Maria Mannone
University of Minnesota
School of Music
Minneapolis, USA

UDC 78.01
doi:10.5937/ZbAkUm1705110M

Kyriaki Gkoudina
University of Minnesota
School of Music
Minneapolis, USA

Evan Tyler
Minnesota Institute for Astrophysics
Minneapolis, USA

Narrating the Origin of the Universe through Music: A Case Study

Abstract: Our project is about the synthesis of a musical piece, based on the timeline of the Universe. We can understand music through visual and gestural analogies. In a similar way, popular descriptions of scientific concepts also use external metaphors and visual support to help comprehension.
We will use music to describe a topic from astrophysics, the birth and evolution of the Universe. We describe the compositional technique used to create the composition "Origin," referring to recent techniques to derive music from tridimensional images and from gestures, under the light of the mathematical theory of music in the context of a narrative.
Keywords: Astrophysics, Music, Composition, Narrative, Gestures

Introduction

Simple but effective explanations in terms of visual analogies, animations, and simplified descriptions are powerful tools to explain scientific topics, especially in Astrophysics and in Theoretical Physics. The creation of analogies with daily experience helps the comprehension of abstract or very technical concepts. Such a metaphor is useful for people who are not able to unfold the content of an equation and also better methods of communicating the main concepts of their disciplines. Moreover, since it is "abstract" and not directly related to the description of physical objects or situations, music is very suitable to make interdisciplinary descriptions of real-life phenomena, and music composition is very flexible to combine and extend new styles and techniques.

In contrast, non-musicians may require some extra-musical references such as narrative or visual representations to better understand abstract music-theoretical concepts and to gain new perspectives on the musical artwork. These may already be present in the declared intent of the composer, as in the case of program music. Otherwise, they can be envisaged in titles, historical references, composers' biographies, artistic currents, as well as in personal backgrounds and listening experiences of the public.

Another option is to sonify extra-musical material. For example, we can use a long continuous tone to indicate a straight line. In this case, there is not a relation of analogy, but a direct mapping of data from a non-sound to a sound domain (Adhitya, 2012; Cage, 1950; Dubus, 2013; Mannone, 2011; Xenakis, 1971). Of course, such a mapping is more effective when a condition of *similarity* (Mannone, 2016) between certain characteristics of the starting set of data, and certain characteristics of the derived sounds is verified (or *music*, if the aesthetic intent is clear). Some of these new techniques are based on mathematical theory of music, especially regarding musical gestures in performance (Mannone & Mazzola, 2015). Correspondences between visual shapes, space movements and pitch and loudness variations are the topic of an intense research between neuroscience and psychoacoustics (beim Graben, 2009; Gentilucci & Bernardis, 2006; Nobile, 2013; Uznadze, 1924) in the main field of the crossmodal correspondences (Spence, 2011).

We will highlight a method or "bridge" of connection between the popular description of a scientific topic and music. The "bridge" is given via the sonification of tridimensional images (Mannone, 2011) reviewed under the light of mathematical theory of musical gestures (Mazzola & Andreatta, 2007). In a nutshell, we can see both a drawing and a musical performance as the result of specific gestures, that can be compared and whose analogies can be studied (Mannone, 2016). We will apply this method to a narrative of the birth and evolution of the Universe, ending with the emergence of human civilization, and focusing on a common origin for all beings. The resulting score will be performed by a full orchestra and will consist of three movements to describe the narrative.

Topic and Main Techniques Used

To describe such a huge topic as the origin of the Universe, it is necessary to make some choices regarding the elements to be sonified, and how to connect them to make a meaningful narration. The intended scope of this work is vast, beginning with the first fractions of seconds after the Big Bang and ending with the lives of our own species on the Earth. The project was first conceptualized by Kyriaki (Kakia) Gkoudina, musically realized in collaboration with Maria Mannone, and helped by the astrophysical advising of Evan Tyler. It is meant to highlight not only the complexity and the fascination of the history of our Universe, but also to emphasize mutual respect among humans, and between humans, environment, and all other living beings, given our common origin and coexistence in the same home.

