

BEYOND QUANTUM MUSIC

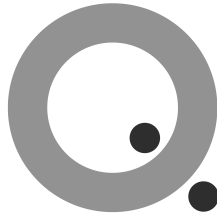
2019-2022



Institute of Musicology
Serbian Academy of Sciences and Arts

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BEYOND QUANTUM MUSIC

2019–2022



BEYOND QUANTUM MUSIC | 2019–2022

Edited by Dr Ivana Medić, Project Coordinator

The project *Beyond Quantum Music* (2019–2022) is a continuation of the pioneering scientific and artistic project *Quantum Music* (2015–2018).

www.quantummusic.org

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PILOT PROJECT

***Quantum Music*, International interdisciplinary project
2015–2018**

***Creative Europe*, EACEA**

559695-CREA-1-2015-1-RS-CULT-COOP1

QUANTUM MUSIC

The original pilot project Quantum Music (<http://quantummusic.org>), co-funded by Creative Europe, began in August 2015 and it was successfully completed in May 2018. The final report was submitted in July 2018 and approved by the EACEA in September 2018. This highly original and innovative project pushed boundaries and brought together the distant worlds of music and quantum physics. Partners on this project were: the Institute of Musicology of the Serbian Academy of Sciences and Arts (project coordinator), New Art Center Belgrade, Center for the Promotion of Science, Kino Šiška Center for Urban Culture Ljubljana and the Danish National School of Performing Arts.

Since the project Beyond Quantum Music presents a continuation and expansion of the original Quantum Music project, it is worth presenting here a short overview of its most important results and outcomes.

Production of the Quantum Music multimedia show

The main outcome of the original pilot project was an interactive multimedia show *Quantum Music*, featuring new, specially designed hybrid keyboard instruments, a new library of quantum sounds developed from the experiments and formulas of quantum physics, and new compositions written especially for this show. Aside from music, the production also contained a visual interactive component that served the educational purpose and explained the basic premises of the quantum world to a wide audience; moreover, all performances were accompanied by lectures given by some of the most renowned quantum physicists of today. In accordance with the project plan, the show co-financed by the EU grant was performed in three European partner cities in Autumn 2017: Ljubljana, Copenhagen, and Belgrade. There were additional, independently organized and financed performances in Singapore (as a pre-premiere), in Aarhus and The Hague (as part of the European tour in Autumn 2017), as well as in London, Paris and New York (after the project officially ended).

The Quantum Music show was performed to sold-out audiences and sparked great interest wherever it was performed. Moreover, the Belgrade show was fully recorded and broadcast by Serbian National

Broadcasting Corporation (RTS). The success of the project and the audience's enthusiasm encouraged us to think of expanding the show by inviting international artists to write new Quantum Music pieces and design new visuals that would be included in the performances.

Development and implementation of an innovative technology – Awarded for the best technological innovation

As part of the pilot Quantum Music project, a new, completely innovative product was developed, which presented a breakthrough in the development of audio technology and its application in the industry of keyboard instruments. This product, the Hybrid Piano (MIDI piano converter) which enables an easy and (for the first time ever) portable connection of the classical piano with quantum laboratories equipment, computers and other electronic devices, has outgrown the framework of the pilot project and become an independent branch of development of the entire project Beyond Quantum Music. The core of this technology can be applied to other types of musical instruments, and a common label for all these products that link acoustic instruments with computers and experimental gear is Quantum Link Technology. The development of the prototype was co-financed by the Creative Europe grant and fully developed within the framework of the first Quantum Music project.

Our Hybrid Piano won a bronze medal in the annual competition for the best technological innovation in Serbia in 2017. In 2018 the New Art Center also received an award for the same product, as the best Serbian startup in the field of creative industries. That prize allowed them to represent Serbia at the global competition of creative industry startups (Creative Business Cup, Copenhagen, November 2018), with more than 70 other startups who won their respective national contests: they were selected as one of the six most investable startups.

Media coverage

The first pilot project attracted the attention of several media companies, especially the Serbian Broadcasting Corporation (RTS),

which produced two documentary films and several features about this project. The Belgrade performance of the Quantum Music show was recorded and broadcast. There were also numerous interviews and other guest appearances in all European cities where the show was performed.

Education

The pilot Quantum Music project encompassed the organization of a number of educational workshops and lectures on topics related to the project. The strongest educational component was reflected in the ways in which it was possible to present such a complex topic as the relation between quantum physics and music to the widest audience. The lectures and/or workshops were given in all cities where the Quantum Music show was performed over the duration of the project: Singapore, Ljubljana, The Hague, Copenhagen, Aarhus and Belgrade.

Connecting notable individuals and institutions

Special evidence of the success of the original Quantum Music project was the fact that several prominent individuals and institutions joined the project during its duration. We should first mention the involvement of the University of Aarhus, led by Professor Klaus Mølmer, who made a major contribution to the scientific foundation of the concept of quantum music, enabling the use of their laboratory resources and experimental results. Although officially not a partner in this project, the University of Aarhus, led by prof. Mølmer, made an outstanding contribution to the quality and sustainability of the project, through practical engagements in the theoretical and experimental phases of the project; they also worked on organizing an additional concert in Aarhus, as well as a series of lectures given by Professor Mølmer on quantum music. Moreover, the Center for Quantum Technologies from the National University of Singapore also joined as an active participant in the project and opened the door for the Asian market. All listed activities and engagements were realized outside the budget of the project itself and represent an important contribution to the quality and dissemination of the project results.

Scientific contribution

The pilot project forged new connections between quantum physicists, engineers, acoustics experts and artists. Through a series of meetings held within the planned and additional activities of the project, new opportunities were identified that could elevate the work on the Quantum Music project to a whole new level, beyond the boundaries of the Art & Science project (which primarily aims at popularization and education) and situate it among the projects that can transgress the existing boundaries in understanding the essence of quantum physics. This topic is of paramount importance, since the philosophical concept of quantum physics is one of the most important issues of our civilization at this moment, and its re-examination through the approach achieved in this project has the potential that has been acknowledged by all of its participants. In that sense, completely new activities within the project were established, i.e. a collaboration between scientists from different branches of science on the establishment and further development of analogies between acoustic and quantum systems.

New synthesizers and the first library of Quantum sounds

As part of the work on the pilot project, the first sound sample library was formed. The results of the experiments carried out at the University of Aarhus, along with theoretical quantum mechanical principles, were used by the direct implementation system to form this unique sound bank. This library was used in the process of composing original musical pieces of quantum music. At the moment, the library contains over 100 sound samples, and it expands very quickly, as new lab results come in. It is expected that this library will eventually have several hundreds of original sounds directly generated from the domain of the quantum world. In the process of working on the formation of the bank, some acoustic phenomena that deserve additional attention and explanation from the aspect of acoustics and quantum physics were recognized, which is yet another new development and contribution of this project. Also, two completely original software synthesizers were created within the scope of the first Quantum Music project.

New music compositions

Several new original compositions were written by Kim Helweg and LP Duo for this project. These compositions are directly based on the laws of quantum mechanics through their rhythmic-harmonic and sound structures, and as such, they represent an important contribution to European contemporary music. The new compositions were performed at all concerts within this project, and they form the basis for further research in the fields of composition, music and musicology.

Two PhD dissertations and several scientific papers

The scientific side of the Quantum Music project was disseminated through two doctoral dissertations, by Sonja Lončar and Andrija Pavlović,¹ then, a scientific conference held in March 2018 in Belgrade, with participants from Germany, the United Kingdom, Italy, the Netherlands, and Serbia; the publication of nine papers in the special issue of the journal *Musicology* dedicated to Quantum Music;² and a series of popular-science articles in the magazine *Elements*, published by the Center for the Promotion of Science.

Installations

The Quantum Music project was promoted, as a spin-off of the initial project plan, at two museum exhibitions in Belgrade. To this end, an interactive museum installation has been developed that illustrates the basic principles of the Quantum Music project. The exhibit is made to be easy to transport, and it is permanently curated in the gallery of the Kolarac Foundation, the prestigious cultural institution in Belgrade.

¹ Sonja Lončar, *Hibridni duo – novi prostori savremenog izvodaštva u ansamblu klavirski duo* [Hybrid Duo – New spaces of contemporary performance in the piano duo ensemble], Belgrade, Faculty of Music, 2018, <https://eteze.arts.bg.ac.rs/handle/123456789/343>; Andrija Pavlović, *Savremeni izazovi rada i saradnje muzičara u klavirskom duu na primeru muzičko-scenskog projekta Kvantna muzika* [Contemporary challenges of work and cooperation of musicians in a piano duo, based on the example of the musical and stage project *Quantum Music*], Belgrade, Faculty of Music, 2018, <https://eteze.arts.bg.ac.rs/handle/123456789/332>

² See pp. 17–18 in this catalog.

Contribution to humankind – opening the big questions

The small-scale cooperation project Quantum Music has far outgrown its “small” classification. The team of preeminent scientists, engineers and artists was systematically selected and expanded over the three-year span and as such, ensured quality at all stages of its realization. The new set of so-called “big questions” concerning new approaches to scientific research of harmony and beauty were opened, with the intention of finding new ways to fund future work on such fundamentally important tasks. For those of us who worked on the Quantum Music project, its most important contribution was precisely the exploration of those key questions and dealing with them in a multidisciplinary way, which opened up opportunities for improvement of both the artistic, scientific and technological levels of humankind today.

Ivana Medić
**Quantum Music, International interdisciplinary project (2015–18),
Creative Europe, EACEA
(559695–CREA–1–2015–1–RS–CULT– COOP1)**

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PDF: <https://insam-institute.com/wp-content/uploads/2018/12/10.-INSAM-Journal-1-Ivana-Medić-Quantum-Music-101-103-2.pdf>

It is not easy to reflect on the project that occupied the better part of the last three years of my life. While the memories and impressions are still vivid, it may be too early to tell whether they will have a lasting impact. The project in question was called *Quantum Music* by its masterminds, former classmates at the Mathematical Grammar School in Belgrade: Vlatko Vedral, Professor of quantum physics at the University of Oxford and the National University of Singapore, and Dragan Novković, Professor at the Department of Audio and Video Technologies of the School of Electrical and Computer Engineering in Belgrade. For the first time, an institution from Serbia – the Institute of Musicology SASA – became the project leader within the *Creative Europe* program, whilst the international consortium of partners and associate partners gathered together cultural, higher education and research institutions from Serbia, Slovenia, Denmark, the Netherlands and the United Kingdom.

The main objectives of *Quantum Music* were to explore how the seemingly distant worlds of quantum particles and everyday sounds could interact and to bring the abstract principles of quantum physics closer to a wide audience by means of music. The project was kickstarted by a series of quantum-acoustics experiments during which particles exhibited characteristics that could be converted into audible

sounds. Namely, in temperatures close to the “absolute zero” (-273,15° C) all wave functions of separate atoms turn into a single wave function; this is the quantum “sound”.³ While we cannot hear it, quantum physicists have been able to work out equations and formulae upon which such events occur; hence Vedral and Novković decided to transfer these inaudible quantum “sounds” to “our world”. My own motivation for accepting their invitation to be the project coordinator was sparked by the opportunity to create something new and thus revive the spirit of the maverick post-WWII avant-garde “obsessed” with progress, innovation, technological breakthroughs and new sounds. At that point (in 2014) I had only recently returned to Belgrade to take up the post of a researcher at the Serbian Academy of Sciences and Arts, having previously lived in Manchester for almost seven years; hence I was institutionally well-positioned to herald a project that aimed to connect science(s) and art(s).

The research took the international consortium in several directions, starting with the creation of new hardware that transformed the classical piano into a hybrid analog-digital instrument. As noted by Jelena Janković-Beguš and myself, “Whilst creating the hybrid piano and soundbanks for it, the scientists, engineers and musicians found themselves ‘on the same wavelength’ [...] although they arrived at that meeting point from different directions. Specifically, the scientists were interested in ‘hearing’ the quantum world, while musicians aimed at expanding the sound range and expressive possibilities of traditional keyboard instruments.”⁴ The idea for creating the hybrid piano came from LP Duo (Sonja Lončar and Andrija Pavlović) whose diverse concert activities include performances both on classical pianos and on a variety of synthesizers, especially old analog synthesizers, of which they are avid collectors. However, they have always complained that even the best contemporary synthesizers possess neither the mechanism nor the dynamic range of grand pianos. The engineer

³ Cf. Marko Rančić, „Kad atomi đuskaju svi kao jedan – Boze-Ajnštajnov kondenzat“, <http://www.svetnauke.org/9674-kad-atomi-duskaju-svi-kao-jedan-boze-ajnstajnov-kondenzat>

⁴ Ivana Medić and Jelena Janković-Beguš, “What Does Quantum Music Sound Like and What Would Pierre Boulez Think of It? *Super Position (Many Worlds)* by Kim Helweg (2017)”, *Muzikologija-Musicology* 24 (1/2018), 83.

