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Geoscience Communication
Discussions

# ElectroMagnetic Music: a new tool for attracting people interest in Geosciences, while sensitizing them to planet sustainability

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**Abstract.** EMusic stands for ElectroMagnetic Music and it is a scientific-musical project born in Italy. The idea is to transform the voltage response collected by Transient ElectroMagnetic Method (TEM), a well-known geophysical tool for exploring the subsurface, into musical pitches. This novel approach enables to extract musical pieces, reflecting the effective geological setting, so that we can claim that any site can be represented by its own soundtrack (i.e. the "soundscape," the audio component of a landscape). As a consequence, it is possible to compose musical tracks describing faithfully the risk and many other geological issues related to different environmental scenarios.

Since the beginning, a band of musicians experimented the EMusic giving concerts all over the world covering different geological locations. The sound representing each scenario was recovered in situ with the above-mentioned methodology. Some excerpts of the concerts have been also reproduced in a couple of occasions during the EGU General Assembly. Other experiments involved EMusic as a soundscape for enhancement of archaeological (Ancient Roman Theater of Ferento) and geo-touristic sites (Viterbo Underground and Vesuvius Volcano). The events were the occasion for sensitizing people about Volcanism, Volcanic risk, Paleontology, Climatic changes, Earthquakes and so on. During the concerts geoscientists introduce every track, by preparing the audience about what they are going to listen. The audience can experience a journey into the Earth by riding the eddy currents produced by the EM field. Not only it is a travel in space, but also in time, as we explore through EMusic older and older geological formations. The various musical-scientific performances - based on the sonification of EM data collected in different parts of the World including Italy – obtained positive feedbacks from the audience that enjoyed the shows.

We are also implementing a project, named Georisonanze, to bring the EMusic in secondary schools to introduce students to the investigation of Earth with modern techniques while sensitizing them to planet sustainability. For the first time, we preview to pass to an evaluation phase, to better understand its intrinsic potential, through targeted tools.

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## 1 Introduction

Music is powerful in sensitizing people, thanks to its capacity to involve everybody, without barriers of language, culture and religion. Most recently, sonification of scientific data is becoming more and more popular, obtaining great visibility in the media. Just to mention the more recent approaches, we enumerate sonification of gravitational waves (Hughes, 2016), planet orbits (Quinton and Benyon, 2016), global temperature variations (Hilgren, 2019), seismic noise (Avanzo et al., 2010), earthquakes (Michael, 2013) and geophysical data (Dell'Aversana et al., 2016). The EMusic (ElectroMagnetic Music) in this trend is certainly the first one utilizing the EM response of the Earth, being the first case of sonification strictly related with the geological structure of the subsurface. The source of the sonification (a voltage) depends upon the electrical behavior of the rocks (i.e. the resistivity). Following this assumption, the basic principles were codified by Menghini and Pontani (2016) Thus, it is not out of place to claim that we can extract the effective "Sound of the Earth". Similar to other sonification process, we adopt a mathematical rule that allows us to translate the geophysical data into audible frequencies. It would be therefore more correct to say that we can produce pitches, rather than sounds. The musical notes can be played by any kind of instrument, also by a human voice. The involvement of the musicians is direct, as they have to arrange an improvisation or a composition, by using these pitches provided by the Earth: the EMusic data are the bricks that will be used to build any musical performance (some examples have been reported by Menghini, 2016, 2018 and Duncombe, 2019). This allows to achieve an effective connection between Art (Music) and Science (Geology), in a way that can be easily understood by common people. Finally, Geoscientists can be considered in all respect as composers, or rather as the medium between the Earth and the performers, also by providing some keywords on the history of the geological site inspiring the musicians.

The project obtained great interest by both the scientific and the musical community: EMusic was invited twice by EGU to play at the Assembly in Wien (2017 and 2018), where we gave also an oral and poster presentations, and also at the Science-Art Session at the last AGU Fall Meeting; Geoscience Australia invited us to play in Canberra and Perth; AGU Centennial Grant awarded us with a 5 hours sound installation based on Airborne EM data collected in Colorado Mountains; we played on the top of Vesuvius Volcano and at the INGV (Istituto Nazionale di Geofisica e Vulcanologia) Open Day; we carried out a tour of 7 stages "Sounds from the Geology of Italy", based on the sonification of EM data collected in some of the most beautiful natural and cultural sites, involving famous international jazzists, like Enrico Rava and Francesco Cafiso.