These topics will be musically rendered using a sonification model under the name of Tridimensional Music in Mannone (2011) with the added condition of *gestural similarity* (Mannone, 2016). The main idea is that a tridimensional shape can be 1. sonified via mapping into a space Loudness-Time-Pitch, and 2. a 3-dimensional shape can be seen as the result of a drawing gesture in the 3-dimensional space. Intuitively, it is similar to describing the shape of an object in the room with the movement of your hand or just your index finger. Continuous lines, points, variations of speed and pressure can be both generators of visuals and of musical parameters (Mannone, 2016, 2017). Pressure and direction of paint brushes in analogy with pressure and direction of strings' bows have already been used to create a score (Saariaho, 1987). When the conversion of music to image and image to music is effective, both sounds and visuals will share some characteristics and can be described as similar. We define two musical gestures as similar if one can be homotopically transformed into the other, and if the spectra of their respective final results (in sound) have strong similarities. For example, a staccato articulation for both piano and percussion has a similar spectrogram and has the same gestural origin which is distinct from the legato articulation. Of course, two gestures can be similar in articulation but different in loudness, and vice versa. This definition can be easily extended to visual art; stippling a canvas is similar to the piano or violin gesture to make a staccato. A singer also makes a similar gesture when singing staccato, with quick movements of the diaphragm. A powerful instrument to investigate and compare gestures is given by homotopy (Antoniadis & Bevilacqua, 2016; Visi & Miranda, 2014).

Recent developments of gestural similarity as a fundamental part of human perception are supported by studies in psychology and psychophysics under the name of crossmodal correspondences (Spence, 2011; Gentilucci & Bernardis, 2006). A good example is the correspondence between higher frequencies and higher points in the tridimensional space, as well as the movement toward high pitches and the movement upward in space.

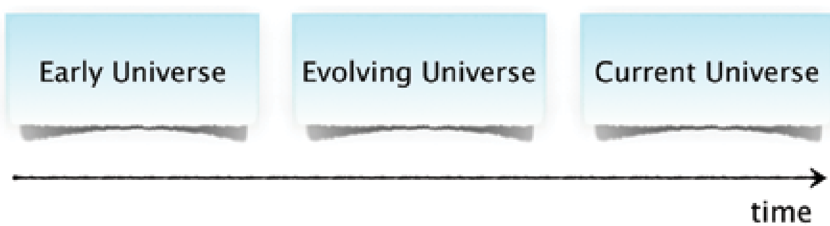
Using these methods, our challenge is to transform the narrative of the birth and evolution of the Universe into music. We need the musical rendering not only of isolated objects but also of a narrative, like building a movie and a story from a collection of pictures. Recent studies (Coegnarts & Kravanja, 2015; Gkoudina, 2015) provide more details about the narrative technique and embodied cognition used in movies. We use analogies and gestural similarities between music and images to represent mathematical and physical concepts, jointly with physical metaphors. A powerful mathematical tool is given by category theory (MacLane, 1971), whose system of points and connecting arrows, verifying certain properties, has a great potential of applications (Spivak, 1978) both to the diagrammatic and the philosophical thinking (Alunni, 2004).

Moreover, physical movements can be used to give intuitive ideas of other physical concepts. For example, the orbit of a planet is described by an equation, but the gesture we would automatically make to give an idea of such an orbit is an elliptical movement of a hand in the space. A simple musical rendition -- a sonification -- of such a gesture in tridimensional space (plus time) can be made with a sound that is progressively varying in loudness and pitch. This simulates the Doppler effect on a moving sound source (Mannone, 2017). It is like drawing in the space: we need to follow an imaginary path with our pencil. The spherical shape of a planet can also be described via a set of melodies going in several directions and returning to the same point, representing the path along the equator and over the poles. In general, more complex shapes can be decomposed into systems of lines, and then recomposed into music. Also representative shapes, such as the rays of a Feynman diagram (see Section 3 for more technical details), can be translated into music via analogous strategies. In Section 3 we will discuss some examples of their musical rendering.

The piece "Origin" is structured upon the actual timeline of the Universe, from the point of singularity until the present state of the universe. The general structure refers to the three stages of the evolution of the universe and is illustrated in Figure 1:

- The early universe: beginning from the point of singularity, the movement will follow the interaction of particles until the era of recombination and the release of photons from the matter.
- The evolving universe: beginning with the "Dark Ages," the movement will depict the effects of gravity, the formation of stars, galaxies and planets, and the reionization of the universe.
- The current universe: set in present age, the movement will include references to the variety of natural and human experiences to emphasize the idea of common origin of all humanity and living beings.

Figure 1



To describe our narrative musically, we will translate many physical processes that have occurred from the Big Bang to present day into music. Because of the level of abstraction required to understand many events at the early universe, creativity and innovation are essential to render the abstractions into music. Below, we will discuss several representative examples of this translation technique. We will discuss here a possible mapping for the Cosmic Microwave Background (CMB), the expansion of the universe, and the process of neutron beta decay.