Darko Lazović fulfilled their dream of creating an electronic instrument that retained genuine piano mechanics and enabled the demonstration of the entire spectrum of pianistic virtuosity, while at the same time introducing a variety of new sound colours and new performance possibilities. This was complemented by the creation of a new software interface for this new hardware, but also of soundbanks synthesized on the basis of equations obtained during the experiments in the quantum laboratories.

The second, artistic direction involved the creation of a new music genre; composition, performances and distribution of the first quantum music pieces based on the study of the behaviour of quantum particles (and not merely on the use of quantum computers), as well as composing new music and rearranging pre-existing music for the new hybrid instrument. This was followed by a creation of an audio-visual narrative that accompanied concert performances of these new quantum music pieces, in order to introduce and explain to the audience the most important phenomena of the quantum world, such as quantum vacuum, entanglement, superposition, wave function and collapse, teleportation etc. The Quantum Music multimedia show was successfully performed in six cities in the Spring and Autumn of 2017 (Singapore, The Hague, Copenhagen, Aarhus, Ljubljana and Belgrade). Further performances were given throughout the year 2018 in London, Paris and New York.

As part of this project, an international interdisciplinary conference devoted to Quantum Music was held on 21 and 22 March 2018 at the Serbian Academy of Sciences and Arts, under the auspices of the Ministry of Education, Science and Technological Development of the Republic of Serbia. The conference that attracted a large number of listeners, as well as considerable media attention, gathered together physicists, mathematicians, engineers, composers, musicologists and pianists, who were either directly involved in the realization of the eponymous *Creative Europe* project, or involved with similar research within their institutions, independently of our consortium.

The project *Quantum Music* opened a new chapter in the relations between science, technology and music, leading to the discovery of new sound worlds. On the other hand, for the first time in its history, music was offered the chance to contribute to science by transferring/

translating quantum experiments to our audible world. Our long-term goal is to continue to popularize the new hybrid keyboard instrument, the soundbank of quantum sounds and the new music genre to the widest possible audience, but also to further the educational side of the project and to expand and intensify our collaboration with prestigious institutions and individuals in the fields of science, arts and technology worldwide.

QUANTUM MUSIC – Issue No. 24 of the International Journal
Muzikologija-Musicology (2018)
Edited by Ivana Medić

<https://muzikologija-musicology.com/index.php/MM/issue/view/no-24>

The main theme of issue No 24 of the journal *Musicology*, entitled *Quantum Music*, was inspired by the eponymous international project co-funded by the Creative Europe program of the European Union (2015–2018). For the first time, an institution from Serbia – the Institute of Musicology SASA – was the project leader within the Creative Europe program, and the consortium of partners and associate partners comprised cultural, higher education and research institutions from Serbia, Slovenia, Denmark, the Netherlands and the United Kingdom.

When submitting our application and, later, signing the contract with the European Commission, we emphasized that the objectives of this project, among other things, included the organization of the first conference on quantum music, as well as the publication of an issue of the journal *Muzikologija-Musicology* dedicated to this topic. I am pleased that both these goals have been achieved. The international interdisciplinary conference devoted to quantum music was held on 21 and 22 March 2018 at the Serbian Academy of Sciences and Arts, under the auspices of the Ministry of Education, Science and Technological Development of the Republic of Serbia and attracted a large number of listeners, as well as considerable media attention. In addition, I presented the research results of this project at the 53rd Annual Conference of the Royal Music Association (RMA) at the University of Liverpool (UK) in September 2017.

The main theme *Quantum Music* contains articles by authors who directly participated in the realization of the eponymous Creative Europe project, but also of scientists who spontaneously joined the research during the project development, as well as articles by authors who are not in any way related to this project, but they are involved with similar research independently of our consortium. A total of nine texts written by authors who are primarily physicists, mathematicians, engineers, composers, musicologists and pianists, illuminate various

aspects of the permeation of quantum physics and music. Vlatko Vedral, one of the most influential scientists today and a Professor at the University of Oxford, explores the theoretical possibilities for hearing the quantum superposition in the article that opens this topic. Alexis Kirke, a mathematician and composer from Plymouth, deals with programming gate-based hardware quantum computers for music, while physicist Andrew Garner (Singapore / Vienna) writes about the musical Mach-Zehnder interferometer. Physicist Klaus Mølmer (Aarhus) and composer Kim Helweg (Copenhagen), each from their point of view, discuss their collaboration within the Quantum Music project, while Jelena Janković-Beguš and I analyze one of Helweg's compositions, in parallel with Pierre Boulez's discussion on music and technology written some forty years ago. Pianists Sonja Lončar and Andrija Pavlović (LP Duo) and engineer Dragan Novković with his students write about the challenges they faced when creating a new hybrid keyboard instrument that enabled us to "hear" the quantum world for the first time, and in the concluding text on this topic, physicist Chiara Marletto examines the aesthetic implications of quantum music.

As a coordinator of the Quantum Music project, I am grateful to the Creative Europe program for recognizing the innovativeness and importance of such interdisciplinary research in the field of art and science, as well as to the Ministry of Culture and Information of the Republic of Serbia and Creative Europe Desk for their financial, logistical and media support. I owe special gratitude to the partners on the project, whose devotion contributed to its successful realization.

Full issue:

<https://muzikologija-musicology.com/index.php/MM/issue/view/no-24>

Individual articles:

<http://quantummusic.org/literature/>

BEYOND QUANTUM MUSIC

**International interdisciplinary project
2019–2022**

***Creative Europe*, EACEA**

607659-CREA-1-2019-1-RS-CULT-COOP1

Beyond Quantum Music is a project exploring the connection between art and quantum physics. Its main purpose is broadening and developing productional, educational and artistic aspects of the pilot project Quantum Music, completed in 2018 – however, this time not only in the domain of music but also in visual and digital arts. The primary goal of the new consortium is audience development in three partner countries, but also in the broader European context. The secondary goal is transnational mobility and establishing a network of organizations and individuals that would continue to perform and promote quantum music and thus secure the long-term sustainability of the project. The project encompasses theoretical concepts and experiments in the domain of quantum acoustics; musicological work related to the study and expansion of the new genre of quantum music, created in the pilot project; expansion of the open-access sample library of quantum sounds and their artistic use; composition of new music pieces based on the principles and sounds of quantum physics; further development of the technology necessary for connecting acoustic and quantum-mechanic domains; design and production of new hybrid instruments based on the Quantum Link Technology. Beyond Quantum Music also encompasses an open call for artists from the domains of music, visual arts and digital interactive art, who submitted works inspired by the quantum world. Another landmark is the production of a new multimedia event "Quantum Music 2.0" that would incorporate awarded works by composers, and visual and digital artists, as well as works by local artists from partner countries. All project results will subsequently be published on the project website <http://quantummusic.org>, while the audio and video recordings and other material will be available on the Youtube channel.

The Covid-19 pandemic (2020–2022) caused many disruptions in the entire cultural sector and the events industry, resulting in some of our project activities being postponed and/or reduced in scope. Moreover, there were some changes in the consortium of partners and the order of activities, because the project team had to adapt to the changed circumstances, including travel restrictions, and the closure of many concert halls and venues. In spite of all these unforeseen setbacks, the project team managed to prepare and produce all planned events and fulfill the ambitious goals of the project.

Some initial hypotheses on the possibilities to connect quantum physics and music

At a physical level, music and sound in general can be viewed as waves of pressure, in which small packets of air compress and expand at a particular rate known as the frequency of the wave, that we perceive as a sound. Waves appear in many contexts in physics. Mathematically, wherever there is something that regularly repeats in time, it can be expressed as a wave. In quantum mechanics, these waves are far removed from our everyday experience. For example, quantum waves can correspond to the changing probabilities of finding a particle in a particular position. Fundamentally, however, the same mathematics that applies to waves breaking on the beach also applies to quantum physics. These mathematical similarities between sound and quantum mechanics form the basis of our attempt to create music from quantum mechanics. We can apply quantum mathematics, but rather than treating the output at any given time as a probability, we instead interpret the value as how compressed or expanded air should be at this time. The effect of this is that the probability waves from quantum mechanics are converted into audible sound waves.

1. [Quantum Filter] Probing quantum systems with musical input

When one listens to music through a hi-fi system, the source (e.g. iPod) transmits its signal through a wire to the amplifier, which boosts this signal, and transmits it through more wires to the loudspeakers. At all points, the electrical waves in the wires match very closely in shape to the sound heard through the loudspeakers. The effect of the amplifier makes the height (amplitude) of these waves larger, although it may also change the shape in some way, corresponding to (e.g.) distortion in an electric guitar amp.

We aim to change the sound using a quantum system, in a similar manner as described above. Rather than using wires carrying the signal in and out, the quantum system uses light lasers; and rather than the large-scale electronic circuits, whose behavior is governed by predominantly classical physics, the quantum system consists of a much small number of atoms, whose behavior is governed by quantum

mechanical laws. Thus, unlike the hi-fi amplifier whose effect on the sound is simple (it makes it louder), the quantum system has a much more complex effect on the sound. In this way, the quantum sounds are genuinely novel, something that has never been heard before.

2. [Quantum Instrument] Listening to quantum states directly

Even when left to their own devices, quantum systems change in time, typically at an ultra-fast rate. For example, an electron in the simplest Hydrogen atom naturally flickers between a quantum 'spin up' state to a 'spin down' state at approximately 1,420,000 times per second (if played as a sound, this would be far outside the range of human hearing, and so to hear these frequencies, we would have to slow them down considerably). Rather than the standard approach in which we input a classical wave and modulate it with quantum effects, this new approach is quantum at its core. This provides us with an opportunity to explore one of the most specific quantum phenomena: coherent superposition. Superposition's most famous example is given by Schrödinger's thought experiment: a cat that is both alive and dead at the same time. When a quantum system is in just one state (e.g. 'the cat is alive'), the sound of the oscillation will sound like a pure tone at some frequency. A quantum system in a superposition of states at the same time will vibrate at multiple frequencies, thus the sound produced will be a chord.

This system can be simulated on modern computers. There are many parameters that can be varied to change the rates at which the quantum system vibrates. These parameters can be rigged for control by a piano keyboard, such that pressing the keys changes the sound. In this way, we have created a new quantum instrument, the hybrid piano, unlike anything that had existed before.

3. [Quantum Music] Exploring other quantum phenomena

The approach to creating new music pieces and artworks attempts to explore more explicitly aspects of quantum physics that are not typically seen in the classical world. Rather than proposals 1 and 2 that focus on the sound itself, the following ideas consider artworks that reflect quantum experience.

a. Interference

The mathematics of waves predicts a phenomenon known as interference, which can be either constructive (where two waves add together to make a larger wave), or destructive (in which two waves cancel each other out). However, in an orchestra, if two instruments each play a note, the audience will always hear two notes. This is because, despite the sound being fundamentally formed of waves, the situation is so complicated that the waves mix randomly rather than interfere. There are many reasons for this: the complicated acoustics of the room, the fact that the instruments don't produce noise from a single point, and the fact that the frequencies at which the instruments are vibrating are slightly different, even for the same type of instrument with careful tuning. By using electronic instruments, there is the opportunity to re-introduce interference at a level before complicated acoustics make it impossible. We envision two (e.g. MIDI) keyboards that produce sound, but if the same note is played on both at the same time, no sound is produced. In this way, the first pianist could play a tune, and the second pianist could then play a different tune, but when both pianists repeat these tunes playing at the same time, the final song will be completely different. This would be directly analogous to an important class of experiments in the quantum theory known as interferometry. In particular, this matches with Deutsch's algorithm, an important calculation for quantum computers, which focuses on whether two possibilities are the same, or if they are different (rather than what each possibility is).

b. Entanglement

Arguably, the most uniquely quantum phenomenon is entanglement, which can be thought of as being more correlated than classically possible. When an orchestra plays together, following the conductor, the sounds they produce are correlated (the more well-rehearsed the orchestra, the more correlation there will be between the sounds produced). If one hears the flutes playing bar 16, one can with high confidence predict that the violins will also be playing bar 16 of the same piece. Entanglement goes a step beyond this. When two systems are entangled, they will correlate on things where it would have been impossible for them to simultaneously agree. Since

entanglement essentially requires more than one system, it is a well-suited topic for us to present in our project involving a piano duo.

c. Bose-Einstein Condensate - BEC

BEC is the so-called fifth state of matter (besides solid, liquid, gas, and plasma states) that was achieved in quantum laboratories for the first time in 1996. BEC provides scientists with the possibility to generate mechanical waves in entirely quantum systems. Since all mechanical waves can be considered sound waves, a whole new branch of quantum physics, called quantum acoustics, has developed since then. What is further interesting is that sound waves that propagate through BEC are in the human hearing range. That means that some non-existent human “quantum ear” actually could hear such sounds. The starting point of this project originates exactly from the idea of having a quantum ear that could hear these sounds. The Aarhus University is equipped with all the necessary equipment needed for such experiments, which will be used for the purposes of further development of Quantum Music within the Beyond Quantum Music project.