This paper describes in detail the method of sonification and refers on the events performed in collaboration with INGV. We describe also the potentialities of the methods from a science communication perspective, even we never conducted a survey to test the efficaciousness of the methods. Nevertheless, we preview in a near future to experiment the method in schools to have the opportunity to conduct a survey for investigating the efficaciousness of the method (we are implementing a project named Georisonanze).

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## 2 The data sonification

The Transient EM method (TEM) is a well-known geophysical technique that is used, since the 50s, by the geo-scientists to detect mining and groundwater resources (add at least one or two references). For an in-depth discussion and presentation of the TEM method you can refer to Nabighian and Macnae (1991). The EM response of the Earth, that is the base for the sonification, is produced by the fast decay of eddy currents penetrating into the subsurface, with a velocity that depends on the resistivity of the medium (it is faster for high resistive rocks and vice versa). These currents are induced into the subsurface due to a rapid change in the magnetic flux produced by a quick turn-off of a current pulsed into a wire loop in the ground (Figure 1). The "listening time", that we use to sonify the Earth response, regards the period in which the system is off and no currents are flowing into the wire (off-time).

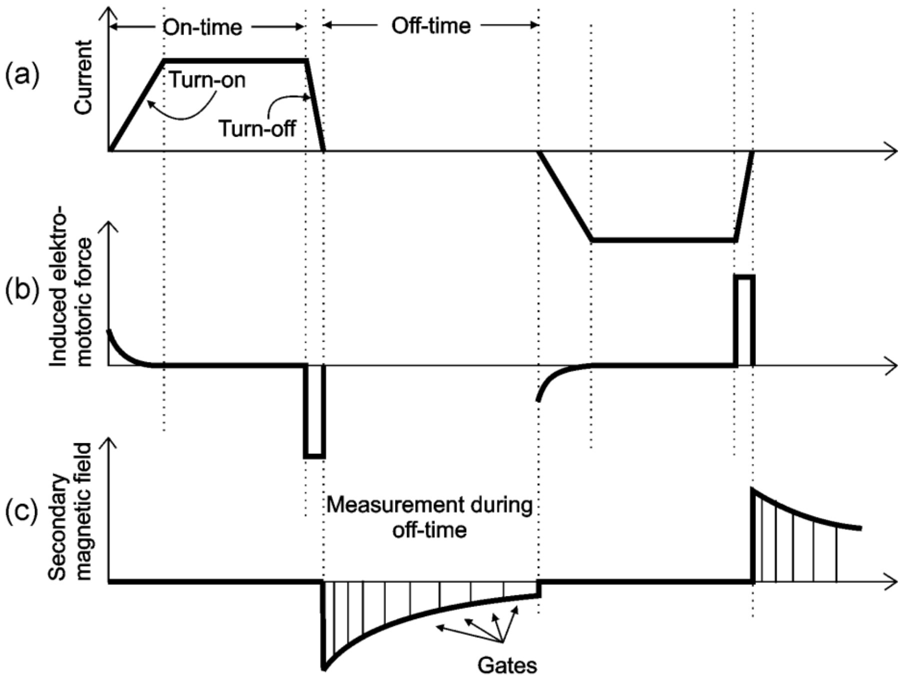


**Figure 1: Current injected in the transmitter loop (a). The induced electro-motoric force in the ground (b). The secondary magnetic field measured in the receiver coil (c). The "listening time" is during the off-time. (from Christiansen et al., 2006).**

Our "ear" is a receiver coil (Figure 2) that records the rate of change of the magnetic field produced by the decay of the eddy currents, in the form of voltage values (transient).

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**Figure 2: The receiver coil that records the Earth EM response.**

The sampling of this response is achieved by means of a series of gates having different widths, which increase with time as the signal becomes weaker and weaker going into depth. Since the voltage response for each time gate is assigned to its centre, it follows that the data are spaced so that they become more and more distant from each other.

