TRANSCRIPT FOR "SONIFICATION: A TOOL FOR RESEARCH, OUTREACH AND INCLUSION IN SPACE SCIENCES" WEBINAR 17 NOVEMBER 2022

Xing Yi Ang: Hello. Hi, everyone. Good morning, good afternoon and good evening. A warm welcome to all of you from around the world. Welcome to this webinar organized by the United Nations Office for Outer Space Affairs. My name is Xing Yi and it is my pleasure to be the moderator today. I am an Asian woman. I have dark shoulder length hair. I'm wearing glasses and a blazer. My pronoun is she/her. This webinar is segment 2 of the online event on sonification. In today's discussion, we will unpack the complexities surrounding the use of sonification in space sciences. Ideas and information collected in today's webinar will also inform an upcoming UNOOSA special report on sonification.

Before we begin, here are a few administrative announcements. First, please switch off your cameras and keep your microphones muted throughout the webinar.

Second, please type your questions and comments in the chat. You may do this at any time during the webinar. My colleague Nathalie will be monitoring the chat. We will attempt to answer as many questions as possible during the Q&A session.

If you prefer to use live captions, you may turn on this function by going to your meeting controls and select More Options then select Turn On Live Captions.

Lastly, this webinar is being recorded. The recording will be available on the UNOOSA YouTube channel after the event.

So today's topic is about sonification in space sciences. I'm sure most of you have seen beautiful images of galaxies and stars. However, have you ever wondered whether it would be possible to experience them through other senses besides our sense of sight? If you take one step back and think about how we obtain data for astronomy, you realize that most of the data from space cannot be seen by the human eye. Specialists translate this data into images and graphs, and the same data can also be translated into sound through sonification. By exploring different ways to interpret and communicate data we open doorways to new discoveries and a more inclusive future.

However, we are at the just at the beginning of that journey. By understanding where we currently stand, we ask where do we go from here? What are the challenges and what can be done to bring the

field forward and to promote a more inclusive research and outreach environment? And to answer those questions and more, we are delighted to have with us here today five experts in sonification.

First, let us welcome Dr. Wanda Diaz-Merced from Puerto Rico. Wanda has a doctorate in computer science, and she specializes in the use of audio to study space science telemetry. Recognized as one of the pioneers in applying sonification to space sciences, she has worked for over 15 years on establishing a framework for sound to be used in scientific data analysis. Wanda, we are delighted to have you here with us. The floor is yours.

Wanda Diaz-Merced: Thank you so much. Good day! Thank you so much to the Office for Outer Space Affairs and Xing Yi Ang for this innovative webinar, for the invitation. Thanks to all the people connected, for the kindness to attend this dialogue, which is key - to me - is key for the space sciences to enrich this long term view of the future in accelerate progress towards the achievement of better science and a better world.

My hair is black. I'm wearing a red turtleneck, and because it's very cold I'm using a black jacket.

I finished a one year experience at the European Gravitational Observatory and from February onwards I will have the honour to work with Dr. Katsanevas at the Astroparticles and Cosmology Lab at the University of Paris in France.

It is true I use sound to scrutinize the measurements acquired by the satellites in outer space. Me being totally blind has nothing to do with it. I use audio because I did experiment simulating an astronomy task and the results evidence that sound increases sensitivity to events in that task that I simulated, events that by nature are ambiguous or blind to the human eye.

Perhaps you know that audio was used in astronomy at the end of the 1800s. We may mention many pioneers, but I will especially mention Dr. Donald Burnett, whose interest in astronomy was influenced by audio of the stellar media he heard from another collaborator. Later, for reasons that scientifically I may not assert, but I may sustain, given my protracted literature search, it was my given impression of, in a natural way visual technologies took over, and it feels that as visual technologies developed, the visual scientific analysis developed more and audio was kind of left behind. They stopped using it or almost stopped using it.

So, from my perspective, visual oriented people prospered as a result of more discoveries and the development of new technologies directed to a fully abled enterprise. People with other performance strategies kind of fell behind exactly for the same reasons. It is not only about the tools available. Why

I say this? Because I found myself without the opportunity to enter and progress in this field in an area of my choosing. The field sunk using audio without a justifiable reason, as I evidenced in my experiments, denying itself from further scientific discoveries and simultaneously depending on widening gaps on human skill and social development. The big question is why the long term view of our science almost totally excluded the use of audio.

Sound is multidimensional, nonlinear, it has a context dependency that may be examined in the entire scene or over both short and long scales. Others have used audio for security, vigilance, safety in spacecrafts, for medicine. In my case, based on my perception as I have not found perception experiments applied to astronomy data, I pay attention to the physics of the sound, the source of the sound. For example, a timpani, which ideally is a copper bowl with a membrane on top, and this is just an example. I annotate how the structure of the tones change, the psychoacoustical effects, modal circles, diameters, et cetera.

Let's think of it just one second. In a two dimensional membrane, the modal frequencies are not harmonics of the fundamental. What about if that may be used to detect changes occurring over space and time? Like for example the sound of a membrane stretching? We need the experiments, right? But we need to have this long term view. I have used audio - in my experience - I have used audio to listen for tones indicating changes of slope characterizing spectral indices, I have listened for rapid changes in brightness, known as scintillation. What I find most useful for my ways of exploring, for example, the radio scintillation is the propagation of electromagnetic waves through media, where the velocity of the waves may change randomly. That will result in things that are - at the least to Wanda's ear - is discernible. Like for example amplitudes.

Right now I'm trying to write an undergraduate astrophysics book on multi-sensorial astronomy. And we also teach a Zoom free course on multi-sensorial astronomy and together with Ruoning, an astronomy undergraduate student, we're working on a low cost device that translates real time to vibration. Real time, it translates to vibration light intensities from a telescope and the proof of concept is already completed. To me, sonification and participation just as we are, to me, it will open new horizons of possibilities for space science. Even though it may not produce immediate benefits, if we really want to transform the history of our science, it is essential to invest in projects such as multi-sensoriality for mainstreaming. If we really want to transform the history of our science, I encourage all

of you to do that. And the key factor to determine that directional for history is the civil society. Thank you so much Xing Yi for the opportunity. Thank you.

Xing Yi Ang: Thank you so much, Wanda, for sharing your perspective on sonification and space sciences. Now let us welcome Dr. Kimberly Arcand from NASA's Chandra X-ray Observatory at the Smithsonian Astrophysical Observatory. She's an expert in astronomy visualization, 3D imaging, and extended reality applications with astrophysics data. She leads the hugely popular sonification project A Universe of Sounds. So please join me to welcome Kimberly.

Kimberly Arcand: Hello, thank you so much for having me here today. And just to start off, so I am a middle-aged white woman with pale blonde hair that today is sort of dyed bright pink and I'm wearing a black turtleneck.

I'm really honoured to be here today. I'm particularly honoured to be sharing the digital stage with Wanda, who I consider a dear colleague and friend. And I would actually like to preface by saying I don't consider myself an expert in sonification, but really rather a learner about sonification, about sonification methodologies and how sonification is perceived and received. And the type of work that I get to do for NASA's Chandra X Observatory is, I think, a wonderful example of how different kinds of astrophysics data can really benefit from sonification as a tool for communication, but also as a tool for research.

I've been 100% inspired by Wanda's work. I think I spent the first, maybe eight years of my career prioritizing only visuals, which, again, when you consider the fact that the Chandra X Observatory studies x-ray light, which no human can naturally see, perhaps really doesn't make the most sense. And so in about 2006, 2007, I started working with 3D modelling and 3D printing, and particularly working with members of the blind and low vision community to make sure that those models and those 3D prints really made sense.

