The 'Sounds of Space' as an Interdisciplinary Means of Science Dissemination

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Abstract. Astronomers, astrophysicists, and space physicists present their research by visualizing scientific data. Plots, images, graphs, maps, animations, and videos are used to describe astronomical phenomena. Is it worth converting our scientific data into sound instead of visualizing it? What would be the benefits of such a transformation? This paper reports on a case study related to space physics and the electromagnetic and particle interaction between the Sun and the Earth. Space weather phenomena, such as magnetic storms and their effects on the near-Earth space environment, can be described by sound.

In astrophysics, the study of pulsars has also led to the use of sound to describe these 'exotic' stars acoustically. Pulsars are dense and highly magnetized rotating neutron stars. They emit electromagnetic radiation, which can also be converted into sound waves. There are many ways to 'sonify' scientific data, creating an 'audible understanding' of scientific phenomena. For example, the quality of magnetic storms or the rotations of pulsars are understood through musical expressions.

The methodological link between the sonification of astronomical data and music resonates strongly with Pythagorean ideas about the 'music of the spheres'. Pythagorean philosophers, astronomers, and mathematicians were the first to talk about the 'sounds' produced by the celestial bodies, relating their orbital characteristics to musical notes.

Sonification and the art of sound can play a key role in scientific research and astronomy education, as well as in science dissemination, artistic performance and music composition. This interdisciplinary method combining astronomy, music, and philosophy has been explored through several paradigmatic projects presented in this paper, which include work with the general public, children, students, and the visually impaired.

Sonification - Making the phenomena perceptible to the ears

Although scientific information is commonly presented through data visualization, sound has also been used to communicate science in recent decades. Scientific data sets are becoming larger and more complex, often containing many components. This means that there are limitations to using techniques based solely on visualization.

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On the other hand, because sound is characterized by multiple parameters such as pitch, volume, timbre, or tempo, it has a multidimensional character. In addition, humans are able to perceive sounds with different characteristics simultaneously and can focus on those that are more important. The human auditory system is also well designed to discriminate between periodic and non-periodic events and to detect small changes in the frequency of continuous signals.[1] As a result, the listener is acoustically equipped to explore data sets of greater complexity. In general, sonification is the use of non-speech audio to convey information. As a computational technique, sonification uses data as input and produces sound as output.

Sonification techniques have been developed and used by scientists, educators, and science communicators in a wide range of scientific fields, including astronomy, space physics, chemistry, geology, seismology, astrophysics, cosmology, and solar physics. In astronomy, sonification methods have been used to acoustically describe our solar system, gravitational waves, solar storms, supernova explosions, or galaxy spectra.[2]

Audification is a more specialized sonification technique that converts data directly into sound. Typical examples are the Geiger counter, invented in the 1900s, which produces a sound in response to radiation levels, and

[1] Gregory Kramer, Bruce Walker, Terri Bonebright, and Perry Cook, *Sonification Report: Status of the Field and Research Agenda* (Lincoln. NE: University of Nebraska – Lincoln, March 2010).

[2] Michael Quinton, Iain McGregor, and David Benyon, ‘Sonifying the Solar System’, in the Proceedings of the 22nd International Conference on Auditory Display - ICAD 2016 (Canberra, Australia: The International Community for Auditory Display, 2016), pp.28–35. https://doi.org/10.21785/icad2016.003; C. Georgiou, A. Andreopoulou, F.-A. Metallinou, T. Moussas, and A. Georgaki, ‘Micropolyphony and Stochastic Compositional Techniques as Tools for the Sonification of Magnetic Storms’, International Audio Mostly Conference: Exploration in Sonic Cultures, Milan Italy Sept. 18-20, 2024. https://doi.org/10.1145/3678299.3678318; J. W. Trayford, Samantha Youles, Nicolas Bonne, and Chris M. Harrison, ‘Ear to the Sky: astronomical sonification for accessible outreach, education and research with STRAUSS’, in *Revista Mexicana de Astronomía y Astrofísica Serie de Conferencias* (RMxAC) (2024): pp.42–46. https://doi.org/10.22201/ia.14052059p.2024.57.10

the pulse oximeter, which produces a tone of variable pitch depending on the level of oxygen in a patient's blood.[3]