Figure 3 shows a typical transient (i.e. the voltage response of the Earth) with the gates figured by using a linear scale for the time. As the transient works out within a few milliseconds, we adopted a time expansion that can be chosen depending on how long we want to arrange the composition (usually we use values between 100,000 and 1 million). Otherwise our ear would hear a single chord formed by all the gates/pitches. Indeed, in the so-called "Flight Mode" we used this approach, as we have to handle several soundings collected during an Airborne EM survey: in this particular kind of prospection, the data are acquired during a flight, so that huge amount of soundings can be sonified. An example was presented at the EGU 2017 Assembly (Menghini and Pontani, 2017) where a flight mode composition was arranged by using AEM data collected over Sierra Leone.

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On the contrary, due to the large dynamic range, the voltages are shown in log scale. Figure 3 refers to an Airborne TEM sounding collected over Selinunte temple, in Sicily and it was the first track of the concert we performed at EGU Assembly in 2018. For each gate we reported the corresponding pitches that were used by the musicians to improvise.

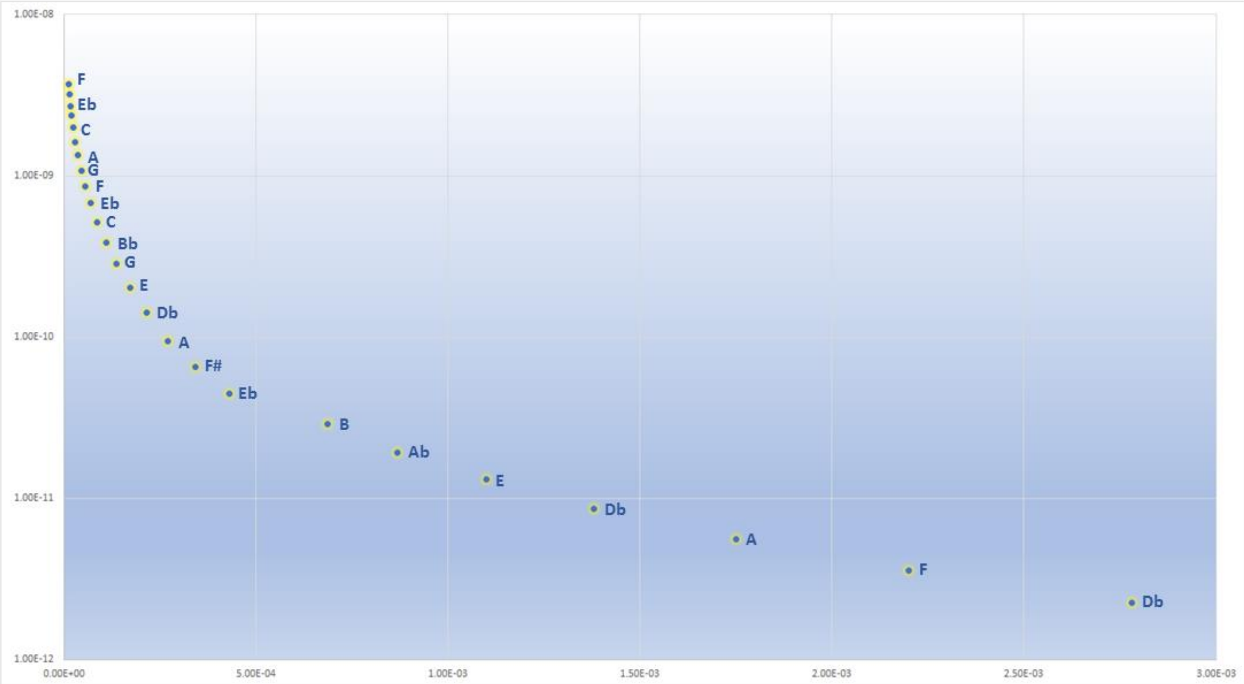


**Figure 3: Sonified transient of a TEM sounding collected over Selinunte temple, Sicily.**

In order to make comparable sonified transients, we prefer to use the same range of voltage, i.e. fixed values for minimum and maximum response: this device allows to compare different geological scenario and different EM systems in an objective way. This approach can be similar to the choice of the edges of a colour scale to figure results.