DUALITY – Portable Hybrid Piano System

As part of the project Beyond Quantum Music, a team consisting of musicians, engineers and designers created a new prototype of the hybrid piano, called DUALITY. The pianists Sonja Lončar and Andrija Pavlović established the eponymous company and assembled a team that could turn their vision to create an ideal analog-digital piano into reality.

The main challenge is to bridge the gap between the analog and digital worlds with respect to music performance, recording and production. Although many companies have tried, thus far none of them has succeeded in creating a digital synthesizer that could compete with classical (analog) piano in the dynamic and expressive range of the instrument, the quality and sensitivity of keyboard digits, virtuosic responsiveness and other technical performances. So, instead of producing a new type of synthesizer, our team decided to transform a classical analog piano into a digital instrument. *Duality – Portable Hybrid Piano System* is a combination of traditional piano and digital synthesizer with analog controls that allow processing of both acoustic and digital signals in real-time, with a lightweight and portable design that can be easily attached to any piano in less than 30 minutes.

The new hybrid system is lightweight, portable, inexpensive, and very easy to install and use. The instrument is adaptable to any classical piano (grand or upright piano) and compatible with all standard types of computer and audio equipment. It cannot harm the piano when placed in it, and it offers huge possibilities for using the existing sound banks and creating new ones. It can be used for live performances to perform any kind of digital sound on the analog piano in real time.

For the project Beyond Quantum Music, Sonja Lončar and Andrija Pavlović composed new music that fully utilized all the possibilities of the new hybrid instrument.

PARTNERS

Institute of Musicology SASA, Belgrade

Project Coordinator

The Institute of Musicology of the Serbian Academy of Sciences and Arts was founded in 1948. As a scientific organization, it conducts projects in the domains of historical musicology, ethnomusicology, avant-garde and experimental music. The Institute publishes monographs, edited books, CDs and DVDs, sheet music, catalogs and the international open-access scientific journal *Musicology*. The Institute is also involved in the organization of cultural events such as exhibitions, concerts, roundtables, promotions, etc.

The Institute was the coordinator for the pilot project *Quantum Music* completed in 2018, and it performs the same role within the new consortium for the project *Beyond Quantum Music*. The Institute coordinates and manages the entire project, distributes funds to the partners and ensures that all activities are done according to the plan. It also implements the communication strategies and objectives of the project. The associates of the Institute will give public lectures, prepare booklets and other printed material and coordinate promotional and marketing activities in all partner cities, which will ensure the long-term impact and dissemination of the project results, as well as their sustainability.

www.music.sanu.ac.rs

<https://www.facebook.com/musicinstsanu/>

DUALITY, Belgrade

DUALITY LTD is a company established in 2020 by Sonja Lončar, Andrija Pavlović and Aleksandar Brkić, for the purpose of developing and producing the eponymous hybrid analog-digital keyboard instrument, supported by the Serbian Innovation Fund. The company is a successor to the New Art Center, also established by Lončar and Pavlović (LP Duo). Regarding the technological development of the

Duality prototype, the company collaborates with HTEC, one of the leading innovators in the field of IT and technology.

<http://duality.rs>

<http://www.lpduo.com>

<http://www.inovacionifond.rs/en/news/grants-awarded-fo-innovative-solutions-of-domestic-companies>

Ars Electronica, Linz

Ars Electronica is a worldwide unique platform for art, technology and society. The focus is always on current developments and possible future scenarios and the question of how these change our lives. Together with artists, scientists, developers, designers, entrepreneurs and activists, Ars Electronica sheds light on current developments in our digital society and speculates about their manifestations in the future. We never ask what technology can or will be able to do, but always what it should do for us. And we don't try to adapt to technology, but we want the development of technology to be oriented towards us. Therefore, our artistic research always focuses on ourselves, our needs, our desires, our feelings.

The first Ars Electronica began on 18 September 1979. Twenty artists and scientists from all over the world gathered at this new "Festival for Art, Technology and Society" in Linz to discuss the Digital Revolution and its possible consequences. The initiative for this came from Hannes Leopoldseder (AT), director of the Upper Austria regional studio of the Austrian Broadcasting Company (ORF), who was passionate about everything that had to do with the future. Together with the electronic musician Hubert Bognermayr (AT), the music producer Ulli A. Rützel (DE) and the cyberneticist and physicist Herbert W. Franke (AT), he laid the foundation stone for a festival that would become the world's largest and most important of its kind.

With Machine Learning and Co, we are initiating the transition from automation to autonomy today. The digital becomes independent for the first time. On the threshold of this new era, we must set the course for our digital society to remain committed to fundamental values such

as human dignity, freedom, democracy, equality, the rule of law and human rights. Together with artists, scientists, developers, designers, entrepreneurs and activists from all over the world, we want to contribute to such a digital humanism.

<https://ars.electronica.art>

<https://archive.aec.at>

MedILS – Mediterranean Institute for Life Sciences, Split

MedILS is an international “renaissance” project created as a scientific and social experiment. Its primary goal is to breed a generation of young scientists: creative, multidisciplinary professionals trained to “think the unthinkable” and produce that kind of experiment.

MedILS is an international, private, non-profit scientific institution. The reason for MedILS to be located in Split is that this particular Mediterranean region is geographically, climatically and culturally exceptional, ideal to trigger creativity and develop young talents. This Institute is bound to become the Center of scientific excellence worldwide. Teaching, learning, and brainstorming are a natural way of life at MedILS institute.

The mission of MedILS is to create a new original scientific culture in the studies of life and its manifestations, by implementing the world’s highest standards of scientific work, style and ethics. Our objective is to become a “household” of original intellects with the freedom to doubt and to practice connective/synthetic thinking in high-risk innovative research.

MedILS is a place for brain-storm gatherings, meetings and practical courses; a center of excellence in the studies of life and its manifestations, in general the study of complex systems, but no research project will be excluded a priori. Multidisciplinary, multicultural, interdisciplinary and international are the desired prefixes for the new generation of MedILS scientists.

MedILS functions as a bridge between European and American molecular biology, in the future with Austral-Asian and, hopefully soon, African science.

Scientists at MedILS work in the (horizontal) style of a cross-inspiring “jazz band” rather than a (vertical) “symphony orchestra” style with one director and a written script (project).

MedILS is becoming a truly international institution totally independent of local governments, with an ex-territorial status (such as the embassies and the EU and UN institutions). Our vision is to bring world-class science, work style and work ethics into this region. It would offer the opportunity for top scientific training without the unavoidable expatriation of young future scientists.

<https://www.medils.org/about-us/about-medils>

Kavli Institute of Nanoscience, Delft Technical University Delft, The Netherlands

The Kavli Institute of Nanoscience Delft is an intellectually inspiring environment of world-leading scientists who perform pioneering research to understand the nanoworld – from quantum physics to nanobiology. The focus is on developing novel concepts and achieving game-changing breakthroughs.

The Institute consists of two departments of the Faculty of Applied Sciences at Delft University of Technology: the Department of Quantum Nanoscience, the Department of Bionanoscience and members from QuTech. These scientists share the joint Kavli Nanolab facility. The Kavli Institute of Nanoscience Delft was founded in 2004 when it was selected and endowed by the Kavli Foundation. Delft is one of five Kavli Institutes of Nanoscience worldwide (Cornell, Oxford, Caltech, Berkeley and Delft, see www.kavlifoundation.org). Current co-directors of the institute are Professor Kobus Kuipers and Professor Chirimin Joo.

Bionanoscience is a vibrant and steeply growing research field that focuses on the interface between nanoscience, synthetic biology and cell biology. With our research, we seek to understand life at the nanoscale.

Quantum Nanoscience is a thriving research field that studies and exploits one of the most radical physical phenomena that occur at the nanoscale, the emergence of quantum mechanical behavior.

Artist in Residence at Kavli Delft

A position at KIND known as 'the Artist in Residence' is offered annually to an artist with an outstanding reputation. The Artist-in-Residence fellowship offers talented artists working in the fields of conceptual art, visual art, photography, music, design, dance, film, theatre, or poetry an opportunity to work on a project within the international and interdisciplinary academic setting of the Kavli Institute of Nanoscience Delft (KIND). He/she will be invited to come to KIND for a period of about 3 months, in which he/she will have the opportunity to closely interact with the scientists at the institute, join in work discussions, experience lab work, and the like. The expectation is that the Artist-in-Residence fellowship will result in a piece of art that relates to nanoscience at KIND.

KIND initiated the artist-in-residence fellowship to promote the relationship between the arts and sciences and thus find new ways to interact and communicate concerning discoveries about matter on the nanoscale. The view is that the cross-fertilization between creative approaches and scientific disciplines will evoke disruptive new insights, strengthen ties, and trigger novel approaches.

<https://kavli.tudelft.nl>

<https://kavli.tudelft.nl/kavli-artist-residence/>

Institut Incontri, Hochschule für Musik, Theater und Medien Hannover

Hanover University of Music, Drama and Media (HMTMH) is an artistic-scientific university in Hanover, Lower Saxony, Germany. It dates back to 1897. The university has approximately 1500 students, taught by 361 teachers in 33 courses for musicians, actors, music teachers, musicologists and media scholars.

Incontri is the name of the Institute for New Music at the HMTMH. Incontri realizes diverse and exciting encounters between composers, improvisers, interpreters and audiences in the field of contemporary music. Incontri accompanies and promotes new music in its encounters with the present, in compositions, experiments and new concepts. Incontri creates a spark for the music of the future by

meeting traditions and exciting new questions. Incontri Institute is affiliated with UrWerk Ensemble for New Music from Hannover.

<https://www.incontri.hmtm-hannover.de/de/start/>

<https://urwerk.org>

Personnel

Ivana Medić is a Senior Research Associate with the Institute of Musicology of the Serbian Academy of Sciences and Arts. She received her PhD from the University of Manchester, and she has been a Visiting Fellow with the Centre for Russian Music, Goldsmiths, University of London since 2009. She was Head of the international project *Quantum Music* co-financed by Cultural Europe (2015-2018), Head of the Belgrade team of the project *City Sonic Ecology – Urban Soundscapes of Bern, Ljubljana and Belgrade*, financed by the Swiss National Science Foundation (2014–2017), and Head of the main project of the Institute of Musicology SASA entitled *Identities of Serbian Music Within Local and Global Frameworks: Traditions, Changes, Challenges*, financed by the Serbian Ministry of Education, Science and Technological Development (2017–2019). She is currently leading the project *Applied Musicology and Ethnomusicology in Serbia: Making a Difference in Contemporary Society (APPMES)*, financed by the Serbian Science Fund (2022–2024). She has published five monographs and over 80 articles and edited ten books and catalogs. She has served as editor and guest editor of journals *Muzikologija-Musicology*, *Contemporary Music Review*, *Arts* and *Literary History*. She is also a multi-instrumentalist, specializing in contemporary music.

<http://ivanamedic.com>

Sonja Lončar and **Andrija Pavlović** are pianists who founded LP Duo in 2004, as well as the NGO New Art Centre in Belgrade and the company DUALITY. Over the past 18 years LP Duo have become one of the most successful European chamber ensembles. Since 2004, these pianists, composers, and innovators have been experimenting with the endless possibilities of playing on two pianos and developing a new approach to contemporary piano music. Blurring the lines between a chamber ensemble and a rock band, they have become one of the most authentic musical ensembles, performing an almost complete repertoire for the piano duo and two pianos, as well as their original music. They gave Serbian and world premieres of more than 30 contemporary pieces. Many composers have dedicated their music to LP Duo.

Lončar and Pavlović graduated, received their doctorates at the Faculty of Music in Belgrade, and completed their Konzertexamen studies at the University of Music and Theater in Rostock (Germany) with Professors Hans-Peter and Volker Stenzl. They won over 30 awards at international music competitions both as solo musicians and as a piano duo. Among others, in 2011 they were awarded the prize for “greatest individuality” at the international piano duo competition in Bialystok (Poland). They were declared one of the eight best piano duos in the world at the largest global competition Dranoff Miami Two Pianos in Miami (Florida) in 2008. They received the City of Belgrade award for youth creativity, as well as the annual award of the Association of Music Artists of Serbia (UMUS) for the best young artists in 2008 and for the best concert of the year 2019. They received the prize *Bryno Frey Stiftung Landes-akademie Ochsenhausen* in Baden-Württemberg in Germany, which is rarely awarded to foreign nationals. LP Duo performed at the biggest festivals and concert halls around the world, such as Carnegie Hall in New York, John F. Kennedy Center for the Performing Arts in Washington, Meguro Persimmon Hall Tokyo, Royal Theater and Opera Copenhagen, Music in Pyeong Chang, South Korea, as well as on tours throughout Europe, the USA, and Asia.