On14 September 2015 LIGO made the first observation of two black holes merging together.[4] The two LIGO detectors recorded the first direct observation of gravitational waves passing over the Earth. The gravitational wave signal was converted to an audio representation. When we listen to the sonification of the event we understand that when the black holes spiral closer in together, the frequency of the gravitational waves increases. Cosmologists call these sounds 'chirps,' because they sound like a bird chirping.[5]

Different kinds of gravitational wave signals are produced when black holes collide, neutron stars spin, and supernova explode. Sonification of the gravitational wave signals can be heard.[6] In astronomy and space physics, radio waves are often transformed into sound waves through sonification, allowing the human ear to perceive various radio sources from the near-Earth space environment and deep space.

Previous examples of sonification include NASA's Juno mission to Saturn in 2016, which received radio signals associated with the planets intense auroras. When the signals are shifted into audio frequency range we can listen to Saturn's auroras.[7] After NASA's Voyager 1 spacecraft exited the heliosphere (the cavity inside which the solar wind is extended), it continued travelling into interstellar space. In 2012 and 2013 it detected vibrations of dense interstellar ionized gas (plasma). The waves that detected by the antennas of the plasma wave instrument were amplified and played through a speaker. These frequencies are within the range heard by human ears.[8]

My own work includes an original idea using 'sounds of space' in musical performance which I have developed since 2018 in collaboration with Tilemachos Moussas, musician and PhD candidate in music

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[3] Kramer et al., *Sonification Report: Status of the Field and Research Agenda*.
[4] LIGO, https://www.ligo.caltech.edu/ [accessed 19 September 2025].
[5] 'The first direct detection of gravitational waves', *Sounds of Spacetime*, Mountclair State University, https://www.soundsofspacetime.org/detection.html https://www.soundsofspacetime.org/detection.html [accessed 19 September 2025].
[6] https://www.soundsofspacetime.org/.
[7] https://www.youtube.com/watch?v=slE2i0O0pDY.
[8] https://www.youtube.com/watch?v=LIAZWb9_si4.

technology. This has resulted in a piece of baroque music orchestrated with ‘Earth Songs’ and the sounds of pulsars.[9]

Two examples developed by me and my collaborator, A. Palaskas, in 2012 are the following sonic landscapes, the result of collaboration between an astronomer, Fiori Anastasia Metallinou and an electronic music composer, Anthony Palaskas.

1. Sonic Landscape produced by the Earth Songs
Our planet, Earth, has a magnetosphere (the area in which its magnetic field extends) that interacts with the solar wind. This interaction disturbs the magnetosphere, causing magnetic storms. During these disturbances, energetic particles from the solar wind enter the Earth’s magnetic field. Trapped particles orbiting the magnetic field lines emit radio waves. Radio waves propagate through the Earth’s atmosphere, ionosphere, and magnetosphere, but cannot be heard by humans because they are electromagnetic waves. They can be detected by our ears when we convert them into sound waves. These acoustic phenomena can even become so rich that they are called ‘Earth Songs’. To compose the music of our planet, we used audio data provided by the NASA Inspire Project and the University of Iowa. The result is a sonic landscape based on the Earth’s songs.[10]

2. Pulsars - the Universe’s most Accurate Clocks
Pulsars are dense and highly magnetized rotating neutron stars that emit electromagnetic radiation (radio waves) from their poles. Their radiation can be observed when the emitting beam points toward the Earth like a lighthouse. The rotation periods of pulsars are very precise, ranging from milliseconds to seconds. The radio waves emitted by a pulsar can also be converted into sound waves. By listening to the sounds of individual pulsars, the different frequencies (pitches) indicate that the star has reached a different state during its evolution. Older pulsars ‘sound’ at lower frequencies, while younger pulsars ‘sound’ at higher frequencies. The pulsar sounds we used for the electronic music compositions

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[9] Travelling from Baroque to Jazz - If my Complaints, https://www.youtube.com/watch?v=oph5dOhbgOQ.