We started dabbling a little bit later on, perhaps best forwarding like a good eight years or so with sonification around virtual reality. So taking virtual reality and then attaching sound in that sort of geospatial way to make sure that virtual reality or other similar extended reality applications would also be inclusive, accessible, and equitable.

During the pandemic I think a lot of things got put on hold, it was difficult to do 3D printing, it was difficult to work in a lab with the VR equipment and so we pivoted at that point to the Universe of Sound program that was mentioned earlier and for that program I partnered with some very wonderful

collaborators, Dr. Matt Russo and Andrew Santaguida at SYSTEM Sounds. Matt is an astrophysicist and musician and Andrew is a musician and sound engineer and my own background, I am not really a musician, but I would say, you know, fellow choir and band geek is how I consider myself.

And I think this idea of using sound to help communicate different kinds of high energy astrophysical processes was really, really attractive. And so we launched a program in 2020 that took different kinds of datasets from NASA, mostly from the Chandra X Observatory or the Hubble Space Telescope, and also more recently from the James Webb Space Telescope, and translated that using a mathematical mapping into sounds. And I think I was really surprised with the response to the program overall. But we did do a research analysis of about 4500 participants to better learn how people receive the sonifications and what kind of value they added. And from that research we found that overall there are definitely increased learning gains equal for people who are sighted as well for people who are blind or low vision. We found that overall enjoyment levels and engagement levels were very high for both groups. The open-ended comment section that we had – overwhelmingly those comments were evocative of emotional responses that people really sort of align themselves emotionally with those sonifications, those translations into sound. And also I think, interestingly, that the sighted groups kind of statistically was very significantly, showing that learning about access for how other people experience data of the universe was new to them and also interesting.

And so that type of research I was really excited about and we hope to continue to do more of this work and figure out, particularly with our partners, where it makes the most sense for these programs to go. So I think I will stop there and pass the baton.

Xing Yi Ang: Thank you Kimberly. Thank you for sharing with us your experiences.

Next let us move on to Dr. Scott Fleming. He's an astrophysicist and the branch manager at the Space Telescope Science Institute in the United States. His team develops the search interfaces and tools for the Mikulski Archive for Space Telescopes, which is home to more than 20 missions. He is a proponent of open data, open-source programming and increasing accessibility for professional astronomers. Scott, you have the floor.

Scott Fleming: Thank you so much, Xing Yi, and good morning from the United States

To describe myself: I am a middle-aged Caucasian male. I have dark brown hair. I have a full beard and I wear glasses. And today I'm wearing a brown sweater or a brown jumper, depending on where you are in the world.

And as mentioned, my team builds the search interfaces that allows the world to access data from more than 20 different missions. Most of those are NASA's space-based telescopes in the ultraviolet, optical and infrared. Some of the missions that we are the archive for include GALEX, Kepler, the TESS mission, the Hubble Space Telescope, the James Webb Space Telescope, and, launching in a few years, the Nancy Grace Roman telescope. In terms of sonification, my team has led a project called Astronify and this is an open-source Python based package for turning one-dimensional data into sound for the purposes of research.

And so there's lots of different types of reasons for doing sonification. We'll probably talk about some of those later, but one aspect is to produce sonifications that are primarily intended for analysis. And so that's what this software tool is intended for. We chose to use tones instead of more musical notes because we wanted to avoid sort of context associated with music and really focus on what the data is doing. And the ways of making the sonification are completely customizable in terms of things like how long the tones play, how often the tones play, and things like that. And in addition to making the package available to everybody so that sonification can become part of our day-to-day lives as astronomers, so that, you know, people can include sonifications in presentations they give at conferences just as a normal way of doing things.

We also are gonna use this tool to make it so that when people search for data at some of NASA's biggest and best flagship missions at one of the world's best archives, sonification is in our search interfaces from the beginning, right alongside any other ways of previewing or accessing these data, and one of the reasons for doing that is to include, you know, increase accessibility to the data, but also to offer, as Wanda mentioned, additional ways to analyze and interpret these rich datasets. So I have a quick example if you want to move to the next slide please.

So what I'll be just showing you as a quick example is some real data from the Kepler Space Telescope. For those who are seeing the screen, to describe what's happening here, this is a measurement of a star's brightness over time and at a certain point, a planet is actually blocking some of the starlight as it crosses in front of the star and our line of sight. And so what's happening is that as the planet walks across the star, as if someone walks across a movie screen, the brightness of the star will decrease and so on the screen there's a plot that has a bunch of measurements and it looks like a U-shape, the letter U.

But what we do with our software is, by default, if a brightness decreases, the pitch will decrease and so as you listen to this data, what you should hear is at some point a [sonification plays] drop in pitch so hopefully those of you were able to hear that and that was output from Astronify sonifying what happens when a planet crosses in front of a star in a sonic way. So that's our main interest and I'm looking forward to talking to more people later during the meeting.

Xing Yi Ang: Thank you, Scott. Thanks for showing that really interesting example. Let us move on to Dr. Chris Harrison. Chris, he's an astrophysicist at the Newcastle University in the United Kingdom. He's interested in making astronomy more engaging and accessible, which led him to coordinate the Audible Universe project. Chris is also the director of the award-winning planetarium show "Audible Universe – Tour of the Solar System". Chris, we are delighted to have you here today, the floor is yours.

Christopher Harrison: Thank you. Thank you very much. Hi, and I'm really delighted to have this opportunity to speak to you and share the stage with these inspiring people.

So as mentioned, I'm an astronomer at Newcastle University. I'm a white male, use he/him pronouns, I have short brown hair and I'm wearing a black polo shirt today.

So as well as studying galaxies and supermassive black holes for my day job I've created and I'm coordinating the Audio Universe project which we launched in December last year. And we're exploring how to use sonification and other multi-sensory methods for three goals. To enhance scientific discovery, to make astronomy, education and outreach more engaging, and also to make astronomy more accessible, which we've been talking about already. We take multiple approaches to do this. We've been performing some academic research, doing some publications, and we've been producing various tools and resources for researchers, educators and the wider public.

One of the key approaches I want to mention that we've been doing is working closely with members of the blind or vision impaired community, school pupils who are blind or have low vision and also their specialized teachers, and we found that this has been crucial with what we've been doing to make sure what we're producing is accessible and we're reaching our primary target audiences. And as an example, as has already been mentioned, is our show. It's called "Audio Universe - Tour of the Solar System" and we created this in close collaboration with a blind school pupil called Amrit, his teacher Rachel Lambert, and a blind astronomer, Nic Bonne, as well as other groups and individuals who acted as consultants for us. Nic and Rachel actually appear as characters in the show.

And this show, which we've made available for planetariums as well as flat screen format, it's in multiple languages. And in the show, everything is represented with sound as well as with visuals. So this means that the visuals are there, but they're not required to understand the show. And we learned a huge amount with this collaboration. And one key thing that we learned was how important it was to provide context and really clear explanations of the sonifications that we're playing so the audience can understand and interpret what they're listening to. And now we've been taking this a step further and we've been making multi-sensory educational workshops combining sounds and tactile models and going into schools and museums to provide this multisensory learning.

One interesting thing that we noticed in the last few weeks is also as well as the blind and low vision people we've been working with, neurodivergent children have been benefiting from this and appear to be finding this multisensory learning more engaging and easier to access than some of their regular school lessons.