The Cosmic Microwave Background (Dicke et al. 1965; Penzias & Wilson, 1965) is a uniform, omnidirectional background of electromagnetic radiation left as a "relic" of the properties of the very early universe. These CMB photons were released during the recombination era a few hundred thousand years after the Big Bang. Before this time, the universe was hot enough for all matter in the universe to ionize, effectively trapping photons within the opaque material and resulting in a uniform temperature. However, once the universe cooled below the ionization temperature, electrons and protons combined to form atoms. In an instant, the universe became transparent to the uniform-temperature radiation within it, resulting in a sudden release of photons into space. These uniform photons, after adjusting their wavelength for redshift due to universe expansion, are now only 2.7 K in temperature (corresponding to a wavelength around 1 mm). We can musically render the modern-day CMB with a low, continuous sound to represent the low temperature and uniformity of the radiation. To enforce the idea of coldness, instead of a single sound we can use an interval of fifth, harmonically characterized by a sense of "emptiness," and already used by composers to represent the cold, as in Puccini's La Bohème.

The universe has been expanding since its origin (Hubble, 1936). The rate of expansion, however, has not been uniform. From the very first faster-than-light expansion of the inflationary period, the universe slowed to a more modest rate of decelerating expansion until around 5 billion years ago when, it is theorized, it entered its dark energy dominated phase and began to accelerate again. The expansion of the universe could be portrayed with a simple pattern of melodic cells and chords, played by two celli, being gradually "amplified'' by the entire string section. Adding instruments will create a feeling of increased loudness (crescendo). This orchestration effect gives the idea of an expanding space to the listener. It is a simple and intuitive way to musically render this idea: there is not only one way of creating the sense of an expanding space.

Finally, we will describe a method of musically interpreting beta decay of neutrons into protons. This decay process during the very early universe is of crucial importance to the chemical and matter composition of our modern universe today. Unbound neutrons, such as those produced very shortly after the Big Bang, are unstable and will tend to decay into protons within minutes. Had this decay continued indefinitely, our universe would have almost no neutrons. However, around 3 minutes after the Big Bang, nucleosynthesis began, binding protons and the remaining neutrons into stable helium nuclei with trace amounts of deuterium and lithium, resulting in an early universe that contained around 25% of helium and 75% hydrogen by mass.

Beta decay is mediated by a high-mass W^- boson (Rubbia, 1985) and produces a proton, an electron, and electron antineutrino. This process is often visualized in a characteristic Feynman diagram, shown in Figure 2. This diagram helps in understanding the behavior of subatomic particles, and easily reconstructs the complex equations that describe their colliding processes (Bilenki, 2013). On the bottom left, we begin with a neutron. This neutron releases a W^- boson, converting it into a proton. The boson has a finite but very short lifetime, after which it produces an electron and an electron antineutrino (the antiparticle is represented with an arrow pointing backwards in time). Each of the particles involved in this interaction have very distinct properties. Neutrons and protons are almost equivalent in mass, with neutrons being only slightly heavier. The W^- boson, in contrast, is around 100 times more massive, while the electron is almost 2000 times less massive than the proton. Finally, neutrinos and antineutrinos have tiny masses somewhere on the order of 10 billion times less than the proton. The charges of the particles also vary, with the neutron and antineutrino having no charge, the proton having positive charge, and the electron having negative charge.

In the piece, there will be musical references to Feynman diagrams. The complexity of particle interactions is analyzed graphically (using the diagrams) and then reduced to a simple geometric structure that constitutes the ideal path of our gestures in the musical parameters. In fact, it is not the phenomenon itself that is being translated to music but its graphic visualization. This structure is generalizable to a wide range of particle interactions besides neutron decay. The general idea is to simplify the complexity of physical phenomena to basic elements that can be easily translated into music and understood by everyone. In the case of interactions or decay, the geometry is given by incident lines. A waved path or dashed line is used to indicate the virtual particle, and straight lines to represent real particles.

The interaction of two particles can be musically rendered by two voices, the first lowering and the second raising, and reaching each other into unison. Specific timbres and pitch ranges can distinguish the particles: a high-pitch for the neutrino, a lower pitch range for massive bosons, and specific timbre choices to make distinctions between particles and antiparticles. The virtual particle can be rendered with a tremolo of several strings which then branch toward two separated voices as it decays into real particles. This general strategy can be used to musically describe the beta-decay process discussed above. In the case of neutron decay, we would start with a single melody representing the neutron, which will vanish into a second melody representing the proton and a new melody (using tremolo) representing the virtual particle. Finally, from the last note of the virtual particle's melody, two new melodic lines would emerge representing the electron and anti-neutrino production.