[10] Sonic Landscapes #1, https://vimeo.com/63457133 [accessed 19 September 2025].

were provided by the Jodrell Bank Centre for Astrophysics. The sonic landscape can be heard on Vimeo.[11]

The 'Music of the Spheres' as a prehistory of sonification

The concept that the Sun, Moon, and planets produce sounds as they move through space is generally attributed to the ancient Greek philosopher, astronomer, and mathematician Pythagoras and his students. These sounds produced by the celestial bodies correspond to certain musical intervals, and when they come together they create a celestial harmony. Using a monochord, Pythagoras is said to have determined the numerical ratios that correspond to musical intervals (octave, fifth, fourth, etc.), thus establishing the principles of music theory.

The rational for a 'music of the spheres' was developed by Archytas (428–347 BCE), a member of the Pythagorean School, as a physical problem, since the rotation of each celestial body corresponds to a certain rotational speed or frequency.[12] Thus, this music is the result of simultaneously sounding 'pitches' produced by the celestial bodies (five planets and the Sun and Moon) as they orbit the Earth (or Sun). However, the music is not audible, but only a mathematical concept. Nevertheless, according to legend, Pythagoras himself was able to hear this 'music of the spheres'.

Aristotle refers to this idea in his work *On the Heavens*, describing the Pythagorean model, but ultimately rejecting this theory.[13] In spite of this assessment, the idea of 'music of the spheres' or 'harmony of the spheres' has inspired philosophers, astronomers and artists since the sixth century BCE to the Renaissance, and was understood as a key concept that reveals the mathematical construction of the universe and its connection with music.

In the seventeenth century, Johannes Kepler (1571–1630) explored the concept of the 'music of the spheres' in his publication *Harmonices Mundi* (*Harmony of the Worlds*).[14] He proposed a mathematical and geometrical

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[11] https://vimeo.com/73878925.

[12] Carl Huffman, 'Archytas', *The Stanford Encyclopedia of Philosophy* (Spring 2025 Edition), ed. by Edward N. Zalta and Uri Nodelman. https://plato.stanford.edu/cgi-bin/encyclopedia/archinfo.cgi?entry=archytas

[13] Aristotle, *On the Heavens*, trans. W.K.C. Guthrie (Cambridge, MA, and London: Harvard University Press, 1921), 290b – 291a.

[14] Ioannis Keppleri, *Harmonices mundi libri V (The Five Books of Johannes Kepler) The Harmony of the World.* 1619. https://archive.org/details/ioanniskepplerih00kepl.

description of the cosmos and actually discovered physical harmonies in the motion of the planets. His calculations showed that the relationship between the maximum and minimum angular velocities of a planet in its orbit around the Sun is essentially a harmonic proportion. The echo of these ancient approaches continues to resonate in modern times. The Pythagorean idea of the ‘music of the spheres’ has been inspiring and still influences artists such as poets and composers. Below, for example, is a fragment of the masque Arcades written by John Milton and performed on 4 May 1634. The play was written to celebrate the character of Alice Spencer, the Dowager Countess of Derby. It refers to the myth of Er, who visited the underworld and heard the ‘harmony of the spheres’ as described in Plato’s Republic:

> But els in deep of night when drowsines
> Hath lockt up mortal sense, then listen I
> To the celestial Sirens harmony,
> That sit upon the nine enfolded Sphears
> And sing to those that hold the vital shears
> And turn the Adamantine spindle round,
> On which the fate of gods and men is wound.
> Such sweet compulsion doth in musick ly,
> To lull the daughters of Necessity,
> And keep unsteddy Nature to her law,
> And the low world in measur'd motion draw
> After the heavenly tune, which none can hear
> Of human mould with grosse unpurged ear.[15]

Also, contemporary composers still pay tribute to the ‘harmony of the spheres’ when they refer to celestial objects in their compositions, thus continuing the Pythagorean idea of making astronomy and music interactive. Amongst these compositions are Paul Hindemith’s *Die Harmonie der Welt*, John Cage’s *Atlas eclipticalis*, Karlheinz Stockhausen’s *Tierkreis – Sirius*, Iannis Xenakis’s *Pleiades*, Anestis

[15] John Milton, ‘Arcades. Part of an entertainment presented to the Countess Dowager of Darby at Harefield, by som Noble persons of her Family, who appear on the Scene in pastoral habit, moving toward the seat of State with this Song’, 1634, https://www.best-poems.net/john_milton/arcades.html. See Plato, *Republic*, 2 Vols., trans. Paul Shorey (Cambridge, MA, and London: Harvard University Press, 1935), 616E.