So with that, I want to finish by playing you one of the sonification that appears in the show. This is being produced with our sonification code called STRAUSS that's been created by James Trayford at Portsmouth University. It's the same code that we used to do the research side of things as well as the engagement and outreach side of things. And in this case, we're taking data of the stars above the European Southern Observatory's Very Large Telescope in Chile. And each star that's visible to the naked eye is represented with a musical note. One thing that you won't hear in full today is how impressive it is with the surround sound, because we also placed these sounds correctly in the spatial position around the room if you've got the full surround sound. So I'll play this clip from the show and the first thing you'll hear is an introduction from our show's tour guide and real life blind astronomer Nic Bonne. So let's see if I can get this working.

[Video plays] The stars are like thousands of pinpricks of light spread across the blackness of the night sky. Our sonification machine will first detect the very bright stars emerging, followed by the thousands of fainter stars that become noticeable later. The brightest stars will be louder and the fainter stars will be quieter. The bluest stars, which are actually hotter, will sound as high notes, and the cooler, red stars as low notes. Here we go.

[Music plays]

Christopher Harrison: OK, I'll stop that there and you can find out more at our website audiouniverse.org and I look forward to discussing all that follows about how we can use sonification.

Xing Yi Ang: Thank you Scott for sharing the video. I would love to visit the planetarium show one day. Thank you so much.

Next, last but not least, we have Alice. Alice Oates is a PhD candidate at the University of Cambridge, focusing on polar studies in Antarctica. She was an intern at UNOOSA and she played an integral role in the sonification research project. Alice, welcome. It's great to have you back!

Alice Oates: Thank you so much. It's great to be back. Really pleased to be invited to this webinar today. I am, as Xing Yi said, I'm a polar person, so you might be wondering what I have to do with this. It's through my internship, so I'm quite new to sonification, especially compared to the other panellists in this webinar. But what I wanted to do was just kind of go over some of the really important things that we emphasize when we were doing this research, as someone who was new to this field and kind of finding all this out for the first time.

So I think that the first thing that we really started getting to grips with as we were doing the research was that sonification is essentially complementary to data visualization. And I think that's quite important, to see it in that respect for other than kind of a sort of a novelty thing because that's really important to the use of sonification in space science. And it, you know, compared to data visualization, it has these specific advantages that have led to it gaining momentum, especially in the space science world. And what we found is that these advantages were really falling into two categories, which are very much connected. And we have heard, kind of touched on these advantages already today.

And the one that initially attracted us to the sonification research was of course accessibility. because it is the sound based way of interacting with data. The accessibility element is there for blind or visually impaired scientists, but as we just heard from Chris, also for other people for whom sound is just a preferred or more engaging way of interacting with data, and also, of course, for just communicating science to people who are non-experts, so whether that's children or adults or anyone really. It's both better if, again, if for members of the public who are blind or visually impaired, but also, again, it is just a very engaging, exciting way for interacting with some of the really complicated ideas that exist in space science. So, for example, people have used it for communicating the sheer scale of space, which is sometimes quite a difficult concept to get to grips with for young children.

But then sonification has huge advantages beyond the accessibility element, and we've heard about this from Wanda especially as well. Space science has a lot of very complex, noisy, multi-dimensional datasets and this issue of big data, it became clear, was something that was an increasing potential

problem for space science and that sonification can play a role in addressing that issue. And the way that humans perceive sound naturally lends itself to working with that kind of data. So with space you can represent multiple dimensions at once, you can represent spatial location. with the right hardware, as Chris was telling us about with the show, and humans, importantly, we're very good at picking out sound from a noisy background. This is known as the cocktail party effect.

And so with the right training and experience, a researcher can use sonification to listen for the signal they're interested in in very kind of complex, noisy data sets in a way that is not necessarily easy to do by sight. So sonification is complementary to data visualization, and it has a lot of strengths that mean that we can do things that aren't necessarily possible just with visualization alone. So by essentially taking a multi-sensorial approach you expand our scientific possibilities.

And one thing that I just want to emphasize that really kind of jumped out in the research we were doing on sonification was just how important it is to have user-centered design of sonification tools and sonified data. And again we've already heard about the value in kind of working with the community who is the end user of sonification tools and sonified data to have an iterative process where you keep developing and improving at all. And that's because, you know, sound perception does have these huge advantages, but it is quite subjective. And for people to really make use of a sonification tool as a research tool the way that Wanda does, for example, the sound does need to be mapped to the data in a way that makes sense. And we all kind of will have minor differences in what makes sense to us that could be down to sensory capacity, cultural background, all of these kind of differences that crop up in everyday life.

And one of the people that we spoke to in the process of doing this research gave are really excellent example that for me just illustrated that in a really simple way which was that if you are trying to sonify, say, keeping it really simple, just a graph of money going up, an amount of money going up through time, what would you choose for the sound to do to represent that data? Would it go up in pitch as you have more money or would it go down? And what this person had done is they'd ask this question to their sort of sighted students who had just said, "Oh, the pitch should go up!" and they couldn't necessarily say why, but the hypothesis was essentially that having been trained in data visualization they just associated 'more' with 'up'. And then they talked to blind and visually impaired individuals and they said, well, actually now the pitch, for us, we think it should go down, and they were able to explain that. And they said it was because kind of from a sort of analytical listening perspective, if you have

more money, it makes a 'thunk'. It makes a deeper 'thunk' when you drop it. So, it's quite, it's a very simple example. That's not kind of an example you'd be working with in kind of professional space science research, but it just illustrates that unless you talk to your user and you have this iterative process of developing the sound mapping, you might be missing things that are just absent from your own experience that could be really beneficial to the end user.

And I'm really sorry, I've just realized I forgot to describe myself. I am a Caucasian woman, I have dark blonde hair, I'm wearing a red jumper and I use she/her pronouns. Apologies for not doing that earlier.

So. Just to kind of summarize that: Because of all these advantages of sonification, we've seen over the last few decades a really interesting and dedicated international community being built up around sonification in space science. There's been a lot of progress about bringing people together, there is the International Conference on Auditory Display, which has also created a dedicated space for publication of research papers on this subject. There are labs dedicated to sonification, and there are still a lot of challenges. For example, if sonification is seen as a novelty rather than an established field despite the fact it has actually been around for quite a long time. I think actually the first International Conference on Auditory Display conference was the year I was born, so this is not a new technology and we need to see it in that light. And the barriers are kind of getting it into the mainstream range from technical design issues to negative attitudes within the research community.

But it's a really fascinating field of work and, as I said, it's got some really dedicated people behind it. So I have high hopes and I'm really pleased that we're here today to discuss sonification. Thank you, Xing Yi.

Xing Yi Ang: Thank you Alice for highlighting the diverse, you know, advantages of sonification and for setting the stage for our panel discussion. So, Alice, you alluded to the need for a user-centric approach to sonification. So I would like to direct the first question to Chris.

Chris, you design planetarium shows essentially for public outreach and that essentially includes people of different gender, age and abilities. So could you share with us some of the design challenges that you face in trying to use sonifications for such a broad and diverse range of people?

Christopher Harrison: Yeah, I think so. We went through an interesting process when we made this show. So it started with we, we the scientists, produced the sonifications in the way that we thought made sense to work for us, we understood what was going on. And then we played them to some young

people. And the feedback was quite brutally honest, like "We have no idea what's going on here, this is very strange."

