"2nd Workshop on Astronomy Beyond the Common Senses for Accessibility and Inclusion (2022)"
Revista Mexicana de Astronomía y Astrofísica Serie de Conferencias (RMxAC), **54**, 28–33 (2022)

https://doi.org/10.22201/ia.14052059p.2022.54.06

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Editors: S. Vargas, B. García, G. Hemming, S. Duffau, N. Vázquez, and A. Pérez-DOI: https://doi.org/10.22201/ia.14052059p.2022.54.06

PAINTING GRAPHS WITH SOUNDS: COSMONIC SONIFICATION PROJECT

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ABSTRACT

CosMonic (COSmos harMONIC) is a sonification project with a triple purpose: analysis (by means of sounds) of any type of data, source of inspiration for artistic creations, and pedagogical and dissemination purposes. In this contribution we present the work recently produced by CosMonic in the latter field, creating specific cases for the inclusive astronomy dissemination project Astroaccesible for blind and partially sighted people, but also aimed at a general public that wants to understand astrophysics in an alternative format. For this project, CosMonic seeks to create simple astronomical cases in their acoustic dimension in order to be easily understood. CosMonic's philosophy for these sonifications can be summarized in a simple metaphor: painting graphs with sounds. Sonification is a powerful tool that helps to enhance visual information. Therefore, CosMonic accompanies its audios with animations, using complementary methods to reach a general public. In addition to providing some cases created by CosMonic for inclusive astronomy, we also share our experience with different audiences, as well as suggest some ideas for a better use of sonification in (global) inclusive outreach.

RESUMEN

(COSmos harMONIC) es un proyecto de sonificación con un triple objetivo: análisis (mediante sonidos) de cualquier tipo de datos, fuente de inspiración para creaciones artísticas, y fines pedagógicos y de divulgación. En esta contribución se presenta el trabajo realizado recientemente por CosMonic en este último campo creando casos específicos para el proyecto de divulgación de astronomía inclusiva Astroaccesible orientado no solo a personas con discapacidad visual sino también dirigido a un público general que quiera apreciar la astrofísica en un formato alternativo. Para este proyecto, CosMonic ha creado casos sencillos en su dimensión acústica para que sean fácilmente comprensibles. La filosofía de CosMonic a la hora de crear estas sonificaciones se puede resumir con una sencilla metáfora: pintar gráficas con sonidos. La sonificación es una poderosa herramienta que puede ayudar a reforzar la información visual. Por eso, CosMonic acompaña sus audios con animaciones, usando canales complementarios para llegar a una mayor audiencia. Además de presentar algunos ejemplos creados por CosMonic para astronomía inclusiva, se comparte nuestra experiencia con diferentes tipos de público así como algunas sugerencias para el futuro de la sonificación en la divulgación (global) inclusiva.

Key Words: astronomy outreach — astrophysics — Inclusive astronomy — sonification

1. WHAT IS SONIFICATION?

Although audification has been around for more than a century as a means of listening to data in science, from physiology to seismology (e.g., Bernstein & Schönlein 1881; Wedenskii 1883; Frantti & Leverault 1965), sonification, as an academic discipline, is a relatively young area of research that integrates a wide variety of professional fields. As in other media, where digitization produced a radical transformation, the 1990s was key to the conceptualization of the phenomenon, in particular, with the impulse of the first International Community for Auditory Display (ICAD) meeting in 1992.

The general consensus defines sonification as the technique that uses data as a source to generate sounds from their transformation, that is, it is a representation of data by means of sounds. Sonification would therefore be the counterpart of visualization.

Nowadays, sonification is present in our daily lives, from car parking assistance to computers. Sounds are used to inform about the success of particular events, such as deleting the trash folder (auditory icons), email alerts or shutting down the operating system (earcons). They can even be the only ingredient to create unique acoustic ecosystems in audiogames[3].

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[3]https://www.audiogames.net

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Aside from the multiple daily uses of sonification in user-machine interactions, there are three main broad areas of applications of this technique to scientific data, considering the receptor and objective of the output, all of them with wide common overlapping areas: a) analysis by means of sounds of any kind of data; b) pedagogical and dissemination purposes; c) source of inspiration for artistic creations and public engagement. Depending on the public and aim of the sonification, the acoustic complexity and the clear presence of the data will have different weights.