Our final goal is that the listener, even if he or she does not know what the piece is about, is able to recover, only via sound listening, a visual image of the movements and of the sequences of events.

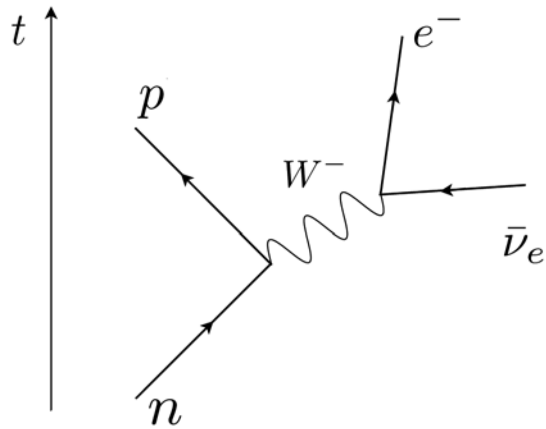


Figure 2

Conclusions

In this article, we described the method of translating physical processes into music which will be used to write a musical piece inspired by the birth of the Universe and our planet. The idea came from the composer Kiriaki (Kakia) Gkoudina, who is writing the orchestral composition "Origin" in the frame of her studies at the University of Minnesota. The challenge was to describe a scientific narrative through music. To overcome this challenge, we will divide the topic into three movements representing different portions of the cosmological timeline. Then, we used perceptive and compositional strategies to musically render a few examples of relevant physical processes that will be included in the final score. Our approach is a result of recent developments of the mathematical theory of musical gestures, applied to visual arts.

From this project and our joint discussions, we have learned how to creatively connect different fields: music composition, narrative, physics, and cosmology.

Future developments of such a technique would include, but would not be limited

to, composition of new scores, new approaches to musical creativity, and definition of powerful tools to enhance communication between artistic and scientific fields. Other applications may involve pedagogy of science through music, and pedagogy of composition through external references, in a unique scientific "program music."
Summarizing, we can use these techniques to:

- Give non-musicians a way to enjoy music through a scientific narrative;
- Allow non-scientists to enjoy scientific topics through music;
- Enhance communication between scholars and students of different fields and disciplines.

All these approaches would benefit artistic creativity and the stimulation of scientific and interdisciplinary thinking.

REFERENCES:

1. Adhitya, Sara, & Kuuskankare, Mika. 2012. "Composing Graphic Scores and Sonifying Visual Music with the SUM Tool,"In: Proceedings of the 9th Sound and Music Computing Conference (SMC 2012). Copenhagen, Denmark, pp. 171–176.
2. Alunni, Charles. 2004. "Diagrammes et Catégories comme prolégomènes àla question : Qu'est-ce que s'orienter diagrammatiquement dans la pensée ?"In *Penser par le diagramme—de Gilles Deleuze àGilles Châtelet,* edited by Noëlle Batt, 83-93. Vincennes: Presse Universitaire de Vincennes.
3. Antoniadis, Pavlos, & Bevilacqua, Frédéric. 2016. "Processing of symbolic music notation via multimodal performance data: Brian Ferneyhough's Lemma-Icon-Epigram for solo piano, phase 1."Proceedings of TENOR 2016 http://tenor2016.tenor-conference.org/papers/18_Antoniadis_tenor2016.pdf.
4. beim Graben, Peter, & Roland Potthast. 2009. "Inverse problems in dynamic cognitive modeling."Chaos 19 (1): 015103.
5. Bilenki, Samoil. 2013. *Introduction to Feynman Diagrams.* Elsevier.
6. Cage, John. 1950. Atlas Eclipticalis.
7. Coegnarts, Martin & Kravanja, Peter. 2015. "Embodied Cognition and Cinema." Leuven: Leuven University Press.
8. Dicke, Robert, Peebles, Jim, Roll, James, & Wilkinson, David. 1965. "Cosmic Black-Body Radiation."Astrophysical Journal 142, 141-419.
9. Dubus, Gaël, & Bresin, Roberto. 2013. "A Systematic Review of Mapping Strategies for the Sonification of Physical Quantities."PLOS ONE 9(4): e96018. doi: 10.1371/journal.pone.0096018.
10. Gentilucci, Maurizio, & Bernardis, Paolo. 2006. "Speech and gesture share the same communication system."Neuropsychologia 44 (178-190).
11. Gkoudina, Kyriaki. 2015. *The evolution of musical narrative from Ancient Greece to contemporary cinema*. B.A. Thesis.Aristotle's University of Thessaloniki.
12. Hubble, Edwin. 1936. "Effect of Red Shifts on the Distribution of Nebulae."Astrophysical Journal 84, 517.