And so I think we quickly learned that we needed to rethink our approach and really get that feedback and understand their needs. And so this is one thing that we know about the context and explaining, but also we learned to make it relatable. So I think we've eluded to the musicality as well and we quickly found that it helped the children to have more familiar sounds to relate to. So we chose, for example, to use musical instruments to represent the planets, rather than what we've done before, just some random space-y sound, and I think that was sort of getting familiar with the target audience and what they were familiar with.

And a thing that I'll mention that has also cropped up is, there was a mention to by Alice, was the cultural differences. So I think what we've done is we've created something that's quite westernized. We've chosen the western musical notes, we've chosen the western musical scale, and this is something that I would say we haven't yet resolved or solved and we should really also think about how these choices might exclude certain cultural backgrounds and that's something we want to work on next.

Xing Yi Ang: Yeah, and on a similar vein, Kimberly, your outreach project essentially is for the general public. So how do you ensure that it reaches the broadest range of audience in the most accessible way?

Kimberly Arcand: Yeah. So, like Christopher has already mentioned, similarly we take an approach of pretty strong user testing as well and we worked with both experts who are blind or low vision as well as non-experts who are blind or low vision, whether it's large groups of students who are doing testing and working on the meaning-making or whether it's experts weighing in on whether that sound really makes sense. I think I mentioned in the comments, we've now started working with Christine Malec who's here. We worked with Dr. Gary Foran, we've worked with a number of students around the US at least to make sure that the value of this material is really value added, right, and that it's not just something that we're hoping adds value to it.

So for us for how we go about working on the dissemination aspect, we really try to take a targeted approach to working with our network of people who are blind or low vision, working with schools, for example, schools for the blind to make sure that we are reaching that target audience, but then we also just use things like social media and newsletters and incorporate it in programs and educational events and virtual field trips for schools, and we pretty much include sonification now in everything we do as a way to keep pushing that out as a valid means of communication and to help other people sort of see

the value which as our research study has shown that people who are sighted are starting to see, at least in our case, that that is a value added, a sort of proposition.

So we've had pretty lovely results. I don't know if I can play a slide really quick for my answer, would that work? Alright, so I'm just gonna share my screen and share my sound and... here we are. OK, so this is a sonification of a sound wave around a cluster of galaxies. It's coming out essentially as a result of the supermassive black hole at the center of that cluster of galaxies, and all that material, that sort of, you know, rushing out, if you will, the energy that's rushing out is hitting all of this hot gas. And that is causing the propagation of pressure waves or sound waves. Mathematically, that note can actually be calculated, what that note of those sound waves happens to be, which is about like 57 octaves below middle C, a B flat, and so what we did in this sonification is to actually take that note and then re-sonify up into the range that humans can hear. And this is what that sounds like.

Sonification should play, but no sound is heard

Xing Yi Ang: Hi Kimberly, you might have forgotten to click on...

Kimberly Arcand: Yeah?

Xing Yi Ang: I don't hear the sound.

Kimberly Arcand: Oh. Alright, let me try again. It seems like it was working. Share sound, include computer sound... Let me know if this works. Nope, does not play at all. Alright, well, I won't play the sound.

Xing Yi Ang: You think it will work if you put it on full screen mode?

Kimberly Arcand: Yeah, let me try that.

Xing Yi Ang: Yeah.

Kimberly Arcand: No, that's really weird. It was playing for me before, but now it's not. Computer is not happy today, which is fine. But essentially that sonification is a really lovely example of taking a physical process that's out there in the universe and making it audible in a way of that translation, and that sonification I think was a bit of a tipping point for us because it got an immense public response and just an overwhelming number of impressions and video views and all that. And so I was really happy to see that sort of large frame buy-in for that sonification. I'll put the URL for where you can find that's on vacation in the chat. So if anyone hasn't heard it, they can listen to it individually.

Xing Yi Ang: Thank you so much. Yeah, well, I'll be sharing the URL with the audience as well. Now, Scott, Astronify is different. You use it primarily for research purpose, and I presume you're less concerned

about the artistic aspects as compared to the clarity for scientific research. So could you share with us some of the challenges that you face in designing Astronify?

Scott Fleming: Sure, there was quite a lot. It is true, our focus is primarily to make sound that you can use to understand what the data is doing. It doesn't mean we don't care entirely about artistic license because you have to have something that's not gonna hurt your ears even if the data is doing something really weird or crazy. And there are important aspects, like the example that Alice gave about the money was really interesting.

We actually did a small case study with a team at MIT, the Massachusetts Institute of Technology, and they're a team that runs the TESS mission, which is looking for planets around other stars. And so they have to look at thousands and thousands and thousands of light curves. These are measurements of the star's brightness over time. And they're looking for those dips I showed earlier. And they use visual techniques primarily along with software, but we wanted to introduce Astronify to see if it could help them understand the signals that they're looking at and add to their ability to look for false signals versus true signals. And we started playing the sonification like I did, and we had a similar situation with what Alice said, which was the default was to say “OK, if the star's brightness drops, let's drop the pitch”. And we played some samples with real data from TESS, but they really care about the shape of that curve. Is it a V shape? Is it a U shape? Is it symmetric or asymmetric? And when we flipped the default that most of us had and instead made the pitch higher when the brightness dropped, they liked that better because most human ears are better at finding small changes at higher pitches than lower pitches. This is an evolutionary trait primarily.

And so even for specific use cases within a specific type of data, the choice of how to sonify the data can be complex and it may depend on your exact scientific needs, which is one of the reasons why it's important for our software to have as much configuration as possible so that researchers can choose how they want to sonify the data to then analyze the data.

Xing Yi Ang: OK, so you seem to be suggesting that there are actually many different ways that we can sonify data, and none of that... there's no right or wrong, right? So this means that in the current field, there are many different projects using different ways to sonify data. So my question is, do you think that these diverse methods have become a systemic problem because it makes the field messy and it prevents simplification from wider adoption? So do you think that it is important to work towards a standard protocol? Or perhaps a standard set of conventions and norms for data interpretation using

sonification. So since we have Scott here, why don't you continue with this question before I move on to the others?

Scott Fleming: Sure. And as somebody who works in an archive of many missions of data, standards is something we think about all the time. It's, in my opinion, and it is somewhat new still, I think the answer is gonna be: Not yet, but it will eventually.

And what I mean by that is I think the number of sonification projects have exploded over the last several years, Chris and another person named Anita Zanella and others, including myself, led a paper recently that was published in Nature and it summarized a lot of the sonification efforts. And it's exploding over the last couple of years, which is good to see. I think it's good to let as many teams and projects explore what's possible first and then after we learn a lot more about what it is to sonify data for whatever purpose you're looking at sort of spread those tendrils out, explore what's possible, explore what works, and then standardize things. Because I think if we try to standardize things too early, we're limiting the ability for us to explore what's possible. And I think we're not quite there yet, despite the long history, as Wanda mentioned.

I think there's a lot of room to discover and improve things still, and I think we're... I like to think of it as a small mini renaissance, hopefully, where we're more and more people at more and more higher levels of position. I think in the past a lot of people have done this in isolated small groups or even individually. Now we have huge networks of people working together. We have entire institutes like my own who are starting to get serious about it and I think with that kind of power behind it, we can explore and then standardize, is what I'm thinking, at least for research purposes.

Xing Yi Ang: And how about Chris? How do you think the future will move forward in terms of standardization versus customization?