LP Duo began as a project of classically trained musicians, but their research and work within different artistic disciplines and avant-garde practices defined the originality of their own music, uniting the seemingly incompatible worlds of classical and popular culture, as documented by their numerous local and international releases, and especially the 2019 album *Duality* (Universal Music). Some of the recordings from this album were also selected by the prestigious publishing house Deutsche Grammophon. They compose music for theater, film, TV, dance choreography, and visual art projects. One of their many alter egos is the LP Elektro project, while Andrija Pavlović is also active under the alias Andy Pavlov. So far, they have released ten albums, with music by Chiel Meijering, Kim Helweg, Gyorgy Ligeti, Mark Mellits and other composers, as well as their own music.

Both members of LP Duo have academic careers – in addition to joint master class programs and lectures at various international festivals, professional conferences, and universities (Chicago, Cincinnati,

London, Singapore), Sonja Lončar is an associate professor at the Faculty of Music in Belgrade, while Andrija Pavlović is an assistant professor at the Department of Stage Design at the Faculty of Technical Sciences in Novi Sad.

Throughout their career, LP Duo has experimented with the sound of various analog and digital synthesizers in combination with acoustic pianos. In recent years, together with a group of collaborators and engineers, they have developed a completely new instrument – the DUALITY hybrid piano, with the support of the Serbian Innovation Fund. By adding special hardware to an acoustic piano, they connect it to a computer and manage to easily manipulate any digital sound, light, or video, merging the worlds of acoustic and digital sounds in live performance.

<http://www.lpduo.com>

Aleksandar Brkić is a scholar in the field of cultural/arts management and cultural policy, with significant experience as a producer and arts manager, working in the intersections of performing arts, visual arts, and design. He joined the Institute for Creative and Cultural Entrepreneurship (ICCE), Goldsmiths in 2016. Prior to that, he was teaching at LASALLE College of the Arts in Singapore and the University of Arts in Belgrade. He is a Fellow of the Higher Education Academy (FHEA) and also contributes as a guest lecturer at the University of Arts in Belgrade; Sibelius Academy, University of Arts in Helsinki, and Ben M'Sik, Hassan II University, Casablanca.

Aside from his academic life, Brkić is active as a producer and arts manager for the last 20 years. He was a production director at Studio Berar company from Novi Sad, working on the concerts of Metallica, Vernon Reid, Dele Sosimi, Esmā Redžepova, Šaban Bajramović, Louis. As an events manager, he was engaged in the production of numerous conferences, biennials, festivals, opening and closing ceremonies, and state spectacles. Since 2021 Aleksandar Brkić is part of the Green Art Incubator (GAI) focusing on supporting and strengthening of green transformation of arts and cultural organizations. He is a creative producer of LP Duo.

<http://www.gold.ac.uk/icce/staff/brkic-aleksandar/>

Dragan Novković is a professor of acoustics and audio engineering at the School of Electrical and Computer Engineering of Applied Studies in Belgrade. He holds a doctorate from the Faculty of Technical Sciences, University of Novi Sad. His main topic of interest is architectural acoustics, both at theoretical and practical levels. He is known for his extensive cooperation with a number of scientists and artists, implementing several projects in the fields of technology, art and science connected with sound and music. Within the *Quantum Music and Beyond Quantum Music* projects, he initiated collaboration between scientists in the field of quantum physics and acoustics, with the main goal of exploring the establishment and further development of existing analogies of those two systems. He produced a great number of music concerts and artworks from other areas as the main sound designer and engineer.

<https://www.viser.edu.rs/profil/novkov?userLanguage=eng>

Veronika Liebl is Director of Organization and Finance at the department Festival/Prix/Exhibitions of Ars Electronica. She studied economics and business science at Johannes Kepler University in Linz with study visits at Harvard University (US) and Université de Fribourg (CH), and the Master of Business Administration program for Innovation Management at LIMAK Linz – Austrian Business School. After finishing her studies she was engaged in various commercial employments, amongst others for the Austrian Economic Chamber. Since 2011 she is in charge of cultural management for the department Festival/Prix/Exhibitions at Ars Electronica Linz GmbH. In this capacity, she is responsible for finances, human resources, public funding, internal operations and project management. Recently, she is mainly in control of all European collaboration projects under Creative Europe, Horizon 2020 and Erasmus+ and, in this position – together with her team – she has managed numerous EU projects both as project coordinator and partner.

<https://starts.eu/regional-centers-experts/veronika-liebl/>

Klaus Mølmer is a Danish theoretical physicist, born in 1963. He obtained his PhD in 1990 and was appointed associate professor in

1991 and full professor in 2000 at Aarhus University, Denmark. Since June 2022 he has been full professor at the Niels Bohr Institute, University of Copenhagen. Klaus Mølmer has led several research centers and programs on quantum optics and quantum information. He has contributed to the understanding and application of dynamics, dissipation and measurements in quantum mechanics and quantum optics. He has developed key concepts for quantum computing gates with ions, atoms and photons. Klaus Mølmer has popularized science in more than 100 talks and in articles and book chapters, as well as in a book (in Danish) *Quantum Mechanics: A Wild World of the Atoms*. He was awarded the status of Fellow of the American Physical Society for his outstanding and insightful contributions to theoretical quantum optics, quantum information science and quantum atom optics, including the development of novel computational methods to treat open systems in quantum mechanics and theoretical proposals for the quantum logic gates with trapped ions. Klaus Mølmer has contributed to the “quantum composition” of music and stage performances with composers, musicians, ballet dancers and other artists.

<https://nbi.ku.dk/english/staff/?pure=en/persons/100435>

Snežana Nešić-Davidović studied accordion and composition in Kiev and Hannover, where she has taught composition since 2007. She is Head of New Chamber Music at the Incontri Institute for New Music, The University of Music, Drama and Media in Hannover. She received commissions from the Staatsoper Hannover, the Philharmonie Luxemburg and the Kammeroper Köln, among others. She has won numerous prizes as a composer and accordionist, among them the first Prize of the Molinari Quartet Composition Competition, and in 2015 her opera *The Rain Passed Over* was awarded a prize at the Festival Oper'Actuel-Work in Progress. She was a scholarship holder from the German Academy of Rome and was Artist in Residence in Montreal and in the Wilhelm Kempff House in Positano. She won first prizes at many international competitions, such as the "International Accordion Days Klingenthal" and played as a soloist with numerous orchestras and ensembles, including the NDR Symphony Orchestra Hamburg and the Lower Saxony State Orchestra.

<https://www.snezana-nesic.de>

Danica Radman, ethnomusicologist, musician and visual artist, is the director and coordinator of artistic events and activities at the Mediterranean Institute for Life Sciences (MedILS) in Split, Croatia. Her education encompasses classical ballet and music (violin, piano, singing). Aside from her work as ethnomusicologist, she is a performer and music theorist. Her research has encompassed: 1988–1991 USA: Harvard Widener Library – Milman Parry collection – Albert Lord Private Collection, consisting of 15.000 Serbo-Croatian folk songs, as the first ethnomusicologist engaged in the research of the Collection, after Béla Bartok. 1990: FRANCE: Deben Bhattacharya's World music collection – 8 years of research, analyzing traditional instrumental and/or vocal music collected and recorded over 30 years in the first half of 20th century, from China to Sweden, for UNESCO and for radio transmissions. 1991–1998: GERMANY – WDR5 Köln Worlds Music transmissions; Radio France for WDR5; 1998–2000: TV Mezzo and TV5monde – music advisor for concert broadcasts (Festival Flâneries Musicales de Reims and others).

From 2000 onwards she has worked as a freelance artist in various domains, from photography to new technologies and sound-image intersections.

<https://www.medils.hr/artscience/o-voditeljici>

GALLERY



KAVLI INSTITUTE
of Nanoscience Delft

KAVLI ARTIST
IN RESIDENCE 2022

1 FEBRUARY - 1 MAY 2022

ANDRIJA PAVLOVIĆ

BEYOND QUANTUM MUSIC

Lectures

8 Feb

Welcome event - mini lecture & performance by Andrija Pavlović

24 Feb

Quantum Music - lecture by Klaus Molmer, Aarhus University, Denmark

Mid March

Hybrid Piano Duo - lecture by Sonja Lončar, Faculty of Music Art Belgrade, Serbia

Concert

21 April

LP Duo - final concert 'Beyond Quantum Music' by Andrija Pavlović & Sonja Lončar



Department of Quantum Nanoscience
Opening the quantum world for innovation



Bionanoscience Department
Think big about life at the smallest scale

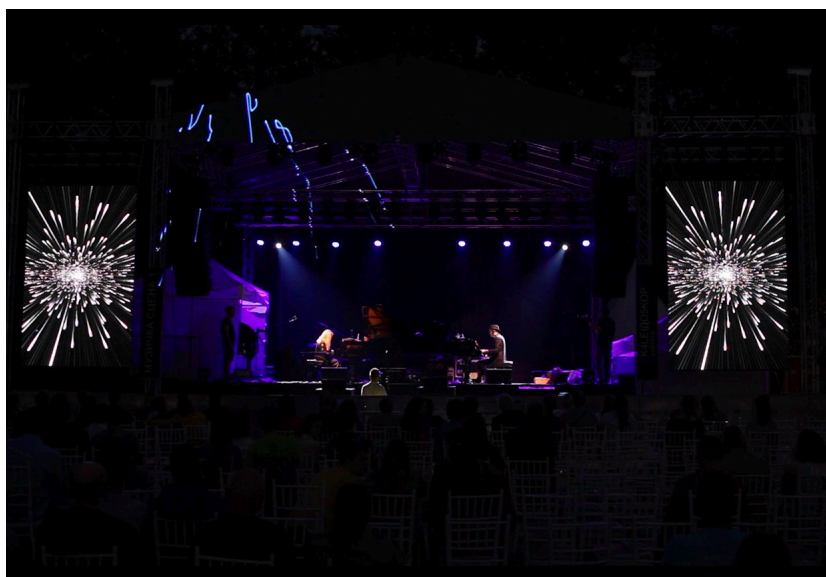


THE KAVLI FOUNDATION

Kavli Artist in Residence, Delft, February-April 2022



Research at the Kavli Institute of Nanoscience Delft with quantum physicist Prof. Dr Klaus Mølmer. Photos: LP Duo



Novi Sad 2022 – European Capital of Culture. Cultural Centre Fabrika,
4 September 2022. Photos: Žarko Andrejić



Ars Electronica, Multimedia concert of LP Duo with Incredible Bob.
9 September 2022. Photos: Tom Mesic, Aleksandar Brkić



Ars Electronica, Multimedia concert of LP Duo with Incredible Bob.
9 September 2022. Photos: Tom Mesic



Ars Electronica, Multimedia concert of LP Duo with Incredible Bob.
9 September 2022. Photos: Tom Mesic, Aleksandar Brkić



Ars Electronica, Presentation of DUALITY Hybrid Pianos.
10 September 2022. Photos: Aleksandar Brkić

LP DUO

BEYOND QUANTUM MUSIC

MEDITERRANEAN INSTITUTE FOR LIFE SCIENCES

ŠETALIŠTE IVANA MEŠTROVIĆA 45, SPLIT

SEPTEMBER 19

20H



Concert in Split, MedILS Institute, 19 September 2022

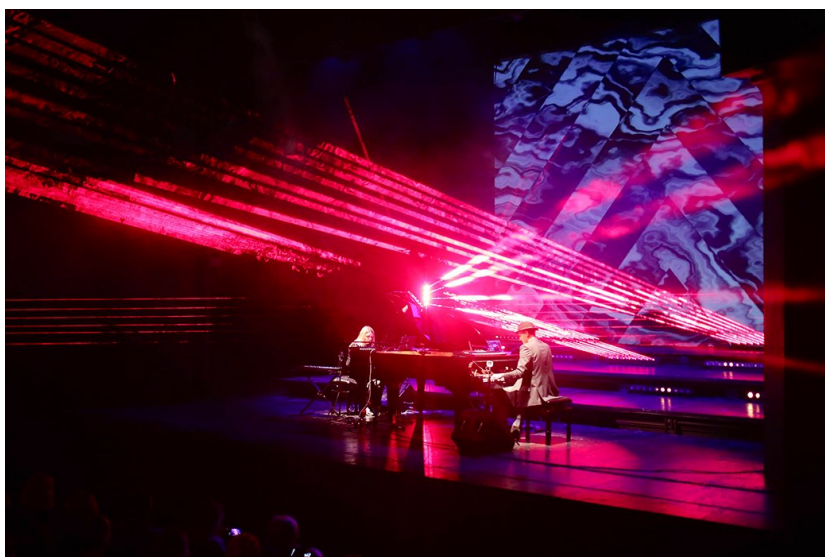


Concert in Split, MedILS Institute, 19 September 2022.
Photos: Aleksandar Topalović