Composers have been at the fore-front of the artistic use of scientific data in their compositions[4]. One of the many recent examples is a piece by Everett (2013) sonifying chemical evolution using biochemical data exploring possible early Earth formations of organic compounds. The holistic artistic experience `Chasmata`[5] (Arranz & López-Montes 2017) with Mars as the leading role, integrates astrogeology, architecture, music, sound art, visual art, sculpture, and the venue itself, where the audience is part of the creative process using their cell phones to interact with more than one hundred musicians and multi-channel site-specific ambisonic electronics. The idea of using the building as part of the creation has been taken a step further in López-Montes & Ibaibarriaga (2021), where the piece is performed and recorded at the very dome where the sonified data has been observed.

However, in general composers are more concerned about the final musical experience as a whole rather than the building blocks of their creation. Their compositional materials act as a powerful self-inspiring creativity engine as well as an exotic component of the story for engaging the audience and point their curiosity to the science behind the scenes for a later more in-depth reading.

As appealing and aesthetically exciting as these works might be, they are not easy to use in some specific outreach activities, as the data is embedded in rather complex musical setups. There is a broad intermediate land between the pure analytical use of sonification and its application for compositions. In the following sections we present a couple of cases produced by the CosMonic sonification project inhabiting this "transitional buffer state". In section 3 we will provide some reflections on the future of sonification, with special attention to outreach.

[4]For example, Lucier's *Music for Solo Performer* premiered in 1965 (Lucier 1967). For an overview of this piece, see Straebel & Thoben (2014).

[5]https://www.thedkprojection.com/chasmata/

2. THE COSMONIC PROJECT

CosMonic[6] (COSmos harMONIC) is a sonification project which aims to explore any kind of data (passenger rail traffic, weather patterns, astrophysical data, ...) in all its acoustic dimensions, from the more analytical science-based approach to artistic applications, with particular care to the nature of the problem and the audience of the final product. In addition, CosMonic is open to collaboration with other projects which seek to create sonification resources to bring a new and different perspective.

As an example of current collaborations, CosMonic has been working on creating custom-made cases for the Astroaccesible project[7] (Pérez-Montero et al. 2017), an inclusive astronomy dissemination project for blind and partially sighted people, also aimed at a general public that wants to understand astrophysics in an alternative format. For this project, CosMonic seeks to create simple cases in their acoustic dimension in order to be easily understood. The idea is to produce brief cases that can be used within an inclusive activity to explain or illustrate astrophysical concepts. CosMonics philosophy for these sonifications can be summarized in a simple metaphor: painting graphs with sounds.

Sonification is a powerful tool that helps to enhance visual content creating powerful synergies thanks to the codification of the information using an alternative channel. Therefore, CosMonic accompanies its audios with visual animations, combining complementary methods so that the described concepts reach the general public. In this regard, the audiovisual content is inclusive, allowing a broad audience to enjoy the information in its multiple dimensions.

All the material produced by CosMonic is uploaded to its own dedicated YouTube channel. Each video contain at the beginning a short audio description, complemented with a fully detailed explanation in the YouTube video description of each sonified case. All the input data has been extracted from the literature and/or catalogues and credited in the text description. There are two versions of each video distributed in two separate YouTube lists: one with audio and text descriptions in English[8] and another in Spanish[9].

CosMonic does not have a fixed set of tools for use in producing its products (audio or video), as

[6]http://rgb.iaa.es/cosmonic

[7]http://astroaccesible.iaa.es/

[8]English CosMonic YouTube channel: https://bit.ly/3tmXhGo

[9]Spanish CosMonic YouTube channel: https://bit.ly/3FfIbVi

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it relies on the best approach for each particular project. For the cases described below, a combination of the ChucK audio programming language (Wang, Cook, & Salazar 2015) and Python (video and data pre-processing) were used.