Of course, this means that we cannot exploit the full frequency range for any sounding: in the case of a highly conductive situation, we could stay within a narrow sequence of high tones, while, for very resistive environment, we could get only low tones separated by wide intervals. It follows that anyone can immediately understand in which geological scenario we are, simply by hearing the EMusic outcome.

We can recognize 4 typical features of a “pure” EMusic composition (soundscape):

1) The pitch is directly proportional to the voltage response: the notes produced by a conductive formation, that produces a stronger response (e.g. clays or shales) are higher than those ones extracted from a resistive rock (e.g. limestones or granites)
2) The pitches must become lower and lower, as the voltage response become weaker and weaker

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3) The interval between two near pitches is linked to the resistivity of the material: it will be smaller (chromatism) in the case of conductive formation, due to the slower decay, while it will be wider for resistive rocks, where the eddy currents travel faster
4) The execution time is dictated by the technical specifications of the geophysical instrument, hence the first pitches will be closer and they become ever more distant during the performance.

How the musicians will work with the soundscapes obtained in this way? They can choose different modalities. One is to reverse the pure EMusic track. Starting from the deeper and late gates/pitches the musicians have the possibility to be tuned in with the earth pitches during the return trip to the surface. As the saxophonist Marco Guidolotti played during this reversed part of Selinunte piece, the relative score has the form shown in Figure 4. The musician chose to fix some chords that can be assigned by grouping the pitches by four. The whole piece can be listened in YouTube (https://www.youtube.com/watch?v=qsTlMZsGoBE&feature=youtu.be), with the first half composed by using "pure" sonified data, and the second one with the interplay of the saxophonist.

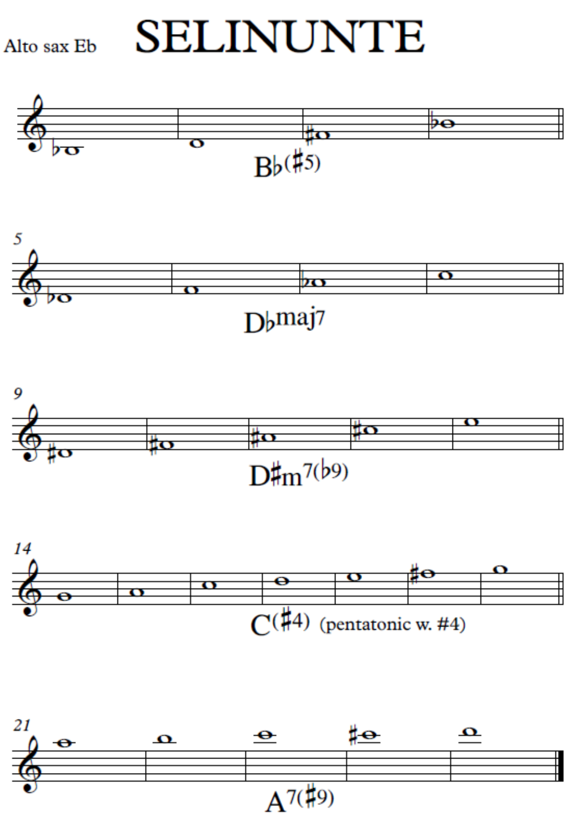


**Figure 4: Score of the Selinunte composition.**

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Another modality is to group the pitches according the different layers crossed by the EM signal. The musicians can use it to compose original pieces or to address the improvisation into more restricted musical scale/chords.

## 3 The EGU experiences

At the EGU Assembly held in 2017 and 2018 we had the opportunity to present two distinct shows, named "Sounds from the World" and "Sounds from the Geology of Italy" (Figure 5) The former was based on data collected in Russia (Siberia), Sierra Leone (Nimini), Canada (British Columbia) and Italy (Castelluccio Plain), while the second used data coming from Sicily (Selinunte), Campania (Phlegrean Fields), Umbria (Castellucccio Plain) and Veneto (Venice). An excerpt is available on https://www.youtube.com/watch?v=qplHWpKPFr4&feature=youtu.be

In each occasion it was possible to explain the geological features and evolution of each sites, talking also about seismic and volcanic risk, ice ages, ore-bodies origin (diamonds and gold) and global warming.