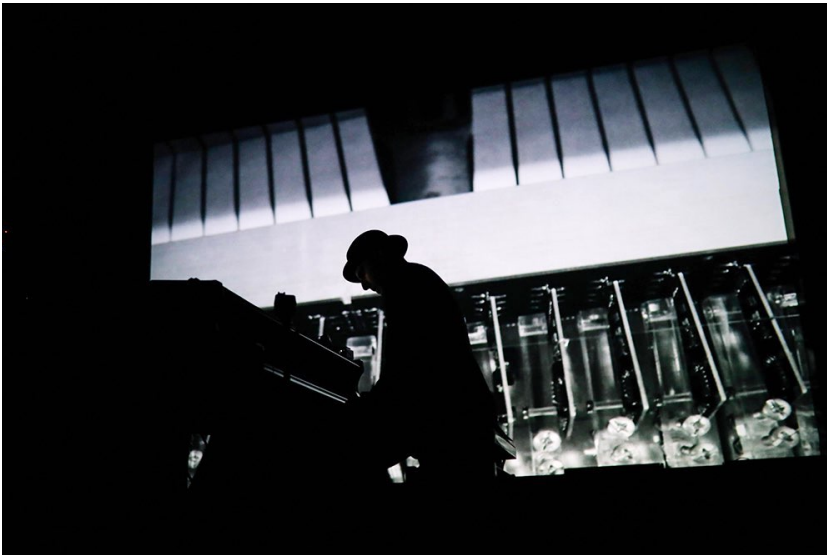


Concert at the Yugoslav Drama Theatre in Belgrade, 3 October 2022.
Photos: Andrej Gođevac

ZERO POINT ENERGY



Concert at the Yugoslav Drama Theatre in Belgrade, 3 October 2022.
Photos: Andrej Godevac



Concert at the Yugoslav Drama Theatre in Belgrade, 3 October 2022.
Photos: Andrej Godevac



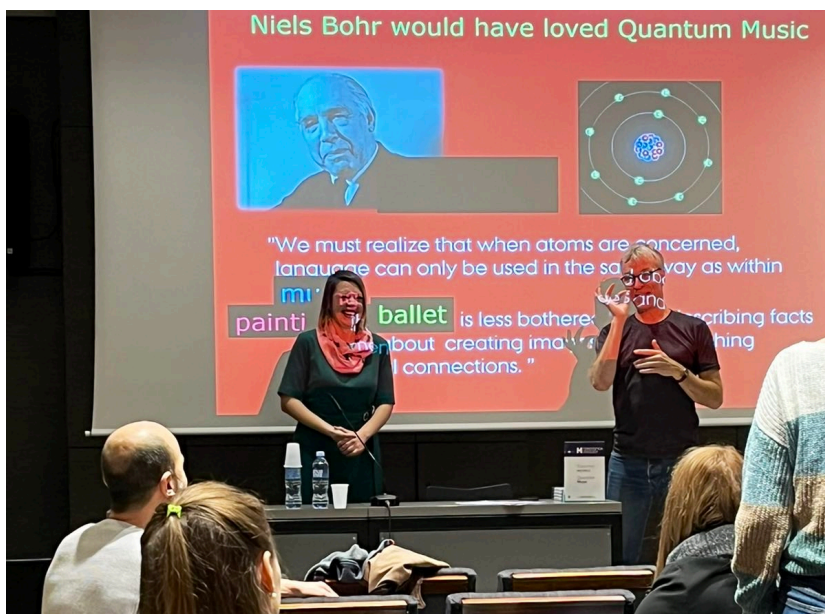
The exhibition *Beyond Quantum Music*, Belgrade, Center for Cultural Decontamination, 10 October 2022. Photo: Igor Vuk



Exhibition Beyond Quantum Music, Belgrade, Center for Cultural Decontamination, 10 October 2022. Photos: Nemanja Knežević



Exhibition Beyond Quantum Music, Belgrade, Center for Cultural Decontamination, 10 October 2022. Photos: Nemanja Knežević



Conference *Seven Years of Quantum Music – And Beyond*, Audio-Visual Center of the Serbian Academy of Sciences and Arts, 15 December 2022. Photos: Bojana Radovanović

EVENTS

CONCERTS

LP Duo

Beyond Quantum Music

Concert for two DUALITY hybrid pianos and synthesizers

INTRO

MAYDAY! MAYDAY! MAYDAY!

SCANNING TUNNELING MICROSCOPE

ROGUE WAVES

COLLAPSE

SILENCE

BETWEEN THE WAVES

QUBIT FUNK

LEMON, HONEY, GINGER

THE END

“Classical elegance, jazz freedom and rock’n’roll power.”

Carnegie Hall, New York

“Brilliant, powerful, intelligent.”

WFMT Radio Chicago

LP Duo (Sonja Lončar and Andrija Pavlović) present their original compositions, created as part of the Art & Science project *Beyond Quantum Music*, co-financed by the *Creative Europe* program of the European Commission (2019-2022), supported by the Ministry of Culture and Information of the Republic of Serbia, Serbian Innovation Fund, SOKOJ, and others. The compositions were created during their artistic residency at the Technical University in Delft (The Netherlands) in the first half of 2022. During this period, Sonja and Andrija had the opportunity to collaborate with the most prominent quantum physicists and microbiologists from around the world, including scientists from the universities of Oxford (UK) and Aarhus (Denmark). **LP Duo** will perform the sounds of quantum computers, moving atoms, and genetic code (immersed in their own, already recognizable musical language) on innovative instruments — **DUALITY Hybrid Pianos**. Sonja and Andrija developed this instrument at their eponymous company, in cooperation with engineers from the reputable American company HTEC and with the financial backing of the Serbian Innovation Fund.

The Art & Science project *Beyond Quantum Music* (2019-2022, co-financed by the *Creative Europe* program of the European Commission) is an extension of the maverick European cooperation project *Quantum Music*, which started in 2015 (also supported by *Creative Europe*). The original idea was to study the sounds and 'music' of the quantum world, through joint efforts and experiments of musicians, quantum physicists, and engineers. The coordinator of the project is the Institute of Musicology of the Serbian Academy of Sciences and Arts. The partners in this project are DUALITY (Belgrade), Ars Electronica (Linz), and the Mediterranean Institute for Life Sciences (Split), in association with the Universities of Oxford and Aarhus, the Technical University of Delft, the Sonar Festival (Barcelona), and the Incontri Institute for Contemporary Music (Hannover). The project has received support from the Ministry of Culture and Information of the Republic of Serbia, Desk Creative Europe, Serbian Innovation Fund, and SOKOJ.

As part of the tour, LP Duo presented this project first in Novi Sad, as part of the program *Novi Sad 2022 – European Capital of Culture, Kaleidoscope of Culture* (4 September), then at the famous *Ars*

Electronica festival in Linz, Austria (9 September), as well as in Split, Croatia, under the auspices of the Mediterranean Institute for Life Sciences MedLS (19 September). The concert held at the Yugoslav Drama Theater in Belgrade on 3 October is the finale of the European tour, included in the program of the *Night of Researchers 2022* event. As part of the Belgrade promotion of the *Beyond Quantum Music* project, a multimedia exhibition and performances by Serbian and international artists inspired by the quantum world took place at the Center for Cultural Decontamination in Belgrade (10–11 October).

LP Duo have been very inspired over the past two years. As exclusive artists of Universal Music, LP Duo have recently released their latest album *Dead Sea* on this label. After the album *Duality* (2019) in which they merged seemingly incompatible worlds, *Dead Sea* is an album that arises and communicates by staying in touch with the subtlest inner experiences and emotions.

PROGRAM

INTRO

All around, you see beautiful phenomena,
you see nature, galaxies, flowers, waterfalls, rainbows,
and a lot of these physical phenomena are described by the same
concepts and ideas.

But when we move down to the very microscopic scale, to the atoms,
which after all are actually what makes up everything in the world
around us,

Life is different. Things are different, reality is different.

MAYDAY! MAYDAY! MAYDAY!

Reality doesn't exist

What we perceive is a small part of reality.

Reality is what you choose to observe.

Reality doesn't exist if you are not looking at it.

“Everything we call real is made of things that cannot be regarded as
real.”

Niels Bohr

SCANNING TUNNELING MICROSCOPE

This is the sound of the scanning tunneling microscope experiment

There are hundreds or even thousands of us

It is very, very cold, close to zero Kelvin

Thousands of us

Thousands of Atoms being manipulated

Jumping around we are manipulated

we are manipulated

we are manipulated

we are manipulated

ROGUE WAVES

Quantum physicists are slowing down the light
Becoming slower, we are energetically efficient
Becoming slower, that's a struggle
Rogue waves are unusually large,
unpredictable and suddenly appearing surface waves
that can be extremely dangerous
extremely dangerous
extremely dangerous
extremely dangerous
extremely dangerous

COLLAPSE

Without anybody to observe it, a particle does not have a well-defined position or velocity. We can only guess where it is, and how fast it is going. It is everywhere at once, traveling at all speeds.
The only way to localize a particle is to observe it. And when we close our eyes, once again only the wave of probabilities remains. But, how do we know that things are like that? How do we know what's going on when we are not looking?

SILENCE

There is no empty space
There is no emptiness at all
Emptiness is illusion
Silence is my quantum vacuum
Quantum vacuum
Zero point energy
Music energy
Silence is my music

BETWEEN THE WAVES

Waves are marvelous forms of energy

Waves transfer energy from one place to another without transferring matter.

The matter is a wave and a particle at the same time.

Two contradictory pictures of reality, separately do not explain the phenomena of the quantum world, but together they do.

This is called the wave-particle duality.

Duality, Duality, Duality, Duality

Waves / Particles

QUBIT FUNK

This is the sound of the quantum computer

LEMON, HONEY, GINGER

“As more and more artificial intelligence is entering the world, more and more emotional intelligence must enter into leadership.” *Amit Ray*

“Success in creating AI would be the biggest event in human history.

Unfortunately, it might also be the last, unless we learn how to avoid the risks.” *Stephen Hawking*

“Humanism directs us to an ethics of care, a practice of care, the development of a compassionate temperament, and the importance of love and kindness.” *Ken Plummer*

THE END

Poetry @ LP Duo

ON THE GENESIS OF THE COMPOSITIONS

INTRO

This is a game with the change of harmonics, as we traditionally know and use them; we called it the "Inflation scale". A complete electronic sound is made on the basis of changing harmonics and creating new scales based on certain molecular states, i.e. quantum systems that the famous Danish quantum physicist Klaus Mølmer "observed" and then shaped into harmonic arrangements, in order to obtain a scale that makes sense and is interesting it sounds. The whole composition is actually an imitation of birth, movement of molecules, changes of quantum states.

MAYDAY! MAYDAY! MAYDAY!

Here we dealt with the question of reality in a philosophical way. What is reality? Does it exist? Does it exist only if we observe it? The father of quantum physics, the Danish Nobel prize winner Niels Bohr, formulated this in the following way: "Everything we call real is made of things that cannot be regarded as real."

SCANNING TUNNELING MICROSCOPE

We worked on the "Scanning Tunneling Microscope" experiment with a wonderful scientist Sander Otte, who works in the quantum laboratory of the Technical University of Delft, The Netherlands. In his laboratory, we directly recorded the sound of moving atoms (we moved them with a type of needle that actually "looks for atoms"). When the atom "jumps", when the needle finds it, a change in sound occurs. Together with Sander, a great lover of jazz and piano, we "assigned" several harmonies to this experiment and built the composition from that material. The basis for the harmonies also came from working with him. So, the path led us from recording and manipulating the sound of atoms in the experiment, to the harmonies that Sonja creates on the synthesizer and Andrija on the piano.

ROGUE WAVES

One of our collaborators from Delft, Kobus Kuipers, allowed us to combine two concepts that he deals with in one composition: one is the slowing down of light, which occurs when light passes through silicon, and the other is the phenomenon of giant waves which appear suddenly, without announcement. Hence, the entire first part is rhythmically based on the delay assigned to Andrija's hybrid piano, which creates periodic waves that rhythmically and dynamically build the material of the composition, which evokes huge waves...