Christopher Harrison: Yeah, so I think it would be good to hear Wanda's opinion on this too, but I'll just briefly say that like with visualizations, we have bar charts, we have pie charts, we have scatterplots, which is sort of standard frameworks that we get trained in and used to seeing. But there's still customizable options within those. So you can change the color, you can change the sample sizes and that's what we want to aim for. But the key thing is that the reason those visualizations work and we can quickly interpret them is we've spent our school life and our careers looking at them and being trained in them, so we can't expect sonification suddenly to work. We're gonna have to kind of have

that learning process and that training process, so people get familiar with these concepts and these frameworks as well. It's quite a long and maybe challenging road.

Xing Yi Ang: Yeah, and you alluded to the amount of training that is required, you know, in order to get us familiar with sonification, and even for data visualization, it took us decades to come to where we are now. You know, why do we use a pie chart? Why do we use a line graph? Are you trying to represent time series data? Are you trying to show proportion? How do I know when to use a histogram? These are basic norms and understanding and concepts that we have... or the previous generation has come to a consensus and come to a set of principles or rules that say for certain types of things is better to use a certain method, right? So it takes such a long time to reach that stage for data visualization and we are seeing that perhaps for sonification we see at the exploratory stage like what Scott had mentioned and then it would take a longer time for us to reach the next stage. So perhaps Kimberly, could you give us some of your thoughts on this? How do you think the field would go?

Kimberly Arcand: Yeah. Well, I think like Chris already alluded to, the idea of standardization is a tricky one because it really is the... perhaps platforms and methodologies that are being standardized in many cases, as we're doing, say, astronomical visualization. And so even today, when we're working on image data from the James Webb Space Telescope or Chandra or Hubble or whatever, those are individual teams that are doing data visualization for very specific purposes. The science team is doing visualization to help squeeze out all of that science from that, you know, those bits of ones and zeros, those data points that are underlining that visual image, and then even if it moves into a public sphere, the image processors and other people that are working on visualizing an image are letting that scientific story drive whatever output that they're doing, right? So even in different kinds of imaging data across different kinds of light, there's no true standard per se, but there are definitely guidelines that I think many of us follow.

So I can sort of imagine that that might be a next step, right? Not necessarily reaching a standardization across the board per se, but some agreed upon basic guidelines that just help make the experience a little bit more usable for folks. However, I think what's always really key is whenever we're printing out data from Chandra, for example, whether it's a sound, whether it's a 3D print, whether it's an image, we always provide a sort of descriptive legend, if you will. It really talks about what the processes were done to do that visualization, that vivification that, whatever, sonification, and why. And I think that is a really key component to any parts of this conversation. For me it's a little bit more about if you're going

to deviate at all from any potential future standard you would be describing why, and presumably it's because that science was driving that particular output in a specific way.

Xing Yi Ang: Yeah, I think that that's a great, great way to move forward. And Wanda, are you there with us? Are you here? Wanda, I think you...

Wanda Diaz-Merced: Yes, yes.

Xing Yi Ang: Great! So Wanda, you've been doing research using sonification for some time now. To some people sonification could be seen as a gimmick rather than a scientific tool, which leads me to the next question, how do you think sonification can gain credibility in the scientific field?

Wanda Diaz-Merced: We do need... this is from my perspective, right, which is maybe different from other people's experience and it's just a first hand approach to... a first experience – my personal approach to the field. And in order for it to be used for research it needs to increase its credibility, right? There are a couple of things happening. It's our economical mindset, the economical mindset of our field which is based on what is perceived possible versus what is perceived as impossible and also the way of things being assessed and impact being assessed in very short periods of time.

As, I think it was Scott said, we have a lot of work to do. We have to increase credibility by performing the perception experiments. What, applied to astrophysics data or gravitational wave data or any spectrum of data, what increases, what hinders attention modalities or perception to mathematical models of those results of those experiments, design training, bring musicians on board in order to learn from them how they train themselves because it requires training to learn how to identify different tones, different pitches, different acoustic effects that takes... I'm not talking only about music. I'm talking about sound perception. It takes training, it takes time. Training has to be researched, it has to be thoroughly... experiments, thoroughly designed in order to gain credibility and mainly it needs the funding.

Because these peoples that are working, are networking, are coming together in order to design the sonifications or are doing design sonification, right, use human perception in order to approach this sound. They do it without the necessary funding to carry all the work that has to be done, and when they get funding only in one year, the funding agency pretends that the sonification field will reach the same aspect of development that visual technologies or visual identification modes have reached over a 100 years, at least, right? So it requires a longer, a longer-term view.

And we have not only to do these experiments, but what we need is for funding agencies to trust that the work is being carried thoroughly and seriously, right? For the betterment of the science and for the betterment of including the civil society, especially the civil society. Getting peoples with disabilities leading the projects, peoples with disabilities at different on-sets of the disability leading the project and leading the perception experiment designs. I do apologize.

Xing Yi Ang: Thanks, Wanda. I think you touched upon some very good points. You talked about evaluation, training, engagement of persons with disabilities and so on. So I would like to ask the rest of the panellists: Do you think that the lack of rigorous and robust evaluation and assessment is one reason why sonification is not gaining as wide an adoption as expected? Perhaps Scott, you would like to begin?

Scott Fleming: Sure. I can begin, although I'll quickly probably pass the baton to Chris because his student actually has done some work on this. I think the answer is yes. To what extent that's the case I'm not sure. It's certainly not the only reason why.

I think there are tons of reasons why sonification is not being adopted as quickly as all of us would like to see in our day-to-day careers. First up, from just awareness to ease of use to simple things like when you give a presentation that lasts 10 minutes at a conference, is it gonna take 2 minutes to figure out if the audio will play in your PowerPoint? I mean basic stuff like that.

But I do think that increasing the amount of peer reviewed tests that show examples where using sound to interpret your data for professional research complements or supplements other traditional methods is important. And there have been a couple of studies like that in peer reviewed papers, there are not that many. And I think that increasing that number is gonna be one important factor to engage and also to what Wanda said, the more peer reviewed papers you can include in proposals to funding agencies, the more likely they are to give you money to continue that work. So it's important in at least two different fronts.

Xing Yi Ang: Yeah. So you touched on the role of the entire community supporting scientific research, including the role of the journals. So Chris, Scott has the nominated you to talk about what the students have done in terms of assessment and evaluation. Could you tell us something about that?

Christopher Harrison: Yeah, yeah, exactly. And I think the scientific legitimacy, it is all about publication. And I think if you want the funders to take it seriously, as Scott was saying, we need to show publications and we've done testings even at these early stages and I'd encourage everybody involved in this work

to try and publish their work for these reasons. So we did do a small scale study with Astronify, Scott's tool, to kind of get the ball rolling, and I was really pleased that Monthly Notices decided to publish this study. I had some ghosting from other journals, when I approach them about this study, because I think it was a bit different. They weren't used to this idea of publishing sonification.

So I'm hoping that if the journals start adopting this, accepting that this is legitimate mainstream science, then the scientific community will follow. And we're really pleased that Nature Astronomy this week published this series of articles, including a review. And for the first time, they accepted sonification as a type of figure, a way to present the data. So with these articles, a sonification of the data is included. They found it difficult, there was a lot of challenges in the background going on to make this possible. You'd think it should be easy, but for reasons I don't understand because I'm not a publisher, it was actually more challenging to say: here's an audio file to represent these data, but maybe this is the step, once the journal start making this possible, scientists can then submit sonifications as part of their journals and more and more scientists then will become exposed to it.