2.1. *Case 1: Transits and Soundscapes*

The first case is the data sonification of a transit, one of the most common techniques used for the hunt for exoplanets. The audio "paints" the observed data of the transit of the extrasolar planet HAT-P-7b (Kepler-2b), located at a distance of 320 pc, discovered in 2008 (Pál et al. 2008). The data was collected from the NASA Exoplanet Archive[10]. In some cases there are light curves from different observations of the same object, both from professional and amateur observers[11]. The telescope collects light information from the star at regular intervals for several hours (in this particular case). In the visual dimension, the horizontal axis represents time (in hours) and the vertical axis represents the relative flux. In the audio dimension, the brightness value (relative flux) is coded with frequency and the discrete nature of the data is represented by assigning a single short sound for each measurement. In the animation each individual observations is represented by a blue dot that appears in the graphic synchronized with its corresponding sonified sound. The first time an observation shows up, to make easier its visual identification, it is plotted in yellow for a brief instant. Then, it turns blue and the next observations appear, repeating the process until all points are located in the graphic. To facilitate the interpretation of the data, a continuous orange line representing the model fit of the data is drawn at the same pace as the individual dots.

Since the data spans for an interval of ~ 6 hours, the whole duration of the sonification is compressed to 20 seconds. The total duration is a balance between the clear individual identification of the "dots" and making it easier to remember the "shape" of the observations in the frequency space. An excessively long sonification could make it difficult to remember the first part of the data once the audio is reaching its end. The relative flux, varying only a few thousandths around 1, is mapped between 20 and 880 Hz. The scatter of the relative flux (and thus, frequency) is due to uncertainties in the measurements. The overall effect is a soft soundscape loosely resembling some bits of "droidspeak".

[10]https://exoplanetarchive.ipac.caltech.edu

[11]The data in this case is from amateur observer Peter Kalajian (KP2).

So far we have just "painted" the individual quantized data. We can now try to extract the fit model that represents the overall frequency (relative flux) behaviour of the transit, blurring out the individual dots and the intrinsic scatter of the observations. This is done in a second sonification using as input the same data. It should be noted that we are not sonifiying the data of a model fit curve, but instead we are extracting this information directly from the audio data itself. It can be seen as a fitting procedure on the audio dimension. This can be done in many ways. We chose a fairly simple method based on the use of networks of simple allpass and comb delay filters controlled by a mix parameter. The result is a dark dense soundscape ("stellar wind" effect) where the average frequency (relative flux) of the dot cloud at a particular instant is enhanced over the individual events.

From these two versions of the same case we can gather two interesting ideas. First, we are able to mimic some of the data fitting/visual plotting procedures in the audio dimension. And second, we can produce and extract very different soundscapes from the same data. We will explore some ideas in relation to this in the last section.

2.2. *Case 2: Stellar Evolution and Emotional Reactions*

The second case is in fact a series of sonifications on stellar evolution, an audio trip through the Hertzsprung-Russell (HR) diagram. These cases show the variation of the luminosity and temperature of stars along their lifetimes as a function of the initial mass. The data was taken from Schaller et al. (1992). Since the goal was to show the variation of these two quantities, we fixed the metallicity of the models to solar (0.02 $Z_{\odot}$) for all the cases. We chose several key masses values to illustrate the highly variable evolution of a star as a function of its initial mass. Each mass has its one audiovideo: 1.25 $M_{\odot}$, 5 $M_{\odot}$, 20 $M_{\odot}$, 60 $M_{\odot}$, and 85 $M_{\odot}$.

In the visual dimension, the logarithm of the temperature (inverted, so from left to right the temperature decreases following the usual HR diagram convention) is plotted on the horizontal axis, while the logarithm of the luminosity goes in the vertical axis. The whole track is already drawn from the beginning and a cartoon image of a star is placed at the beginning of the track. Once the evolution sets off, the star moves along the track. A label on the upper left of the plot shows the actual time in units of million years as the star moves through its life cycle.

In the audio dimension, luminosity is represented by the frequency (the more luminous the star, the higher the frequency) and temperature is mimicked by the vibrato, the higher the temperature, the higher the rate[12] of the vibrato. This seems a rather intuitive mapping as temperature may be related with high activity and vibrations, such us boiling water and molecular heat (molecules vibrate faster as they heat up). Unlike the first version of the previous case, here the sound is continuous and the evolution unfolds in a smooth way. The sound of a bell indicates the passage of time, struck at regular intervals depending on the lifespan of the star. All these settings are briefly audio described at the beginning of the video. The duration of the sonifications, as in the previous case, was set to around 20 seconds.