In all compositions, two Artificial Intelligence "beings", Amy and Brian, actually "play" with us, presenting parts of the concepts and phenomena that we dealt with, poetically drawing the narrative into a sociological moment. For example, in *Rogue Waves*, the text "Extremely Dangerous" repeatedly runs through, while in the previous composition, *Scanning Tunneling Microscope*, there is a comment about atoms being manipulated (which is indeed the case in the experiment), but in a figurative sense. Is that what happens in the microscopic world actually a mirror of us, the people who listen to it? The analogies are great and inescapable.

COLLAPSE

This composition evolved from our previous pilot project *Quantum Music* (2015–18), and the title refers to the Bose-Einstein Experiment (BEC). If there is no one to observe the particle, it has no defined position and size. It could be anywhere, and we can only guess where it is and how fast it is moving. It is everywhere at the same time. In this case, the quantum sound was created by the process of additive synthesis, based on the equations of motion of the observed particles created for us by Klaus Mølmer.

SILENCE

The most poetic composition *Silence* is related to the whole concept of quantum music and the idea that "silence" is actually identical to "quantum vacuum". We started it by recording a "deaf room" in Delft for several hours, then turned up the volume and were surprised at what could actually be heard there. Then we followed up on that

"silence" with the idea of creating a composition "out of nothing". "Silence is my quantum vacuum", "Zero point energy", "Music energy", and "Silence is my music", are just some of the poetic "words" that Amy, our Artificial Intelligence friend, interprets.

BETWEEN THE WAVES

The work refers to the phenomenon that a particle is also a wave (wave / particle), which is the concept of Duality. Waves are a huge source of energy; matter is simultaneously both a wave and energy. Duality is a reconciliation of contradictory, conflicting phenomena.

QUBIT FUNK

We worked on this composition together with two wonderful scientists, quantum physicist Eliska Greplova and bionanoscientist Dimphna Meijer. They started working together and studying quantum systems, finding connections with neural systems, cells, molecules, and vice versa... Using quantum computers, the two try to calculate and predict certain behaviors of neurons. Eliska and Dimphna extracted the frequencies of those qubit neuron experiments for us, which we then transferred into sound. First of all, we made a powerful bass line, on which we further added new elements: a minimalist accompaniment, which transitions into the funky groove of qubit (qubit - 0 and 1 at the same time, while the bit is either 0 or 1), and ends with a romantic and gentle atmosphere of fraternization of machines and man, artificial and natural intelligence. All this happens to the beat of the real sound of quantum computers that we recorded in Delft, in a special department where scientists deal exclusively with quantum computers "Qu-tech". We recorded quantum computers for several hours and their "rhythm" was transformed into the rhythm of the entire composition.

LEMON, HONEY, GINGER

Our project is fundamentally humanistic; while diving into the world of quantum particles and artificial intelligence, it is necessary to develop emotional intelligence to lead us forward.

BEYOND QUANTUM MUSIC

MUSIC, SOUND, AND AUDIOVISUAL ART

Multimedia Exhibition – Installations – Live Performances

Centre for Cultural Decontamination, Belgrade

Monday, 10 October 2022

19:00 Opening

INSTALLATIONS

Tadej Droljc: THE HOLE

Dragan Novković and Filip Mikić: LET'S BE STILL

LIVE PERFORMANCES

19:30 Andreja Andrić: CONCERT FOR SMARTPHONE NETWORK

Performers: Maja Bosnić, Małgorzata Żurada, Marija Šumarac & Andreja Andrić

20:15 Joe Beedles: ADDITIVE DUALITY

21:00 Timo Hoogland: PRISM

21:45 Jiří Suchánek: ATOM TONE

Curators:

Ivana Medić (Institute of Musicology, Serbian Academy of Sciences and Arts)

Sonja Lončar & Andrija Pavlović (LP Duo; DUALITY)

Producers:

Janko Dimitrijević and Andrija Dinulović (Turbina, Belgrade)

BEYOND QUANTUM MUSIC

Music, Sound, and Audiovisual Art

Everything in the universe vibrates – light, sound, and every atom or quantum particle. There are inherent analogies between quantum systems and acoustics. Quantum particles oscillate at frequencies far beyond the audible range, in a medium that is not mechanical in the classical sense; hence one can not speak directly of quantum sound, but only of analogies that clearly point to a connection between the worlds still beyond the reach of contemporary science.

Beyond Quantum Music is an international project co-financed by Creative Europe that aims to explore connections between visual arts, music, and quantum physics by means of artistic experimentation, resulting in live performances and other types of interactions with European audiences. The project presents quantum physics and the quantum world to a wider audience and contributes to the creation of a new music genre: Quantum Music.

In 2020 we published an Open Call, looking for adventurous artists to explore the deeper meaning of the universe through the quantum physics phenomena. We welcomed submissions for any kind of digital art, sound installations, video works, as well as music that connects analog and/or acoustic instruments with the digital ones, the old and new sound worlds.

The covid-19 pandemic caused many delays and setbacks, however, we are happy to present the artists whose works were selected to be presented at the Belgrade exhibition, hosted by the Centre for Cultural Decontamination (CZKD): Andreja Andrić (Serbia/Denmark), Joe Beedles (United Kingdom), Tadej Droljc (Slovenia), Timo Hoogland (The Netherlands) and Jiří Suchánek (Czech Republic). Andreja Andrić will be joined in a live performance by three fellow composers: Małgorzata Żurada (Poland/Switzerland), Maja Bosnić (Serbia) and Marija Šumarac (Serbia/Finland).

The exhibition will also showcase an installation created by visual artist Filip Mikić and produced by Dragan Novković, electro-engineer and acoustician, who was one of the initiators of the Quantum Music project, together with quantum physicist Vlatko Vedral.

The Belgrade exhibition and performances were curated by Ivana Medić (Institute of Musicology SASA), Sonja Lončar and Andrija Pavlović (LP Duo; DUALITY), and produced by Andrija Dinulović and Janko Dimitrijević (Turbina).

<http://quantummusic.org/>

Andreja Andrić: CONCERT FOR SMARTPHONE NETWORK

Concert for Smartphone Network is a work for a distributed networked ensemble of mobile phones. It is at the same time a music composition, a piece of distributed computer software and collective improvisation practice. The performers develop the music together and use the network system to explore new ways to connect with each other through collective music-making.

Both the software and the music work have been developed by Denmark-based Serbian composer and computer programmer Andreja Andrić during the first half of 2020. The software performs sound synthesis, visual effects, and music-related network communication. It combines and synchronizes the individual music lines of different performers into one music flow, mitigating network delays over long-distance networks. This makes it possible for The Ensemble to perform together in precise synchronization without having to be in the same place. The work is performed by the Ensemble consisting of Maja Bosnić (Serbia), Małgorzata Żurada (Poland/Switzerland), Marija Šumarac (Serbia/Finland), and Andreja Andrić (Denmark/Serbia), performing in live streaming from their respective countries.

The project evolved from its predecessor and companion work Concert for Computer Network, which was created by Andrić in 2019 for a similarly distributed ensemble of laptop performers.

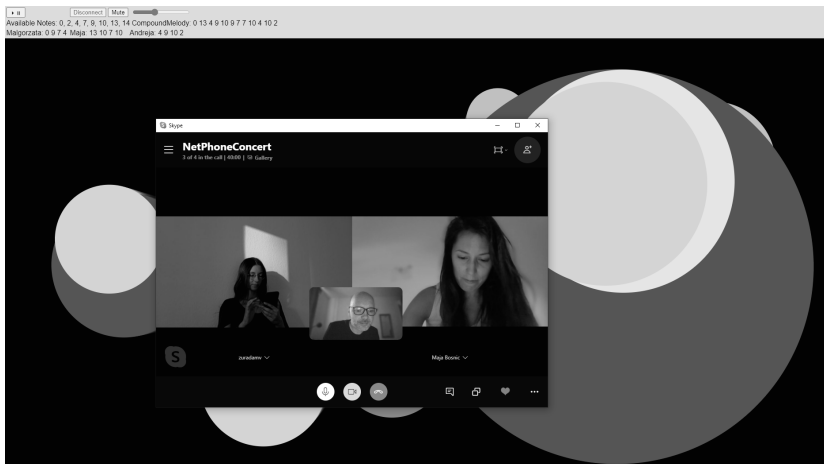
Certain aspects of the composition are built into the software itself. Some other aspects are free and the musicians can improvise and explore within the limitations and possibilities that the software provides.

The work is typically an hour-long performance of fast intense loops of synthesized sound. The music explores variation, repetition, and dependencies between harmony and sound color in natural (non-tempered) scales and low (1-bit) sound resolution. This is a point in which Concert for Smartphone Network connects with Quantum music. Namely, it takes inspiration from an idea of a limited number of discrete quantum states, and has the sound, on the micro-level, oscillate between two discrete states in ever different combinations. This idea, coupled with a trance-like state that the piece evokes in listeners and performers alike, connects with the studies of consciousness from the quantum perspective, as exemplified in research by Prof. Dejan Raković of the University of Belgrade (“The Transitional States of Consciousness as a Biophysical Basis of Transpersonal Transcendental Phenomena”, in *Int. J. Appl. Sci. & Computat.*, Vol.7, No.3 (2000), pp. 174–187).

The performers use a simple touch-and-swipe interface where they change the melodic content and various parameters of sound. The audience can

follow what the performers are doing through a computer screen showing what the performers are typing, alongside a visual effect.

Concert for Smartphone Network and its predecessor and companion work, Concert for Computer Network, have been performed many times. Twice in real-life concerts: at club Dim in Belgrade (duo Bosnić/Andrić, 8 January 2020) and at Udstillingstedet Spanien 19c in Aarhus (Žurada/Andrić, 23 November 2019). Further performances were distributed and live streaming, first as a live-streaming event on YouTube (Žurada/Bosnić/Andrić, 21 April 2020), then at the Station of Commons (Žurada/Bosnić/Andrić/Visti, 31 May 2020), Network Music Festival (Žurada/Bosnić/Andrić/Visti, 17 July 2020) and Oscilloscope monthly event (Žurada/Bosnić/Andrić, 25 August 2020).



Andreja Andrić is a Serbian composer and programmer, living in Aarhus (Denmark) since 2014. He enjoys playful explorations of mathematical processes and chance. He uses computer programming as a key means of artistic expression, with the aim of discovering pristine, dynamic, and complex sound worlds. A pioneer of solo smartphone symphony as a music genre and of smartphone recital as a concert practice, he is also active in the fields of computer music, video, and software art. His works have been performed in festivals such as World Music Days 2019 in Tallinn, Estonia, eviMus festival (Saarbrücken, Germany, 2019), and Festival Futura in Crest, France (2018). He holds a PhD in Music Informatics from the State University of Milan, Italy.

<http://andrejaandric.altevista.org/>

Małgorzata Żurada is an interdisciplinary artist, researcher, and art writer from Poland, currently based in Zurich (Switzerland). She develops her works from esoteric theories and rituals of the past and present. The main areas of her research are visual languages connected to various belief systems and means of coding secret knowledge. Recipient of grants and awards, including a scholarship from the Ministry of Culture and National Heritage of the Republic of Poland in 2016. Co-founder and curator of galleries Basen (2009) and 81° (2011–2013). She works mainly with sculptural installations, digital images, text and sound.

<http://mzurada.com>

Maja Bosnić is a composer and performer from Belgrade. She is drawn to impossible missions, absurd solutions, limited material, playfulness, uncertain outcomes, audience participation, treating instruments as ready-made objects of expression, and treating real-life objects as musical instruments. Maja received a PhD in Music Composition from Goldsmiths, University of London (UK). Bosnić's works have been performed in festivals, such as Impuls (Austria), CTM Festival, Darmstadt Summer Courses, and many others. She was awarded scholarships by the Ministry of Youth of the Republic of Serbia, Donaueschinger Musiktage 2014, and Delian New Music Academy in 2019. She works at the Faculty of Music in Belgrade, Department of Composition.

<http://majabosnic.net>

Marija Šumarac is a sound designer, composer and trombonist from Serbia, living in Finland. She holds a MA in Recording and Sound Design from the University of Arts Belgrade and she is currently studying at Aalto University, MA Sound in New Media. She gained performing experience in ensembles such as the Youth Philharmonic, FMA Big Band, New Spark Jazz Orchestra, and many others. Her orientation towards sound manipulation through working experience in film, radio (Electronic Studio of the Radio Belgrade 3), theatre, television, and video games strongly influences her composition and drives her interest in sound manipulation. She has presented her work internationally at venues, festivals, and events such as Prague Quadrennial 2019, Ars Electronica Linz, European Science Open Forum (ESOF) Trieste, Speculum Artium Trbovlje, gallery Studio106L.A. and UCLA ArtSci Center Los Angeles.