Logothetis's *Himmel Mechanic*, Philip Glass's *Orion, Einstein on the beach*, Vangelis Papathanasiou's *Mythodea*, and Tori Takemitsou's *Orion and Pleiades*.

Earth.

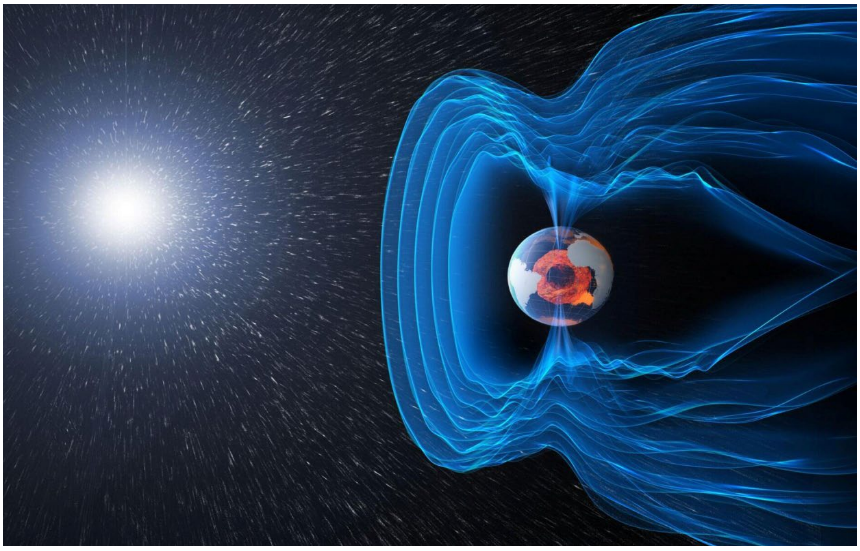

Fig. 1. Solar wind flows towards the Earth. The geomagnetic field lines (coloured in blue) define Earth's magnetosphere.

'Sounds of Space' - Selected Projects

Sonification techniques have been developed and used by scientists, educators, and science communicators in a wide range of scientific fields, including astronomy, space physics, chemistry, geology, seismology, astrophysics, cosmology, and solar physics. In astronomy, sonification methods have been used to acoustically describe our solar system, gravitational waves, solar storms, supernova explosions, or galaxy spectra.[16]

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[16] Michael, McGregor, and Benyon. 'Sonifying the Solar System'; C. Georgiou et al., 'Micropolyphony and Stochastic Compositional Techniques as Tools for the Sonification of Magnetic Storms'; J.W. Trayford et al., 'Ear to the Sky: astronomical sonification for accessible outreach, education and research with STRAUSS*,* pp.42–46.

The following examples report on the sonification of magnetic storms, resulting from my collaboration as a space physicist and researchers from the Department of Audio and Visual Arts of Ionion University in Corfu and the Music Department of the National and Kapodistrian University of Athens in Greece.

‘Hearing an Intense Magnetic Storm’

The strength of a magnetic storm is measured by the geomagnetic index, Dst, which is defined as the instantaneous worldwide average of the deviation of the horizontal component of the magnetic field in the equatorial region from a geomagnetically quiet level.[17] The instruments that measure the magnetic field deviations are called magnetometers. They are placed on the ground, forming a network around the globe. Magnetometers are also mounted on space missions to measure the geomagnetic field above the ground, as well as to measure the magnetic field of other planets.

The Kyoto Geomagnetic Data Center provides geomagnetic field data from a worldwide network of magnetic observatories to promote research and education in the fields of solar terrestrial physics and geomagnetism. For this work, the Dst index was provided by the above center.

