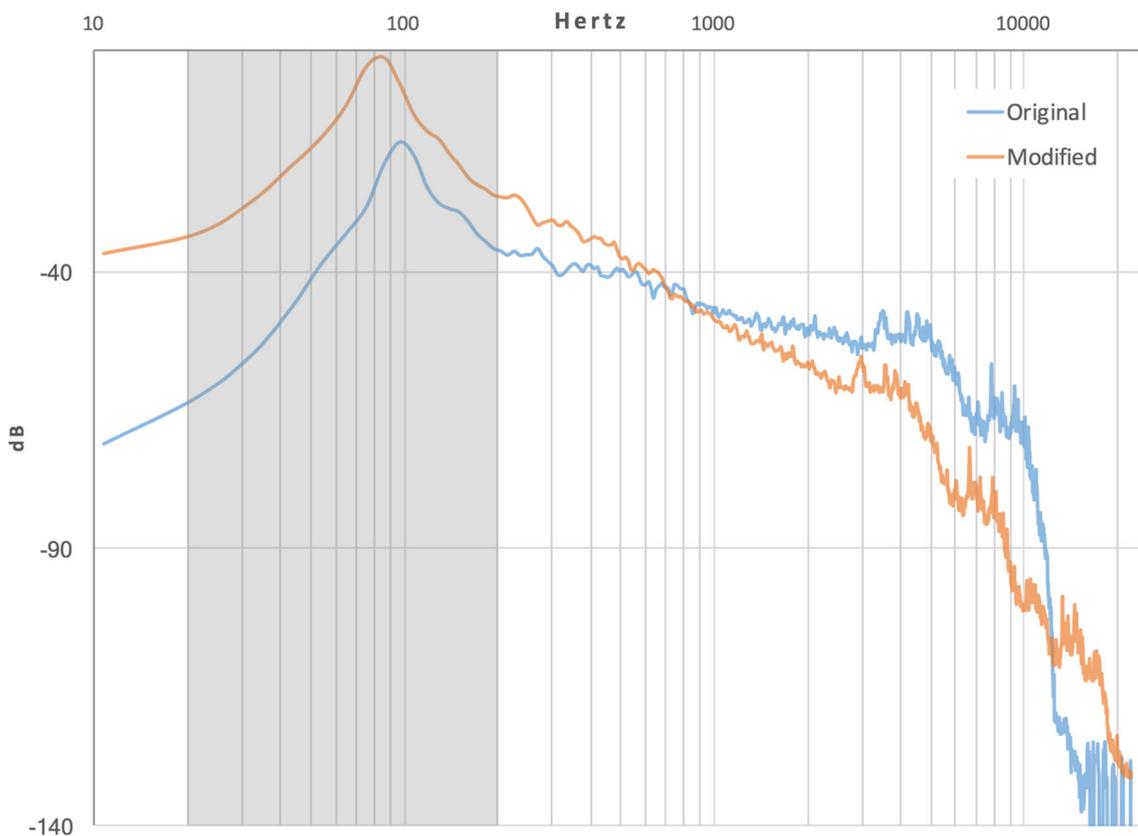
some sounds proved to be too high-pitched when tested in the sound lab together with the students. These sounds scored low in the evaluation for  $W_1$ . We then performed a Fourier analysis of the frequencies through Audacity,<sup>6</sup> a free, open-source software for audio recording and editing. Ideally, our goal was to bring the sounds into the subwoofer range (10–200 Hz), which is a loudspeaker that reproduces low-frequency sounds and is easily transported through the special panels in the sound lab. Through the use of Audacity, we transposed the sounds to lower frequencies (Fig. 3), this allowed the original sound to be in the physical spectrum of vibrations. It proved easy to produce impactful sounds out those which originally were too high-pitched.

<sup>6</sup>[www.audacityteam.org](http://www.audacityteam.org)