<https://soundcloud.com/marija-sumarac>

Joe Beedles: ADDITIVE DUALITY

Incorporating the concept of the Quantum Synthesizer alongside a wholly additive synthesis palette, I explore ideas of complementarity in the manner of Niels Bohr through an exploration of phase and beat frequency relationships. I simultaneously extend the dimensionality of the sound waves, scaling audible frequencies to drive a laser beam that projects the sound's visual counterpart in a physical space. Patterns produced by the laser frequently resemble atomic nuclei and particle formations, hinting at wormholes and vacuum states.

Ideas and concepts concerning the quantum field are often difficult to grasp or daunting to the uninitiated – I confess that the conversation surrounding quantum mechanics often makes me feel out of my depth. However, being invited to creatively respond to some of the fundamental principles within quantum theory, it was exciting to interpret these ideas in a way analogous to my understanding of the harmonic relationships present in additive synthesis and laser-beam modulation, elucidating some of the core concepts through play and experimentation. The immediate experience of being able to hear and see the direct translation (of what is essentially a study on vibration and wave relationships) brings about a new-found awareness on the subject of quantum theory and I hope will inspire new understandings and interpretations within a diverse audience.



Photo: Nadine Oliver

Joe Beedles is an artist working with audio, video, laser, and lights. Primarily an electronic musician, Joe also creates gallery installations that often see him removing himself from the role of performer and instead allowing autonomous systems to generate content from algorithms or pre-set rules; where audio elements trigger lighting and projections simultaneously.

His work has been featured in both club and gallery contexts internationally. His hypnotic AV live show has been featured at Future Everything festival at The Whitworth, Manchester, No Bounds festival in Sheffield, and Cafe Oto in London. Joe has held residencies at The Banff Centre, Canada (2016), Chongqing, China (2017), Johannesburg, South Africa & Maputo, Mozambique with the British Council (2019).

<https://joebeedles.website/>



JOE BEEDLES

Tadej Droljc: THE HOLE

The Hole is an audio-visual installation that brings to light the intoxicating quality of echoes that are generated in a hole. Here echoes – multiple reflections of sound – are implemented as light reflections instead. The dance of the bouncing photons forms light structures and invites the audience to turn into listeners and listen with their eyes. Long sound echoes generally create a sensation of frozen time and act stimulating. They allude to the afterlife and to mystery, no wonder temples use them to create a sense of contact with the divine. In this sense, this work is no exception: it also considers the hole as sacred, however long sound echoes are replaced with light echoes. At the quantum level, the hole is an essential component of everything material while at the abstract level it represents the source of imagination.

The Hole is a place where we came from and where we are headed. The hole is the essence of matter and the source of imagination. The hole is elusive energy that can be experienced only as an undefined feeling. This infinite potential of the hole, combined with its striking presence, acts as a mysterious portal into a different reality.

Tadej Droljc: concept, light composition, laser programming, 3D modeling, CAD drawings, rock painting, and fine texture

Miha Zupan: implementation of the basic rock structure and assistance in finishing

Marko A. Kovačič: sculpting, carving, and basic rock texture

Dijana Jež: moss craft

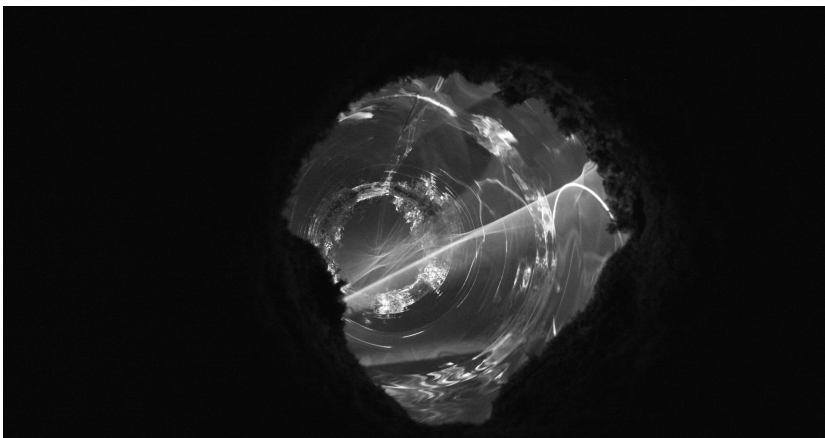


Photo: Jure Niedorfer

Tadej Droljc is a Slovenian artist and creative coder who works at the intersection of sound, image, and light.

For his work, Tadej was awarded the Lumen Prize Student Award, the Dennis Smalley scholarship in electroacoustic music, and he won the most promising Video Artist prize at Madatac. His practice-based doctoral research was awarded the Vice Chancellor's Award for an outstanding thesis at the Centre for Research in New Music. A work from his collaborative project Synspecies won the Edigma Semibreve award and was shortlisted for the Lumen Prize in the category of moving image.

Tadej performed and exhibited at festivals such as Ars Electronica, Mutek, Paris Biennale NEMO, L.E.V., Brighton Digital Festival, Semibreve, Sonica Glasgow, Lunchmeat, Node, etc. As part of his collaboration with Ars Electronica's Future Lab on the project Immersify, his work is permanently exhibited at Ars Electronica's Deep Space 8K and was presented at events like Inter BEE Tokyo, IBC Amsterdam or Marché du film – Festival de Cannes.

<https://www.tadej-droljc.org/>



TADEJ DROLJC (photo: Joan Russell)

Timo Hoogland: PRISM

I am always searching for new ways in which I can use phenomena in nature as input to generate rhythms, melodies, sounds, and visuals. In the past, I have used concepts like Pythagoras' Harmony of the Spheres (orbital rotation ratios) and chaotic models like the famous Lorenz Attractor to generate audiovisual installations and performances. In my previous research, I used the absorption and emission spectra of a Hydrogen-like atom as a starting point for sonification. When an electron is excited by absorbing a photon, upon collision the electron moves to a higher energy level in the atomic orbital (or orbital shell). When the electron falls back to a lower orbital the energy is released in the form of a photon particle/wave. The color that appears is determined by the photon's wavelength or frequency.

In this work, I reimagine the sonification of atoms with my current research in live coding, algorithmic composition, and generative music. Atoms will be live generated through code and their emission spectra of visible light are used as overtone series for synthesis. This is done by translating the wavelengths of the light spectrum to an audible range by dropping the frequency by many octaves. The interference patterns that emerge by combining all the frequencies result in various rhythmical and harmonic/disharmonic sounds. During the performance, different emission spectra will be explored and used in a live-coded manner. The rhythmic and harmonic structures are combined with an experimental mix of electronic music. The visuals will complement the performance by giving an impression of the emission spectra.



Photo: Carolien Teunisse

Timo Hoogland is a computational artist, live coder, music technologist and educator from Apeldoorn (NL). He livecodes experimental electronic dance music and develops generative audiovisual compositions, installations and performances. He graduated from the Masters of Music Design at the HKU University of Arts Utrecht in 2019, where he developed the livecoding environment Mercury to help research and develop algorithmic composition techniques and generative visuals in livecoded audiovisual performances. He built a site-specific generative av-work titled *c26h21n3o3+o2*, inspired by bioluminescent lifeforms, presented in the former Pieter Baan Centrum in Utrecht during the Uncloud Festival 2020. He worked on various audiovisual projects ranging from live stopmotion animated audio-reactive visuals in the LoudMatter project - together with Marieke Verbiezen performed in Bergen - to generative visuals for Biophonica, a live electronic piece about mass extinction by Evelien van den Broek - premiered during November Music in Den Bosch. He has an active role in organizing livecoding meetups and Algoraves with Creative Coding Utrecht, is part of the Netherlands Coding Live community and performed at various events and festivals such as ICLC, ADE, Gogbot, Tec-Art, Droidcon Turin and React Amsterdam. He teaches creative system and sound design at the HKU Bachelor of Music Technology.

www.timohoogland.com/



TIMO HOOGLAND (photo: Annebel Bunt)

Jiří Suchánek: ATOM TONE

Atom Tone is an experimental project based on the sonification of atomic data. It is the result of Jiří Suchánek's sonification research during work on his PhD thesis. The project attempts to convert chemical and physical logic into a musical one. The base dataset for the formation of all the sounds consists of atomic spectral lines recalculated into sound frequencies. Each oscillator used in additive synthesis is tuned to the recalculated exact light frequency of the atomic emission spectral line. Each element thus creates a specific atonal "chord". This spectrum is then modulated with several customizable processes. Parameters for these processes are set up only with numbers taken from Mendeleev's periodic table of elements related to the chosen atom. The aim is to discover musical logic based on the inner proportions and selected properties of the atoms.

"Music as a chemical reaction... or chemical reaction as music?"

This project is based on spectral microtonal aesthetics and is searching for specific qualities found thanks to developed sonification methods.

The project Atom tone can take several art forms – audiovisual performance, sonic object, and immersive installation. For the Beyond Quantum Music event, the project will be presented in its purest form – as a fixed media sound composition.



Photo: Filip Dušek

Jiří Suchánek is a sound and media composer, experimentalist and constructor focused on creating permanent audio-light installations and systems that are usually interactive and placed in natural or public spaces (like a cave, astronomic observatory, or bridge). In his works, he often involves natural, chaotic, thermodynamic processes in the generation or controlling of emerging music and light patterns. He promotes the idea of open, shared authorship, where the environment is a co-author of the art piece. Through the transformation - sonification of chaotic events, he explores the possibilities of experiencing and knowing reality through sound. It examines the psychological and metaphysical effects of the complex vibrations created in this way and the influence of the author's design of the entire sonification architecture on the resulting perception. His electroacoustic music also intertwines an interest in non-linearity, organic sound forms that arise from observing nature. In his intermedial work, he normally synesthetically combines sound, light, objects, mechanics, electronics + code with carefully selected spaces. Among other things, he received the Excellence in sound art @ sound design award at the prestigious international conference *klingt gut!* Symposium on Sound in Hamburg 2018 for his project "Atom tone" sonifying Mendeleev's periodic table of elements and spectral lines of atoms. He realized a large number of long-term multimedia installations in public space, exhibited and performed concerts at a number of international festivals and conferences such as CTM, UNSOUND, ICAD, NEXT, NCCA, STIMUL, ENH, NIME, *klingt gut!* STEIM, or Institute of Sonology. In 2020, he defended his dissertation at JAMU on the subject of Sonification in musical composition and sound art. Among other things, he teaches subjects dealing with sound art, sound production, and audio technologies at art universities in the Czech Republic (FaVU VUT, JAMU). In 2020, he founded the association SVITAVA – transmedia art lab.

www.jiri-suchanek.net



JIŘÍ SUCHÁNEK

(photo: Karolína Kohoutková)

Dragan Novković and Filip Mikić: LET'S BE STILL

The installation *Let's Be Still* condenses the eternal relationship between cognition and comprehension. The ever-renewable information matrix of what is called reality intertwines the issues of relationships at micro- and macro-levels, which in turn define the observed in the consciousness of the observer. This very beginning, the primary information field as a source of all energy, even life, experiences its embodiment in the eyes of observers. The notions of space and its antipode, a negative, reactive, extra-spatial component in this work evoke the archetypal structures of *Alice Through the Looking-Glass*, Alice who freely enters and leaves an imaginary world. *Let's Be Still* emphasizes the need for original peace – negative space, counter-space, whose immeasurable relations in non-stop movement generate space and time in which we all exist.

Author of the installation: Filip Mikić

Consultant: Dragan Novković

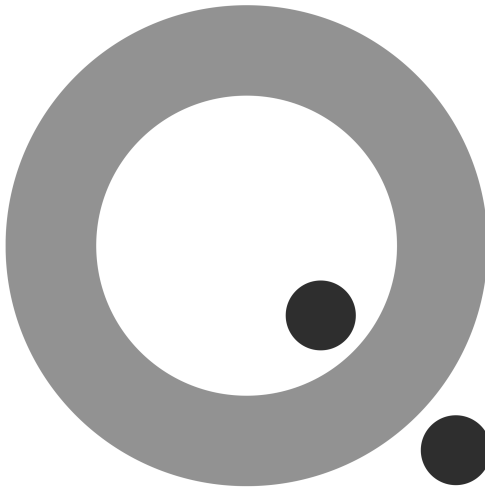
Dragan Novković graduated from the Department of Telecommunications at the Faculty of Electrical Engineering in Belgrade, where he also obtained a Master's degree in Technical Acoustics. He defended his doctoral dissertation at the Faculty of Technical Sciences in Novi Sad. He is a professor at the Audio and Video Technology Department of the College of Electrical Engineering and Computer Science in Belgrade. For more than twenty years, he has been intensively engaged in studio work and has collaborated with a large number of artists. He has recorded over 200 concerts as the main sound engineer. He designed over 40 studio and concert spaces in our country and abroad. He is active in the field of designing and leading international projects in the fields of higher education and culture. Through engagements in the NGO Kulturakt and the New Art Center, he participated in the implementation of several dozen projects in the field of culture and art in our country and in the region. He is one of the initiators of the projects *Quantum Music* (2015–18) and *Beyond Quantum Music* (2019–22).