Our goal was to sonify a geomagnetic storm that occurred in March 1989. This geomagnetic storm caused a nine-hour outage of the Quebec power transmission system in Canada. Significant power grid disturbances were reported, as well as communications blackouts and radio signal interference.

Fig. 2 visually describes the change in the Dst index, the horizontal component of the geomagnetic field, as measured on the ground. We can see that the magnetic storm lasted several days and that Dst reached very low values, which means that the geomagnetic field weakened during this event.

[17] National Centers for Environmental Information. ‘The Disturbance Storm Time Index’, https://www.ngdc.noaa.gov/geomag/indices/dst.html. [accessed 19 September 2025].

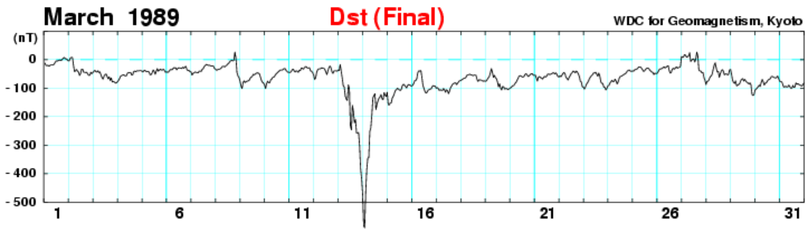

Fig. 2. The geomagnetic index Dst, defines the intensity of a magnetic storm. We see here the fluctuation of Dst index in March 1989, when an intense magnetic storm occurred.

A magnetic storm usually begins with a sudden drop in the north component of the geomagnetic field that lasts for a few hours. This is the initial phase of a magnetic storm. It is followed by a rapid decrease in Dst, called the main storm phase, which lasts about a day. Dst initiates a rapid recovery, although the total recovery phase may last several days. The above phases of the March 1989 magnetic storm are shown in Fig. 2. But instead of studying the plot visually, can we also hear the magnetic storm? By selecting data from the Kyoto Geomagnetic Data Center, we sonified the geomagnetic field disturbance for the entire month of March 1989. The data were played at such a speed that each hourly value of Dst resulted in 1 second of sound. An installation was created that allowed the user to navigate through the whole month within 12 minutes of sound.[18] The interactive audio installation was presented at the Athens Science Festival in 2016. The sound design and programming was done by Emmanouel Rovithis, postdoctoral researcher at the Department of Audio & Visual Arts of Ionion University. You can listen to the magnetic storm here: https://sonicmanos.com/index.php?id=magneticstorminstallation.

‘Sonification of ENIGMA data’

The National Observatory of Athens operates an array of 3 ground-based magnetometer stations located in Greece; the HellENIc GeoMagnetic Array (ENIGMA). The array provides measurements for the study of geomagnetic activity resulting from the solar wind-magnetosphere coupling. ENIGMA is the first magnetometer array ever operated in Greece, which also contributes to a worldwide collaboration of

[18] E. Rovithis, F.-A Metallinou, and A. Floros, ‘Hearing a magnetic storm: an Educational Interactive Audio Environment’, in the 8th PanHellenic Conference of Acoustics 2016, 3-4 October 2016, Athens.

organizations and national agencies operating more than 300 ground-based magnetometers, the SuperMAG. The purpose of SuperMAG is to provide scientists, teachers, students and the general public with easy access to measurements of the Earth’s magnetic field.

Using ENIGMA data from 12–15 October 2016, when a moderate magnetic storm occurred, Vasileios Agiomyrgianakis, a postdoctoral researcher at the Department of Audio & Visual Arts of Ionion University, sonified the magnetic field data. While listening to the produced sound, an artistic visual product described the magnetospheric activity. The audio and visual product, inspired by the October 2016 magnetic storm, is now used by the ENIGMA website for public outreach.[19] You can watch and listen to the video on YouTube.[20]

During COSPAR 2022, the 44th Scientific Assembly held in Athens, a session titled ‘Dialogues between Space Science and Art’ was organized to bring together scientists and artists to present their work related to science-art projects.[21] Space scientists, musicologists and artists participated in the session. Original works on sonification of space science data were presented during the session.[22]