Xing Yi Ang: And Kimberly, how do you think we can sustain this momentum in getting more of our large major stakeholders like NASA or space agencies or those scientific data archives to be part of this movement?

Kimberly Arcand: Yeah, well, I think there's a few things. I think, one, sonification as a valid, accepted part of the existing astrophysics scientific enterprise / system, right, is new. New things can be scary. It needs the support, it needs administrative support, it needs the proper training, it needs the integration into existing tools. There are a lot of technical issues. I mean, I tested playing my sonification multiple times successfully and then for some reason today, I didn't want to play, right? There are all of these issues that do have to be overcome.

But I think really importantly, like Wanda has already mentioned, you know, those funding agencies need to have a little bit of trust and support. It's something that with the sonification program that we started, which was just, you know, started as a very very small project, no explicit funding, just kind of squeaking it out of the existing time that we had to do that has started to prove some interesting value and starting to add value to the conversation and that's great. So we are slowly building up the case and now we have more people in our sort of funding hierarchy that are supportive of it, that now even know what sonification is and that are slowly learning that this is a valid means of in this case communication.

And so for me, I just see it as a very slow series of steps. But again, like Wanda mentioned, it's that longitudinal goal that really needs to be underlined because, you know, I don't want any of these things to seem like a flash in the pan like what we're doing, and even within a group that's already well funded in general, not having a dedicated line of funding specific to sonification is a bit of a danger zone for me, because then, you know, some... a new manager comes aboard and doesn't see the value of this, doesn't recognize the sort of credibility here. It could be in danger.

And one of the issues I do see over the sort of credibility aspect when it comes to publishing is something also that Chris mentioned, which is, you know: Where do you go to publish? Because not each journal is comfortable with this type of interdisciplinary, which it often is, work, right? It's not just... in many cases it's not just an astrophysicist doing this, it's astronomers, computer scientists, human computer interaction specialists, engineers, all different kinds of specialties are often required to do this kind of work. And that means it's interdisciplinary, which means that's not always gonna be as attractive to maybe more traditional journals, right? So there's, I think, there's a lot of nuance here that needs to be figured out and decided upon.

Xing Yi Ang: Yeah. Thank you so much. And Wanda, Wanda are you there? So what's your take on this? How do we gain the trust of these organizations? How do we get them to continue the momentum on sonification? What more do you think can be done?

Wanda Diaz-Merced: This is a very interesting question, Xing Yi, and I will thank you so much for the question. I will go back to first mentioning the theoretical and experimental evidence that we need right. It was not until I did my experiments that I was given a serious opportunity because I had experiments to show, that I was given some opportunity in order to perform somehow in the science. But in order to change the mindset we may need to bring sonification to a credibility point in which sonification from the beginning, in the implementation and design of every single project in the space sciences will have a saying. So it will not be left out of the projects from the beginning, which is the tendency that is happening nowadays when projects are being designed not only sonification, but the user-centered design, the accessibility approach is taken in consideration at the very end instead of being taken in consideration from the very beginning. In order to do that, as we have been saying: No funding, no evidence. No evidence, no funding.

We have to do it - we have to address it symmetrically as we perform the experiments to continue carrying the voice of education and awareness. Now as part of these events, I think that all the nations

that are space nations should be represented in these kind of discussions and engage on bringing a multisensoriality and accessibility from the very beginning. Multisensoriality for mainstreaming, right, but also accessibility to the design of these projects from the very beginning.

Xing Yi Ang: Thank you. And what do you think is the role of – what role do you think the United Nations can play in promoting the use of sonification as a tool for research, outreach and inclusion?

Wanda Diaz-Merced: I think that all the space agencies or all the nations that are... not all the states have space agencies, all the space nations and all the nations that are members of United Nations should belong to your project and your project is in a position of performing an assessment not only an assessment of, of designing, of making sure that the agreements that are reached in between the people doing sonification, the scientific community, the space agencies, that those agreements are implemented for the sake of the science and for the sake of the future generations, new employment opportunities, new skills, be in development.

I think that your office can - will play a very important role in implementing and making sure it is implemented in the different countries. Because they say – I have to say this, I apologize – They say they will do things and they don't do it. We know this. They do not do it and the numbers they report are – I have to say it – they are not honest. So someone – and I think your office can play a vital role in making sure that things that are agreed upon will be implemented in the different space nations. I apologize.

Xing Yi Ang: No, no, no worries. No apologies at all. Kimberly, you work at NASA, so how do you think the United Nations and NASA could perhaps collaborate to promote the use of sonification?

Kimberly Arcand: Well, honestly, I think events like this are a really great first step to get the conversation moving because this does help lend that sense of credibility and legitimacy to such projects and the report that's coming out, for example, where I can absolutely see extending this type of project into a working group conference, like different kinds of events that can keep the momentum going and that can really try to draw in those various space agencies like NASA, like ESA, like many of the other ones. And to encourage participation, to try to agree on working together on research on the astrophysics data side, on the communication side, on all the various elements.

And like, as Wanda mentioned, making sure people who are blind or low vision in general are part of that conversation right from day one. And I think your office has a lot of potential to be able to really help direct this type of work in a way that will start to show the value to other constituents, other, you know, members around the world. So yeah, I look forward to that.

Xing Yi Ang: Thank you. And how about Scott? Coming from your position as a branch manager at the Space Telescope Science Institute, how do you think the United Nations or institutes like yours can continue to promote sonification?

Scott Fleming: Yeah, my answer might surprise some. I think it's education of young students. Two people mentioned what I was going to mention as well earlier, which is you know, you go to any random person and show them a simple line chart or a pie chart or histogram and say: What's bigger? or What's happening here? Most people will be able to understand that pretty easily even if they don't do science or mathematics as a career. And that's because they've had months and years of training as part of their standard education. And that's true in most nations, if not all of them, honestly. That doesn't exist for interpreting sound. And there have been some questions in the chat, I saw, about what role does education have or music education have, Wanda mentioned it, others have mentioned it. It's essential. And so I think the power of things like NASA and space excites students, it draws people out to events in ways that a lot of things don't, and the power of the United Nations to organize and support, arming educators with material and understanding to teach students as well as organizing events to celebrate space like the beautiful picture that Kim has behind her from James Webb, and apply sonification to students so that they can get that basic understanding and get inspired to perhaps use that in STEM careers so that when they get to their career stages where they might be coming to my institution as a college student, for example, or a professional, they will already have that understanding in their lives. So I think education and outreach is honestly gonna be the biggest thing, from my perspective.

Xing Yi Ang: Thanks. And Chris, do you have anything to add to that?

Christopher Harrison: I think a lot of great things have been covered, but I think if there's a set of guidelines and procedures that the United Nations could take ownership of, this would be very helpful in how you integrate sonification into education, into the journals, into the scientific process, and just to give a specific example, working with the editor of Nature Astronomy, she asked me: "Oh, is there a set of guidelines I could go to in how we can put sonification into our journal?" And I'm not sure that such a thing exists. And, so, she was looking for some procedures, how should this be accessible? How do we incorporate that?

Likewise, if you're organizing a conference, maybe you could have some similar set of guidelines about how sonification could be or should be incorporated, and this is something the United Nations could maybe write down and help disseminate around the world.

Xing Yi Ang: Thank you. So, maybe just one last question before we move on to the Q&A, because I see that our chat is heating up, is warming up and heating up and we have lots of questions coming in from the audience.