As some stars, depending on their initial mass, end up exploding as supernovae, we have marked this event at the end of the tracks, both visually and aurally, with a cartoon image and the sound of an explosion.

These cases are good examples of multi-dimensional sonifications, where several variables unfold concurrently with event information: from multi-parameter mapping (luminosity-frequency, temperature-vibrato) to auditory events in the form of auditory icons (supernovae explosion) and earcons (bell). The level of complexity in the audio dimension is moderate, but it has been tested to work successfully for a general audience. Although in general the use of timbre and loudness are the most common companions to pitch in multi-parameter mapping, some of those acoustic variables (i.e. loudness) do not show an effective high dynamical range (in the comfort zone) when used simultaneously with others, in particular with pitch. Here the use of the vibrato has been proven to perform particularly efficiently for its discriminating ability.

3. A FEW REFLECTIONS ON SONIFICATION

This last section provides some general reflections we believe deserve some further attention, in particular (although not entirelly focused on) the realm of outreach, dissemination and artistic applications of sonifications.

3.1. *Soundscapes and Emotions*

In section 2.1 we have described two very different renditions of the same input data information. These created contrasting soundscapes, from the more gentle "droidspeak" to the dark dense "stellar wind". These two distinct sound atmospheres are likely to generate diverse reactions and emotions to different audiences. The friendly "droidspeak" will more likely be preferred by young children, while the dark soundscape will be the choice for an adult audience, composers or sound artists interested in complex acoustic environments. This is the case in our experience. The "dark" soundscape tends to frighten the young audience, especially if the illumination of the venue is faint (generally, to increase the contrast of the screen). On the other hand, this is the preferred option, combined with a darkly lit atmosphere, for more mature audiences seeking deeper experiences. The combination of audio and a particular environment setup creates synergies reinforcing the emotional side.

With case 2.2 we have experienced a different and more amusing type of reaction in the public. The final steps in the evolution of some stars (e.g., listen to the 20 $M_\odot$ case) stay for some time in a certain region with lower temperature and thus, slow vibrato rate. The contrast between high rate vibrato at the beginning of the life of the star and the low, maintained vibrato rate puts a smile on the faces of the public and even makes the audience laugh (if presented properly).

In general, a significant number of sonifications of the universe available for outreach on the internet have a "spooky" (audifications in particular) spirit or a dark/mysterious character. As exciting as these might be, not all ears will have the same (positive) reception. We may arouse other types of emotions with which to experience the (otherwise silent) universe.

All these cases illustrate the power of sound to evoke quite diverse mood states and point to the need to know, where possible, the type of audience that will listen to our sonifications, and even prepare accordingly the atmosphere of the venue to reinforce or dilute some of these effects.

3.2. *Complex Sonifications and Ear Training*

From high school to college, we have been trained for years to interpret increasingly complex plots. When we look at a graph, we are not aware of this long trained skill that allows us to read intricacy relations from the visual point of view. All in all, especially in journal articles, we encounter dense and elaborated plots that require several minutes of our attention. A significant fraction of these figures cannot be completely deciphered without the help of a detailed caption.

This fact has several implications for sonifications. First, we cannot expect a sonification (especially a complex one) to be understood without a context and description of the content, a function

[12]The speed with which the pitch is varied. The amplitude of the vibrato is kept constant in these cases.

similar to a caption figure and a legend. Second, in most cases we might need to listen to a sonification several times, in the same way a plot is visualized for several minutes, focusing on different aspects of the data.

The sonification field and its many applications is growing and we might venture it is here to stay and will become a common source for understanding data. As any other field, it evolves, creating more challenging content, in particular in science and analytical applications. We cannot assume an untrained user will be able to handle these complex acoustical data as fluently as the visual content. Therefore, we argue it would be helpful to prepare future sonification users from the early stages. Basic and advanced ear training from primary to high school might be an interesting curricula to implement if we aim to deal with rather complex sonifications in the future. It should be noted this does not imply formal musical training[13], but a more general training focused on recovering/interpreting information from the aural channel.