A prototype project realized by two postdoctoral researchers from the Department of Audio & Visual Arts of Ionion University, Martin Carlé and Vasileios Agiomyrgianakis, was the sonification of the magnetic storm that coincided with the launch of 49 Starlink satellites by SpaceX on 3 February 2022. This event led to the loss of most of the satellites launched, with significant technical and economic consequences. The audio piece produced in this work employs data sonification methods programmed in SuperCollider to retrace the solar wind events that caused the loss of the satellites. Data were used from the ESA Space Weather Portal, NASA, the European Swarm cluster and the worldwide INTERMAGNET network of ground-based magnetometers.

[19] HellENIc GeoMagneic Array, *The Earth’s Magnetic Field*, http://enigma.space.noa.gr/ [accessed 19 September 2025].
[20] Fiori Metallinou, ‘Sounds of a Magnetic Storm’, https://www.youtube.com/watch?v=yQB8XNPkL2k.
[21] COSPAR 2022, https://www.cosparathens2022.org/.
[22] https://app.cospar-assembly.org/2024/browser/session/1059.

Benefits – What we gain from sonification

1. Scientific research

Today, researchers of all kinds need to explore more information than ever before. Astronomers use a variety of ground-based and space-based telescopes sensitive to different parts of the electromagnetic spectrum to study objects in near-Earth and deep space. Detectors at different wavelengths equip space missions and send large amounts of data back to Earth for astronomers to process. Recognizing the power of the auditory sense, researchers have developed new tools for pattern recognition and data analysis.[23] The number of sonification projects in astronomy has increased rapidly in the last decades.[24] Sonification is gradually proving to be a useful tool for scientific research.

2. STEAM education

Scientific information revealed by sonification can be used for educational purposes; science can be presented in a more attractive way that would increase the effectiveness of learning. Collaboration between astronomers, musicologists, computer scientists, composers, and artists is needed to develop innovative visual and aural tools for STEAM (Science, Technology, Engineering, Arts, and Mathematics) education. Teachers should be trained in sonification methods to introduce their students to the perception of astronomical phenomena through sound.

The interdisciplinary teaching astronomy through physics, mathematics, music, poetry and philosophy offers students multiple stimuli, forming a broader perception of our cosmos.

3. Educating the visually impaired

Visually impaired students in particular need special tools to understand science. The ear is excellent at perceiving time-based information such as rhythm and pitch. It is also able to detect rapid or transient changes better than the eye. Humans are also accustomed to perceiving multiple sounds

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[23] G. Kramer, 'An introduction to Auditory Display' in G. Kramer, ed., *Auditory Display, Sonification, Audification and Auditory Interfaces* (Reading, MA: Addison-Wesley, 1994).

[24] A. Zanella C. M. Harrison, S. Lenzi, J. Cooke, P. Damsma and S.W. Fleming 'Sonification and sound design for astronomy research, education and public engagement', *Nature Astronomy* 6 (November 2022): pp.1241–48.

simultaneously. In addition, we have the ability to filter signals from noise, and to localize sound.[25] The above advantages of the auditory sense make sound a useful and effective tool in the education of the visually impaired. It has also been shown that students with dyslexia or autism can benefit from alternative learning modalities. [26]

4. Science dissemination

The interdisciplinary approach can also be applied to the public understanding of science. Innovative curricula, educational programs, video games, science museum and planetarium programs are being developed using data sonification. Science communicators have the advantage of engaging a broader audience while using alternative methods of communicating astronomy, such as sound.

5. Artistic performance

Electronic music composers, sound designers and performers uses sonification products and are inspired by astronomy in their performances as described in this paper.

[25] Paul Lunn and Andrew J. Hunt. ‘Listening to the Invisible: Sonification as a Tool for Astronomical Discovery’, University of Huddersfield, UK, March 2011
[26] David H. Rose and Anne Meyer, *Teaching Every Student in the Digital Age: Universal Design for Learning Association for Supervision and Curriculum Development.* Springer, Volume 55 (2007), pp.521–25.