So the last question is: What is your dream scenario in terms of sonification? What do you hope to see in the future and what do you think are some of the steps that we can take now to move towards that future? I see Scott nodding. I take it as an indication that you would like to go first.

Scott Fleming: Well, I nod a lot. I have... I only nod because I have had this dream for a long time, ever since I started my work in sonification. And it's a fairly simple one. I would like every single time someone shows a plot on a PowerPoint at a meeting, to have it play sound. It's very simple. I think that at that point, sonification would be considered part of being a professional astronomer. Every astronomer shows plots. Every astronomer shows PowerPoints. And every single person says: "As you can see here", and they leave it at that. And that is exclusionary to people who have difficulty seeing or are not visual learners, honestly. And so if we can get it so that playing sound behind plots being shown at presentations at talks is as natural as giving a PowerPoint or wearing a name badge, I think we've reached it. So that's my dream for the future, at least the first milestone.

Xing Yi Ang: Right. And Wanda, what is your dream scenario?

(No Reponse) Well, I think we will get her back in the few seconds. How about we move on to Kimberly? Kimberly, what's your dream scenario?

Kimberly Arcand: Yeah, I think I would love to have sonification as well as haptification, the use of vibrational information and other ways of knowing as part of the data pipeline, much earlier, as Wanda sort of already alluded to. I would love for it to be a tool that's used right away in research. And I would also love for it to be a tool that's used immediately for communication. So on both parts of that expert to non-expert spectrum, sonification is incorporated very, very early on and part of the entire process and not just an add-on, not just something that's done in those later stages. And I think that would really, really be helpful for establishing not only the sort of credibility of it, but also just helping greatly expand the usability of it.

Xing Yi Ang: And how about Chris? Share with us your dream.

Christopher Harrison: I'll second about what Scott and Kimberly said, but I'll add in a similar vein to Scott. Every time I see a documentary or a show about astronomy, the sound is used in a meaningful way to communicate the messages and the data, just like visuals are the standard way now.

Xing Yi Ang: Thank you. And Wanda, do we have you here?

Wanda Diaz-Merced: Xing Yi, yes. Forgive me, I lost the microphone for a little bit. My dream for the future, besides addressing accessibility right on a daily basis and inclusion is to be able to witness a transformation of the discourse in our field of work. You know, to completely transform this kind of a little bit exclusionary discourse that only allows me to participate halfway in research, depending on others to find things, so it's the other person that is finding the event and not me. The event is identified by other person if I'm only depending on visual modes.

But also in terms of changing that discourse is to allow users, even though we were talking about the standardizations at some point, to allow users to use their own context to approach the information to participate in the field just as they are, using their own sensibilities and to their own maximum.

My dream is for that discourse to be completely transformed, if not today, tomorrow, in three days, but our addressing of it has to begin with concrete actions right now.

Xing Yi Ang: Thank you. And Alice, what do you think is the optimal scenario for you?

Alice Oates Well, for me, I think, it's actually, I think my kind of dream for this field would be quite recognizable to any academic in any field, which is to see the funders really investing in this important work in trusting scientists who are saying this is something that can really go somewhere and also just seeing in general kind of across the board, an inclusion and valuing of researchers with disabilities from undergraduate university students, all the way to professional scientists. And I think that's not really specific to sonification, but those are some things that really stood out to me, when we were doing this research, that are lacking.

And it would just be really wonderful to see a funding model in academia that promotes disability inclusion and promotes kind of innovative, new, exciting science like this that perhaps still has some things to prove but has a lot of really exciting uses and potential. So that would be my – that's my dream scenario.

Xing Yi Ang: Yeah, absolutely. You know, I always think that funding is like the oil that will move the scientific gears, so, no funding - mhm, anyway. So thank you to all the speakers. We had a very rich discussion today and I think you guys have given us a lot of food for thought and the topics that we have discussed together so far I think sum up very well the challenges that we face in using sonification in space science. So from design challenges to gaining scientific credibility to the multidisciplinary efforts

that is required to mainstream disability in space science. So you guys have highlighted so many areas that we need to continue to work on.

So now I will open the floor for the Q&A session. I will hand over to my colleague Nathalie to read out the questions submitted to us through the registration form and in the chat. Nathalie, over to you please.

Nathalie Ricard: Thank you very much Xing Yi. I'm a Caucasian woman with dark hair. I'm wearing a blazer. I'm wearing a blue scarf and I have quite a few questions for you because we had questions from the audience here, we also had plenty of questions beforehand when people registered for the webinar, so I've tried to group them by themes.

So maybe first we have questions about really concrete tools. What would you recommend for educators to use? Are there already tools available? I saw there were already some listed in the chat, so that was a particular question from Annamaria Lisotti. She's working in high school and she's looking for suggestion on what her students could use to make sonification out of the data. So maybe if you have any specific recommendation if you can just put a link in the chat for Annamaria and I think that will also be helpful for a lot of other people.

Then we had an interesting question that is kind of opening the question of how to make sonification more standard in research, was a question from Adrienne. So do you know if there are other aspects of astronomy that also took time to become accepted as a standard tool? Whether maybe for astronomers there have been also like tools or methods that really took some time and so did you think that can be some parallels there? Who would like to take the floor?

Christopher Harrison: I could say something. It's not quite a tool, but I'm just thinking about sort of multi-wavelength astronomy and for example, radio astronomy previously has been very impenetrable to most of the community and you had to be a super specialist in radio astronomy, or submillimeter astronomy, but everything's moved on. And now the things like ALMA, are making it much more easy for non super specialists to be able to access this type of astronomy because they're providing the tools, the resources and the products and that a non-specialist can still do something useful, so we might think about a parallel there that if we want sonification to be quickly picked up by other people who may not be super specialist in the sonification, we need to provide the tools and the resources in a really accessible and easy to use way and then it will become more mainstream just like radio became from a fringe to more mainstream use now.

Nathalie Ricard: Thank you. Kimberly?

Kimberly Arcand: Yeah, I have to completely agree with that. Before I think it used to be much more common that it was a x-ray astrophysicist and a radio astronomer and everybody was very, very siloed, but today there's more and more of a push and you're seeing definitely results in that area where people just tend to be, they might have a specialization, but they are multi-wavelength astronomers. Because today I think the value of multi-wavelength astronomy has become really, really apparent. And all of the work that's been done to make x-ray data accessible, radio data accessible, et cetera has been really key to that.

But I would also say there's maybe other parallels with like virtual reality and other kinds of areas of extend reality which is not yet completely accepted either, but as a research tool, virtual reality is something that has been growing, that people have been trying to codify and to quantify and to establish, you know, credibly in journals and all that. And you see that uptick, but it's not yet established either. So I think there are some existing parallels that are still trying to grow. A lot of those barriers are still technical barriers. Some of them can be funding barriers and just kind of general awareness barriers as well. So that's kind of the area that I'm seeing.

Nathalie Ricard: Thank you. Still in the areas of parallels, we had a question about whether there are other fields of scientific research where data visualization cannot really offer useful result, where sonification could offer useful results. So do you see any other areas of science that could benefit from sonification besides astronomy?

Scott Fleming: I'll just say I have heard sonifications in many different fields of science. I've heard sonifications of movies of bacteria that have been swimming and analyzing how light bounces off of them and trying to see what's going on visually was too hard, so a team made sound out of it and was able to analyze the data that way.