**Table 1** Results for the second section of the evaluation sheet

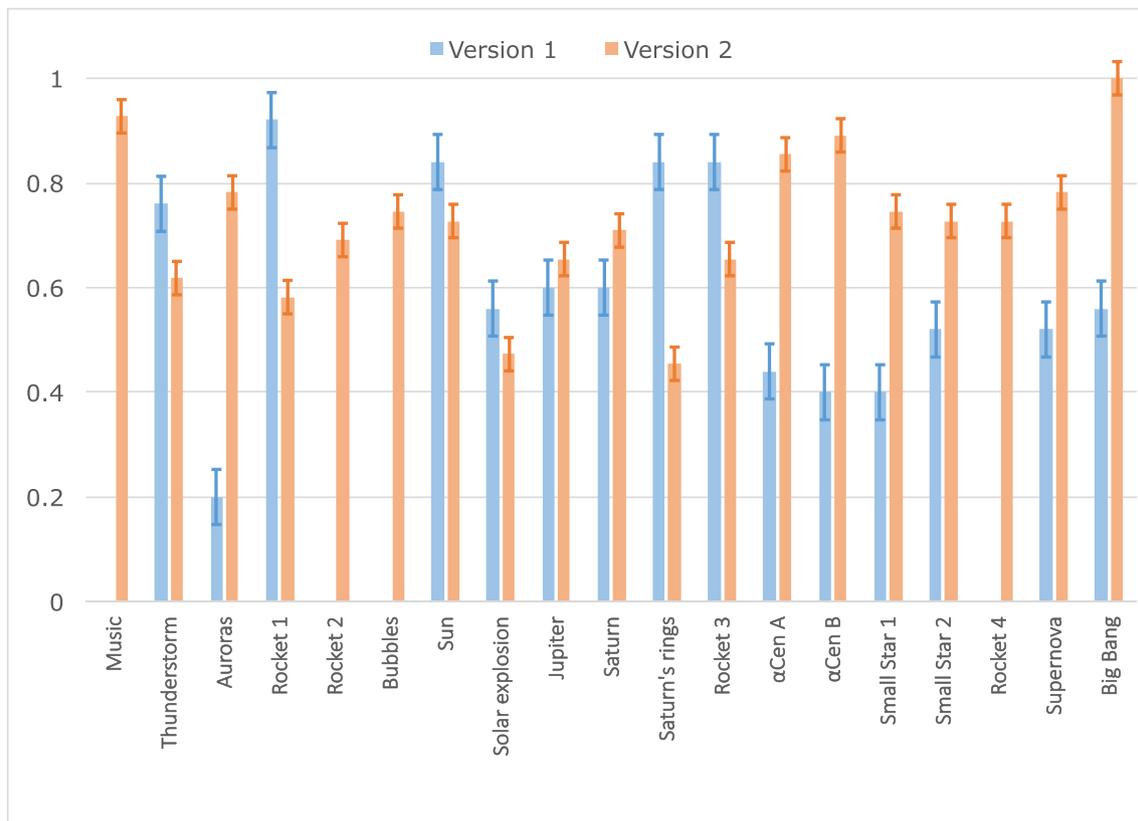
Questions	W <sub>1</sub> <sup>a</sup>		W <sub>2</sub> <sup>b</sup>	
	Yes <sup>c</sup>	No	Yes <sup>c</sup>	No
1. Did all vibrations feel different from each other?	83.3%	16.7%	100%	0%
2. Were you excited during the presentation?	91.7%	8.3%	92.5%	7.5%
3. Did you learn something new about the Universe today?	91.7%	8.3%	100%	0%
4. Was the presentation too long?	0%	100%	N/A <sup>d</sup>	N/A <sup>d</sup>
Things you learned today (no. of mentions) <sup>e</sup> :	N/A <sup>d</sup>		Sound (19) Stars (7) The sun (7) Temperature (4) The earth (4) Planets (2) The moon (1)	

<sup>a</sup>12 respondents  
<sup>b</sup>53 respondents  
<sup>c</sup>Somewhat, mostly, completely  
<sup>d</sup>Not asked  
<sup>e</sup>Not a required answer



**Fig. 3** An example of changes in frequency to transpose sounds into lower frequencies to produce easily detectable vibrations. The sound of auroras on the Earth is shown broken into its respective component frequencies. The blue line shows the original unmodified sound, the orange line shows the sound modified through the Audacity software

in order to decrease the total frequency output (20–100 Hz range) to produce additional output through the subwoofer and reduce high frequency signals (> 1000 Hz). The subwoofer range is shown in gray (20–200 Hz)



**Fig. 4** Breakdown of average score by sounds for  $W_1$  and  $W_2$ . Most high-frequency sounds in  $W_1$  showed great improvement when they were transposed into lower frequencies in  $W_2$ . We cannot offer a quantitative explanation for sharp drops in global average score of Rocket 1 and Saturn's rings

The final global average score for  $W_1$ , was  $0.6 \pm 0.05$ , while  $W_2$ , with modified sounds, scored a global average of  $0.72 \pm 0.03$ , on a scale from  $-1$  to  $1$ . Most high-frequency sounds in  $W_1$  showed great improvement (see Fig. 4) when they were transposed into lower frequencies in  $W_2$ , like Alpha Centauri A (+ 0.41) and B (+0.49) and dwarf star GD358 (+ 0.35). We cannot offer a quantitative explanation for sharp drops in global average score of the sounds of rocket 1 ( $-0.34$ ) and Saturn's rings ( $-0.39$ ), which were presented without modifications during both versions of the presentation. However, we do believe that with the modified sounds in  $W_2$ , these two particular sounds no longer were noteworthy compared to the other presented vibrations. Some select sounds fare worse also in  $W_2$ ; however, we believe these are expected fluctuations given different audiences, and are almost within the error bar margins.

Dwarf stars vibrate in different modes with subtle variations. Students were able to properly identify the differences between dwarf stars, in agreement with research by Shibata and Kwok (2006).

The answers provided by students in the second part of the evaluation sheet (collected in Table 1) indicate they

learned about stars, sound, and the sun through the activity, than from any other subject.

We had shortcomings with the students that have a secondary disability. They enjoyed the imagery and the vibrations, making this a innovative and positive experience in STEM learning, but their attention spans were shorter and there were no questions during the Q&A session. In the future, we believe they would benefit more of an activity redesigned to be shorter and would serve the purpose of an introduction to astronomy concepts.

## Conclusions

The Deaf have often been overlooked when designing informal STEM education and public outreach activities. Considering that around two dozen sound labs have been setup in schools for the Deaf in the USA and worldwide, and that they can easily be installed elsewhere, more schools and institutions could take advantage of the activity. Given that astronomy has been proven to be a gateway into science, we proceeded to create a hands-on workshop to convey astronomical phenomena through vibrations. Our results

show that this novel approach proved to be an engaging and likable activity for students with a varying degree of deafness and school grade.

We interactively improved the workshop together with the input of teachers and students, and have a final activity that can easily be reproduced elsewhere with a high degree of success. We have made all resources available at [www.astro.ucr.edu/outreach/vibratinguniverse](http://www.astro.ucr.edu/outreach/vibratinguniverse).

Our promising results have allowed us to continue developing other sensorial activities related with astronomy, which will be the target of a future paper.

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## Compliance with Ethical Standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Conflict of interests** The authors declare that they have no conflict of interests.

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