<https://www.viser.edu.rs/profil/novkov>

Filip Mikić is a freelance visual artist. He graduated from the High School of Fine and Applied Arts in Belgrade in 2006, majoring in applied graphics. In 2011 he graduated from the Department of New Media and Visual Communications, Megatrend University, Belgrade. He has participated in several group exhibitions in Serbia and worked on numerous theatre performances in Serbia and abroad.



DRAGAN NOVKOVIĆ (photo: Ivan Zupanc)



**SEVEN
YEARS OF
QUANTUM
MUSIC – AND
BEYOND**

International
Conference

Keynote Address

Prof. Dr Klaus Mølmer

(Niels Bohr Institute, Copenhagen)

“Science and Music – Where Curiosities Meet”

Serbian Academy of Sciences and Arts
Institute of Musicology
AVA Center
15–16 December 2022

Organising Committee:

Dr Ivana Medić
Dr Marija Dumnić Vilotijević
Dr Bojana Radovanović
Dr Marija Maglov
MA Miloš Bralović
MA Monika Novaković
MA Stefan Savić
MA Marija Hauk

PROGRAM

Thursday 15 December 2022

AVA Center, Serbian Academy of Sciences and Arts

Knez Mihailova 36, 1st floor

Plenary Session

Moderators: LP Duo (Sonja Lončar and Andrija Pavlović – DUALITY)

- 11:00 - 11:15 Opening Address
 Olga Sismanidi (EACEA, Brussels)
- 11:15 - 11:50 Ivana Medić (Institute of Musicology SASA, Belgrade)
 “Seven Years of Quantum Music”
- 12:00 - 13:00 Keynote Address
 Klaus Mølmer (Niels Bohr Institute, Copenhagen)
 “Science and Music – Where Curiosities Meet”
- 13:00 - 13:30 Discussion
- 13:30 Lunch and Cocktail (at the Institute of Musicology SASA, 4th floor)

Friday 16 December 2022

Institute of Musicology, Serbian Academy of Sciences and Arts
Knez Mihailova 36, 1st floor, Room 410

<https://zoom.us/j/95417342969?pwd=UG13MC9HdmorNTh5MnNqU3Z0OXI0Zz09>

Moderator: Ivana Medić

- 10:00 - 10:30 Aleksandar Brkić (Goldsmiths, University of London)
“From STEM to STEAM: LP Duo and Translating and Interpreting Between Art and Science”
- 10:30 - 11:00 Dimphna Meijer (Delft University of Technology)
“How Neurons Form Networks”
- 11:00 - 11:30 Eliška Greplová (Delft University of Technology)
“Quantum AI Meets Quantum Music”
- 11:30 - 12:00 Sander Otte (Delft University of Technology)
“Jazz Improv With Atoms”
- 12:00 - 12:30 Discussion and closing remarks

ABSTRACTS

Plenary Session

Dr Ivana Medić, Senior Research Associate
Institute of Musicology, Serbian Academy of Sciences and Arts
ivana.medic@music.sanu.ac.rs

Seven Years of Quantum Music

In this introductory talk I discuss cooperation projects *Quantum Music* (2015-18) and *Beyond Quantum Music* (2019-22), co-financed by Creative Europe and Serbian Ministry of Culture; the development of new hybrid instruments DUALITY was also supported by the Serbian Innovation Fund.

When starting the project, there were several pressing questions to answer: Is it possible to write "new music" in the 21st century? What does it mean to be "new"? Can the present-day "new music" be as relevant as it was some 50-60 years ago? Being a fan of the maverick avant-garde period in postwar European music, I have felt for quite some time that contemporary music has become boring and predictable, so I jumped at the opportunity to get involved with something new. In this presentation, I will describe this project and its main objectives – to bring the imaginary principles of quantum physics closer to a wide audience through music and to demonstrate how the laws of quantum physics and the aesthetics of music interact. The research has taken us in several directions simultaneously; I will outline them all and present our results. I will also dissect the "newness" of our project, as well as the possibilities of marketing such a project when the network and the infrastructure that used to support the post-WW2 "new music" have largely dissolved.

Ivana Medić is a Senior Research Associate at the Institute of Musicology SASA, Associate Lecturer at the School of Computing in Belgrade, Visiting Research Fellow with the Center for Russian Music,

Goldsmiths, University of London, and a convener of the REEM/ BASEES Study group. She is Head of the international projects Quantum Music (2015-18) and *Beyond Quantum Music* co-financed by the EU program *Creative Europe* (2019–22), and Head of the project *Applied Musicology and Musicology in Serbia: Making a Difference in Contemporary Society* (2022–24) financed by the Serbian Science Fund. She is Vice-President of the Serbian Musicological Society.

KEYNOTE ADDRESS

Dr Klaus Mølmer, Professor
Niels Bohr Institute
University of Copenhagen, Denmark
moelmer@phys.au.dk

Science and Music – Where Curiosities Meet

Along with my research and teaching in university environments, I have carried out many outreach activities in schools and given talks to general audiences. These have brought me in contact with people from all strands of life and have led to discussions of quantum physics with poets, authors, painters, theatre directors, composers, musicians and ballet choreographers. Such discussions have been extensive and systematic with Danish composer Kim Helweg and with Serbian composer and musician Andrija Pavlovic, and they have led to an exchange of inspiration and content for orchestral, solo cello and piano duo concerts and for ballet performances, and new musical scales that all incorporate narratives from quantum physics. In this talk, I will share my experience and my thoughts about the process of establishing a common working language for scientists and artists. I am deeply thankful for these interactions, and apart from sharing my excitement and enthusiasm for every process and project that we have entertained, I will try to articulate my thoughts about how these provide not only new material and insights for the arts but also for the sciences.

Klaus Mølmer is a theoretical physicist, born in 1963. He obtained his PhD in 1990 and was appointed associate professor in 1991 and full professor in 2000 at Aarhus University, Denmark. Since June 2022 he has been full professor at the Niels Bohr Institute, University of Copenhagen. Klaus Mølmer has led several research centers and programs on quantum optics and quantum information. He has contributed to the understanding and application of dynamics, dissipation and measurements in quantum mechanics and quantum optics. He has developed key concepts for quantum computing gates

with ions, atoms and photons. Klaus Mølmer has popularized science in more than 100 talks and in articles and book chapters, as well as in a Danish textbook on Quantum Mechanics. Klaus Mølmer has contributed to “quantum composition” of music and stage performances with composers, musicians, ballet dancers and other artists.

Dr Aleksandar Brkić, Lecturer
Goldsmiths, University of London, United Kingdom
Institute for Creative and Cultural Entrepreneurship
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From STEM to STEAM: LP Duo and Translating and Interpreting Between Art and Science

Working as a creative producer of LP Duo on a number of projects, initiatives and project ideas, including (Beyond) Quantum Music, often placed me in challenging situations that required engagement in the processes of (re)interpretation and translation. Artistic and scientific research are colliding, with different challenges in professional, social and creative realms asking interdisciplinary teams to work in spaces of insecurities hoping it will lead us to successful innovations. I will discuss different challenges that we faced together in the process of developing creative spaces that engage artists, engineers and scientists in efforts to move towards the unknown and construct the "spaces of potential", translating and interpreting them in and for the world of arts and science. This process of bridging the perceived differences between the worlds of STEM ("useful") and STEAM ("useless"), is one of the main pillars of LP Duo's art&science methodology.

Aleksandar Brkić is a scholar in the field of cultural/arts management and cultural policy, with significant experience as a creative producer and arts manager, working in the intersections of performing arts, visual arts, and design. He joined the Institute for Creative and Cultural Entrepreneurship (ICCE), Goldsmiths in 2016. Prior to that, he was teaching at LASALLE College of the Arts in Singapore and the University of Arts in Belgrade. He is a Fellow of the Higher Education Academy (FHEA) and a guest lecturer at the University of Arts in Belgrade and Ben M'Sik, Hassan II University, Casablanca. Aleksandar Brkić is a member of the Regulations Committee of Goldsmiths. He is a series editor of "Routledge Focus on Global Creative Economy" published by Taylor&Francis and an Associate Editor of The European Journal of Cultural Management and Policy.

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How Neurons Form Networks

In my research lab at TU Delft, the Netherlands, we study how neurons form networks at the molecular, cellular and tissue level. In this talk, I will give an introduction to the basic principles of neuronal network formation and zoom in on the cell biology of the neuron, the main functional unit in our brain. I will emphasize the current outstanding questions in our field, and explain how we can tackle these questions with a bottom-up approach. I will discuss how interactions with writers, artists and music composers are a driving force behind our team science, create novel insights and foster new collaborations.

Dimphna Meijer is Assistant Professor and tenure-track group leader in the Bionanoscience Department of the Applied Sciences Faculty of Delft University of Technology (TUD) since 1-10-2018. She obtained her MSc (*cum laude*, 2008) in Experimental and Clinical Neuroscience from Utrecht University (UU). She carried out her PhD research (2009–14) on biochemical characterization of neuronal transcription factors in the Neurobiology Department of the Harvard Medical School (HMS) in the research group of Dr. Charles Stiles. After returning to the Netherlands for postdoctoral work in the Crystal and Structural Chemistry Department at Utrecht University, she joined the TU Delft Faculty in 2018 where she established the Quantitative Neurobiology group.

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Quantum AI Meets Quantum Music

At Quantum Matter and AI Lab at TU Delft we are working on merging artificial intelligence and quantum computing with the ultimate goal of making these two fields mutually beneficial and more widely applicable in the new generation of technology. Trying to combine two radically different emerging technologies oftentimes leads to interdisciplinary collaborations and exciting intersections with other fields. One of our recent use-case playgrounds has been neuroscience and specifically processing of the large amounts of data biological neurons exchange with each other with the help of artificial intelligence and potentially also quantum computing. It was no surprise this interdisciplinary project that caught the attention of LP Duo, our artists in residence at the time. They worked with us to create a composition that has ingredients from all the fields mentioned above, thus adding to the efforts of merging and information exchange within diverse scientific efforts. In this talk, I am going to explain how one can conceptually combine artificial intelligence, quantum computing and neuroscience and how can all these fields contribute to the work of innovative music composers.

Eliška Greplová is Assistant Professor at Kavli Institute of Nanoscience at Delft University of Technology in the Netherlands. She leads "Quantum Matter and AI" group which works at the intersection of quantum technologies, artificial intelligence and condensed matter physics. She is a visiting researcher at Microsoft Research Amsterdam and a member of World Economic Forum Global Future Council on Quantum Computing. She co-founded Virtual Science Forum, a platform for online scientific events. Previously, she was a postdoctoral researcher at ETH Zurich in the group of Sebastian Huber. She obtained her PhD under the supervision of Klaus Mølmer at Aarhus University and worked in the group of Ignacio Cirac (Max Planck Institute of Quantum Optics) during her master studies.

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Jazz Improv With Atoms

In our research, we study the interaction between quantum spins of individual magnetic atoms. We use scanning tunneling microscopy to position the atoms in arrangements of our choice. The exact placement of the atoms on the underlying crystalline surface determines the sign and strength of their magnetic interactions as well as the spin-orbit coupling experienced by their spins. As such, the positioning of the atoms offers us a toolbox where we can tune various design parameters that influence the resulting physical behavior of the combined spin system. There exists an interesting parallel between this approach and my hobby, jazz piano improvisation, where a limited set of tools can also provide a seemingly unlimited wealth of unexpected possibilities. In this talk, I will give a brief introduction to both my research and my hobby and elaborate on how each provides inspiration for the other.

Sander Otte works as a professor of physics at the Faculty of Applied Sciences at TU Delft. He is currently a teacher in the Applied Physics program providing courses in both quantum and classical mechanics. Sander Otte is involved in the Pre-University Physics MOOC, because he wants to reduce the gap between physics taught at a high school level and at an academic, more formal, level. Having performed research in various labs in The Netherlands and the United States, he now leads his own research group, which investigates atomic scale phenomena using low-temperature scanning tunneling microscopy. In particular, his group focuses on the transition between quantum nature and the classical manifestation of matter.

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