3.3. *Inclusive (Cultural) Aesthetics?*

A significant number of outreach/artistic sonifications either present mysterious/dark soundscapes or have a western classical/pop approach (and instruments). Some tools to create these materials rely on technical architectures that imprint a cultural bias scheme[14] and therefore are not particularly suited for other musical aesthetics (Cornelis et al. 2010; Thompson 2014).

Our strongly rooted cultural and linguistic concepts might influence the way we unconsciously picture the world. For example, Mandarin speakers in general conceptualize the future as behind and the past as in front of them (also translated into co-speech gestures), and those space-time mappings are affected by different expressions (Gu et al. 2019). In addition, different cultural traditions may have quite different instrumental timbres, music scales, aesthetics intervals (consonance) or complex polyrhythms that appeal in a particular way to the emotions. Artistic sonifications can also be inclusive from a culturally aesthetic point of view, mixing different timbres, styles and even temperaments, as has been explored historically in the past (García-Benito 2021).

We have seen that not all audiences are not alike and can react in many different ways to the same sonic source. The (silent) universe does not have a particular sound and it should speak in many languages. We should encourage sound artists, sound engineers, composers and artist in general with experience in or from different cultural backgrounds to create a more inclusive aural representation of the silent universe.

R.G.B and E.P.M. acknowledge support from the State Agency for Research of the Spanish MCIU through the "Center of Excellence Severo Ochoa" award to the Instituto de Astrofísica de Andalucía (SEV-2017-0709). R.G.B. also acknowledges support from grants P18-FRJ-2595 and PID2019-109067-GB100.

REFERENCES

Arranz, A. & López-Montes, J. (with the collaboration of Ibaibarriaga, I., Schipper, C., and Corral, A.G.). 2017, Guggenheim Museum (Bilbao)

Bernstein, J. & Schönlein, C. 1881, Bericht ueber die Sitzungen der Naturforschenden Gesellschaft zu Halle, 18-27

Cornelis, O., Lesaffre, M., Moelants, D., & Leman, M. 2010, Signal Process, 90, 4, 10081031

Everett, S. 2013, In: Proceedings of the International Conference on New Interfaces for Musical Expression (Daejeon, Republic of Korea: Graduate School of Culture Technology, KAIST), 277–278

Frantti, G.E., & Leverault, L.A. 1965, Bulletin of the Seismological Society of America, 55:125

García-Benito, R. 2021, liner notes for El clave del Emperador: Diego de Pantoja and His Legacy, Todos los Tonos y Ayres & Íliber Ensemble, IBS Classical (IBS 142021), Compact Disc

Gu, Y., Zheng, Y., & Swerts, M. 2019, Cognitive Science, 43, 12 (e12804)

López-Montes, J. & Ibaibarriaga, I. 2021, ExoSounds, ZawpRecords, Digital Album, https://zawpklem.bandcamp.com/album/exosounds

Lucier, A. 1967, Fylkingen Bulletin: International Edition. Art and Technology, II 2: 167/401

Pál, A., Bakos, G. Á., Torres, G., et al. 2008, ApJ, 680, 1450. doi:10.1086/588010

Pérez-Montero, E.J., García Gómez-Caro, E., Sánchez Molina, Y., et al. 2017, Highlights on Spanish Astrophysics IX, 742

Schaller, G., Schaerer, D., Meynet, G., Maeder, A. 1992, A&ASS, 96, 269

Straebel, V., & Thoben, W. 2014, Organised Sound, 19(1), 17-29

Thompson, W. F. 2014, In: Music in the social and behavioral sciences: An encyclopedia, 1, 790-791 (SAGE Publications, Inc.)

[13]Needless to say, formal musical training would be more than enough for this purpose. However, as enriching as this is, not everybody might feel attracted to studying the complex intricacies of music notation or counterpoint rules.

[14]For example, generally sounds are quantized in twelve fixed chromatic notes per octave tuned in equal temperament.

Wang, G., Cook, P. R., Salazar, S. 2015, Computer Music Journal, 39(4):10-29

Wedenskii, Nikolai J. 1883, Archiv für Physiologie 313-325

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