**Figure 5: A moment of the "Sounds from the Geology of Italy" show at EGU2018.**

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Besides the "artistic" performances we gave also oral and poster presentations, reporting experiences in collaboration with INGV, responsible for the TEM ground-based data acquisition. One of the posters launched the Mutenage Project, illustrating five specific global environmental emergencies: pollution of aquifers, seawater intrusion along the coastlines, seismic risk, drought and permafrost melting. For each of these, the TEM method can be an excellent diagnostic tool, as the voltage response is greatly affected. Since well-defined musical "footprints" are associated to the geophysical variations, through the sonification process, we believe that the impact of climatic-environmental changes are easily understandable to common people and students of every age and grade. One clear example is provided by the effect of seawater intrusion, that is well marked by the progressive increase of the voltage and hence of the pitches, when approaching the coastline. Hence, we also expect that the EMusic can be a powerful didactic tool, besides being a new source of inspiration for musicians.

During EGU2018 Assembly we presented a PICO poster ("Diatomites sound like a B13 chord"), showing an excerpt of an EM concert in the Ancient Roman Theater of Ferento, Central Italy (https://www.youtube.com/watch?v=IaQLhoEQi84&feature=youtu.be).

It was the occasion for discussing the active role of geoscientists, in charge of introducing every track for preparing the audience about what they are going to listen. In this particular case, the audience experienced an original journey into the Earth travelling into older and older geological formations. The first composition allowed us to explain how the TEM method works, going into technical details of the instrumentation in plain language. We introduced the audience on how geophysicists can model the subsurface, by comparing the decay rate of the transient with the interval among pitches. During the second composition the musicians began to interplay with the pitches provided by the Earth: we reversed the first track, so that people listened to the return, from the maximum exploration depth (in this case about 100 m) to the surface. The saxophonist and the guitarist were able to improvise over the EMusic base, by using the same pitches, in a sort of natural jam session, where the Earth is the band leader. Then, we analysed each geological formation, by showing the musical mood provided by the relative pitches.

## 4 The Concerto Vesuviano

On 21st September 2019 we were at the Vesuvius National Park performing the "Concerto Vesuviano", in collaboration with the Association of Geologists of Campania. Visitors assisted the TEM data collecting (Figure 6), being able to experience the geophysical equipment at work.

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**Figure 6: TEM data acquisition at the top of Vesuvius Volcano.**

The EM response was sonified on-site and the pitches were immediately transferred to the musicians (the Marco Guidolotti Quartet and the EMusic artistic director Stefano Pontani) to prepare the concert. As the subsurface was formed by very resistive rocks (lava and scoriae of the last activity in 1944) the signal was weak, so that it fell very quickly into the background noise. Moreover, due to the high resistivity, the pitches were low. We extracted only 6 useful gates and this outcome greatly limited the possibility to arrange a full concert of more than 1 hour. We involved the audience in the contingencies of the case, having also the opportunity to discuss with people the limits of Science. Scientists can get unexpected results, not always positive. Being aware of this risk, we had already thought to use a second TEM sounding collected over a more favourable situation: in fact, this test was carried out in a quarry where we had the opportunity to characterize the historical pyroclastic flow responsible of the destruction of Pompei, until the older layers of the Somma volcano that preceded the Vesuvius building. Thus, we were able to split the transient into 3 different pieces. The full concert is available on YouTube, starting at about minute 40 (https://www.youtube.com/watch?v=Xh_tY22E1_A&feature=youtu.be&fbclid=IwAR0bqdEHslm1pD-Up8z_uiMQ7dxvODISckwlDhZOe4slWIwyvMIZ7JGaU_I)

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## 5 INGV Open Day

On 29th September we proposed the EMusic Project at the INGV Open Day, in Rome (Figure 7). It was a rare opportunity to involve families and people of different educational background, by playing 3 different EMusic pieces inspired by 3 topics welcomed by the media: seismic risk, volcanic risk and environmental pollution. The EMusic band, formed by Marco Guidolotti on sax, Stefano Pontani on guitar and Riccardo Marini on electronics, twitted with INGV researchers presenting on the subjects. Musical compositions were based on EM data collected in Castelluccio Plain (close to the Mt. Vettore fault that triggered the last seismic sequence in Central Italy), Australia (in an area affected by seawater intrusion) and Vulsini area, Northern Latium (where the Pleistocene volcanism built huge structures, like the largest volcanic lake in Europe). The show was greatly appreciated by the audience.