I've heard sonifications of oceanography data, studying the oceans. I've heard sonifications of health data from COVID statistics. You know, even something as simple as temperature maps. You know, we all are used to interpreting data differently by looking at weather maps, where you have a map of temperature and blue is cold and red is hot. And we're not measuring color. We're using color to represent what we're actually measuring, which is temperature in that case. But you can have a sound be blue and a sound be red and have that same approach, even if the data itself is a map or two-

dimensional or three-dimensional or multi-dimensional. So I think there's pretty much no limit to the fields of science that can benefit from sonification. And I've seen plenty of examples myself.

Nathalie Ricard: And do you see any other field also beyond science?

Scott Fleming: Yeah, I mean, I think anything that has data. If you're talking about, I mean separate from art and outreach, which is its own area of sonification, I mean economics, you know, even history, I think, has potential to be able to take, large amounts of written text potentially and look for patterns in it or stuff like that, sonically. There's a lot of potential. I'm not aware of specific examples, but it's another powerful way. You can think of sound, use of sound to analyze data in the same way that people are using machine learning, in my opinion. It's another approach besides looking at it that you can use to interpret large amounts of data, whether you understand the data or not, and I think sound and machine learning and other stuff like that are different approaches to analyzing datasets, whatever they may be.

Nathalie Ricard: Sounds very useful. Thank you. Now moving to a different theme: How can associations of students with disabilities best support your projects? We have plenty of students who were also interested in the webinar, so, you know, if I'm a student or I'm an association of students with disabilities: How do I get involved? What can we do? I see Scott nodding, if you would like to take the floor. Sorry, Chris maybe first and then Scott?

Christopher Harrison: Yeah, I can say, I mean one thing just like we went through the process creating our show, we were really looking for that sort of collaborative creative process and we try something, we try some sonification, we get that feedback and that interaction, I think this is really useful. The various tools that have been presented try them out, give us feedback, how accessible are there, how intuitive are they? This is really useful and contributions that I think we'd all appreciate.

Scott Fleming: Yeah, I would say we are pretty much every project is interested in getting feedback and testing. In cases where the software, like Astronify, is open source and you have an interest in learning how to do coding, you can contribute to the software directly yourself and help us build these tools and help us add features to the software directly. And I also wanted to mention there's a lot of opportunities to join either projects directly by contacting the teams or there's a really neat group called Sonification World Chat. Many of the people here are part of it. And it's a group of people interested in sonification for all science, not just astronomy, that meet once a month to discuss and present work we're doing on sonification. And so if you're interested in that, send me or Chris or Kim or anybody else an e-mail, we're

all part of that group chat and we'd love to have you join us during our meetings and listen in and network with a lot of other people and help us out as we do some of these projects.

Nathalie Ricard: OK, so, sonification group chat.

Scott Fleming: Sonification World Chat. Yeah, I'll put the name in here and I'll try to find a good link. But if not, feel free to contact us.

Nathalie Ricard: Great. We also discussed music, the link to music. You talked about involving musicians. We had a question from Veronika Bachleitner about whether it's important to apply music theoretical knowledge to sonification to achieve better results. Is it a topic where you see you need like the musical theory to improve the results? Who would like to take the floor?

Wanda Diaz-Merced: Music is very mathematical. I will jump in. Music is very mathematical. And the ear is very complex in its mathematics, but I will leave the ear outside. The musical pentagram also is very specific, right, in the way that the octaves are managed and all the et ceteras. So music to me, it has a very important component. Even though what I do is to listen to sound, not musicalising, not musicalising the data, my data has no harmonic expectation. People cannot even... their attention modalities, they zoom out completely from the data, I don't zoom out because I have the interest of exploring the information, but it's worth researching how music theory will have a part in supporting people, especially sighted people who make conscious sense of everything using the center of the visual field, how it may help them to grow more sensitive to events in the data that by nature are blind to the human eye.

Nathalie Ricard: Thank you very much Wanda. Kimberly?

Kimberly Arcand: And I would just add, I feel like in general the music community is a really important group to include in this type of work because they do have a lot of knowledge about this. And for the types of projects that I work on, for example, which do have a sort of musical component to them, one of the most frequent questions I get is from musicians and related artists who want to be able to play these sounds, they want to be able to incorporate them into their own work. They want to be able to disseminate them in their own way.

And so we've actually started working with a composer who is trying to essentially translate the sonifications that we've done into something that would be playable for other musicians to be able to enjoy but also produce. And I think there's some really great areas of overlap for learning between

music education and science education and computer education in schools that, I feel like excluding the music and music education community would not be to our benefit.

Nathalie Ricard: Thank you. And then maybe because I see we have only a few minutes left as the last question, what advice would you have for students who want to learn sonification and to eventually work in this field in astronomy? What specific training would you recommend for them? I see Scott nodding.

Scott Fleming: Common theme here. I was just thinking, I'm a little biased, but these days, especially in astronomy, computer programming is so important. And so if you're a student, especially because our package is a software package. I think learning how to do good code development. In particular Python is what most of astronomy is using these days, is a useful skill. I think some aspect of training your ear, not musically, necessarily, but to interpret the sounds is a good skill to practice, although you might need to do that on your own.

And I think just the standard stuff, basic statistics, basic mathematics, and of course the subject itself. If you're interested in sonification in astronomy, read astronomy books, study physics books, or if you want to do chemistry or whatever else, like, make sure you have a good solid foundation there too.

Nathalie Ricard: OK, thank you. Any other piece of advice beside computer science? Seems to be a consensus. Computer science is very helpful I see.

Wanda Diaz-Merced: I will, Nathalie, I will – forgive me for interrupting, but I will underline what Scott has said. Learn your mathematics. Learn it well. Learn the mathematics of sound, it is different from light, right, sound is very messy, but learn the mathematics that describe it. Learn how to identify it, if you want to use sonification, learn to identify it auditorially. Learn the physics and train yourself right, bring it, bring it to your work field and just start using it, right? If you have the interest, what it takes is it only takes one person to begin and then others will. Others will follow through.

Nathalie Ricard: Indeed. Thank you very much, Wanda. Apologies if I did not ask your questions, but I'm sure our speakers will be more than happy to answer any question you might have. Feel free to contact them and feel free to contact the Sonification World Chat. And over to you, Xing Yi, thank you.

Xing Yi Ang: Thank you. Thank you. Nathalie. She has been doing a wonderful job moderating the chat. And thank you to all our speakers. I really enjoyed today's discussion. And if I may put one last question to all of us before we end this session. So as we reflect on the insights from today's webinar, what is one thing that you think you can do to contribute to accessibility in space science? Each of us may be just a

tiny piece of the puzzle, but I think, together, through collective efforts, we will be better placed to achieve our vision of an inclusive future. And by raising awareness of disability inclusion in space sciences, I hope this webinar will bring about a positive chain reaction and encourage more stakeholders to join us in our efforts to create an equitable and inclusive space.

So, ladies and gentlemen, we have now come to the end of the webinar. On behalf of UNOOSA, I would like to extend my sincere thanks to all the speakers for their time today. Thank you also to the audience for your active participation in the discussion. I hope this webinar has started meaningful conversations that we will all continue to have after today. And please do follow the UNOOSA Space for Persons with Disabilities project at unoosa.org and check out our other videos on sonification available on YouTube. And before you go, please take some time to fill in the feedback form. This will help us to improve our future activities.

So thank you once again, a big thank you to all of you. Thank you and have a good day. Ciao.

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