13. Mac Lane, Saunders. 1971. *Categories for the Working Mathematician*. Heidelberg: Springer.
14. Mannone, Maria. 2011. *Dalla Musica all'Immagine, dall'Immagine alla Musica. Relazioni matematiche fra composizione musicale e arte figurativa (From Music to Images, from Images to Music. Mathematical relations between musical composition and figurative art)*. Palermo: Edizioni Compostampa.
15. Mannone, Maria. 2017. *Musical Gestures between Scores and Acoustics: A Creative Application to Orchestra*. Ph.D. dissertation. University of Minnesota.
16. Mannone, Maria. 2016. "Introduction to Gestural Similarity in Music: an Application to the Orchestra."Under review.
17. Mannone, Maria, & Guerino Mazzola. 2015. "Hypergestures in Complex Time: Creative Performance Between Symbolic and Physical Reality."In Proceedings of the MCM 2015 Conference, edited by Tom Collins et al., 137–148. Springer, Heidelberg.
18. Mazzola, Guerino, & Moreno Andreatta. 2007. "Diagrams, Gestures and Formulae in Music."Journal of Mathematics and Music 1 (1): 23–46.
19. Nobile, Luca. 2013. "Words in the mirror: Analysing the sensorimotor interface between phonetics and semantics in Italian." In *Iconicity in Language and Literature 10 : Semblance and Signification*, edited by PascalMichelucci, Olga Fischer and Christina Ljungberg**,** 101-131. Amsterdam/Philadelphia: John Benjamins.
20. Penzias, Arno, & Wilson, Robert. 1965. "A Measurement of Excess Antenna Temperature at 4080 Mc/s."Astrophysical Journal 142, 419-421.
21. Rubbia, Carlo. 1985. "Experimental observation of the intermediate vector bosons W^+, W^-, and Z^0."Reviews of Modern Physics 57 (3), 699.
22. Saariaho, Kaija. 1987. Nymphéa.
23. Spence, Charles. 2011. "Crossmodal correspondences: A tutorial review."Attention, Perception and Psychophysics 73: 971–995.
24. Spivak, David. 1978. *Category Theory for the Sciences*. Cambridge: MIT Press.
25. Visi, Federico,& Miranda, Eduardo. 2016. "Instrumental Movements to Physical Models: Mapping Postural and Sonic Topologies through Machine Learning."*Porto International Conference on Musical Gesture as Creative Interface*, 2016.
26. Xenakis, Iannis. 1971. Formalized Music. New York: Pendragon Press.
27. Uznadze, Dimitri. 1924. "Ein experimenteller beitrag zum problem der psychologischen grundlagen der namengebung"("An Experimental Contribution to the Problem of the Psychological Foundations of Naming"). Psychologische Forschung, 5(1-2):24–43.

SCORES and RECORDINGS:

Cage, John. 1950. Atlas Eclipticalis. Boosey & Hawkes
CD:
"Atlas Eclipticalis with Winter Music," Live, Cornish Theatre, Seattle, Washington, 11 December 1983, 6:30 Pm, Mode, ASIN: B000MDH6AC, Audio CD (February 27, 2007), SPARS Code: DDD

Saariaho, Kaija. 1987. Nymphéa. Edition Wilhelm Hansen, Helsinki.
CD:
Los Angeles Philarmonic Orchestra, conducted by Esa-Pekka Salonen, Audio CD (February 1, 1995), Label: Ondine, ASIN: B00000377R

Narativizacija porekla Univerzuma kroz muziku: studija slučaja

Apstrakt: Naš projekat je o sintezi jednog muzičkog dela, zasnovanog na vremenskoj liniji Univerzuma. Muziku možemo da tumačimo kroz vizuelne i gestovne analogije. Slično tome, da bi olakšali razumevanje, popularistički opisi naučnih koncepata takođe koriste spoljne metafore i vizelnu podršku.
Koristićemo muziku kako bismo opisali jednu temu iz astrofizike, rođenje i evoluciju Univerzuma. Opisujemo kompozicionu tehniku koja je korišćena u stvaranju kompozicije *Poreklo (Origin)*, ukazujući na nove tehnike stvaranja muzike od trodimenzionalnih slika i gestova, u svetlu matematičke teorije muzike u kontekstu naracije.
Keywords: astrofizika, muzika, kompozicija, narativ, gestovi