**Figure 7: INGV Open Day in Rome.**

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**6 Feedback**

Since we have never conducted a survey, for the moment we can only suppose that the EMusic have great potentialities for raising interest of people on Earth sciences studies, while sensitizing them to planet sustainability. Our supposition is based on the people's mood we perceived during our several experiences around the world. Eventually, EMusic can stimulate people to get interested even on the functioning of sophisticated equipments and the physics beyond a complex method like TEM. At the same time, EMusic can stimulate people's curiosity on how rocks are characterized by different physical parameter (in this case resistivity) and how geoscientists exploit this feature to explore the subsurface.

The presence of musicians can stimulate people to study in deep the relationship between frequency and musical notes, the use of the tempered scale (in theory we could assign to any pitches the effective frequency, i.e. microtones, and not the closest one listed in the twelve-tone scale commonly used in Western Music, since Bach's time), how a series of pitches can suggest a mood reflecting a specific formation, how the musicians face the improvisation rules.

Since we are convinced of the potentialities of the method from a science communication perspective, we expect to bring soon EMusic in secondary schools. At present we are implementing the "Georisonanze" Project. In this way, we hope to encourage students of scientific institutes to approach Music and students of musical-artistic schools to understand the utility of STEM subjects.

Up to now we had the possibility to approach people during a concert, giving geoscientists the possibility to confront themselves with common people. As we have already remarked, we hope to have stimulated the audience to learn about the geological evolution of the site from where the EM data were acquired thanks to the introduction provided by geoscientists. We hope also to have sensitized people to planet sustainability through a fantastic voyage into the Earth, both in space (depth) and in time (past geological periods), talking about climatic changes, paleontology, extincted animals, volcanic and seismic risk, rocks' formation, paleogeographic reconstructions, etc.

Certainly, we have attracted media interest. As an example, with respect to the Concerto Vesuviano, we can list a whole page on one of the most popular Italian newspaper, La Repubblica (Fig. 8), a video from the same newspaper (https://www.youtube.com/watch?v=WlrcSqxeE0k), an article on its scientific supplement. Last but not least, the event was subject of a question of a popular TV quiz broadcasted by the National broadcast RAI 1 channel.

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la Repubblica Domenica, 22 settembre 2019 pagina 15

Rep

Napoli *Società*

Un gruppo di geologi e un esperimento: un'apparecchiatura "cattura" le vibrazioni sul cratere e le trasforma in suoni. Allo show duecento spettatori (e il sindaco)

Quota Mille Un'immagine del Vesuvio alla Quota Mille (foto Stefano Renna)

*L'iniziativa*

La musica del Vesuvio i "rumori" del vulcano sono un concerto jazz

di Stella Cervasio

Il pubblico
Al "concerto" del Vesuvio hanno assistito duecento persone, fra le quali Luigi de Magistris (in primo piano). A destra, l'apparecchiatura

*Il San Carlo*

La "Traviata" dei giovani: tradizione senza scossoni

di Sandro Compagnone

Regista Lorenzo Amato

**Figure 8: A full page of La Repubblica newspaper dedicated to the Concerto Vesuviano.**

## 7 Conclusions

The EMusic Project through worldwide performance has already showed great potentialities in raising people's interest on Geology, Geophysics and Music in an enjoyable way. Encouraging feedbacks come from the direct contact with the audience during the several performances that already took place and from the media. We have several reasons to suppose that the method is a useful tool to sensitize people to Geoscience topics, spanning from natural risks (seismic, volcanic and geomorphological) to climatic changes, from pollution issues to landscape evolution. Music is certainly a unique medium to raise awareness of the most urgent topics that threaten Earth. Coupling music with geosciences can at the same time emphasize the central role of STEM matters in our society encouraging people to appreciate the use of Maths and Physics in an artistic context.

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