DOI https://doi.org/10.2298/MUZ1824061H
UDC 789.983:792.01
530.145:78.01

# Composing with Quantum Information: Aspects of Quantum Music in Theory and Practice

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Received: 10 April 2018
Accepted: 7 May 2018
Original scientific paper

Abstract

*Quantum Music* is the title of a research project that opened up an opportunity to investigate the relationship between art and science – to be precise, between music and quantum physics. The idea was to create a platform for innovative work with musical composition and musical instruments inspired by the theories of quantum mechanics. The further development was carefully put into the hands of the different members of the project with such different competences as sound design, physics, musical live performance, composition, light design and musicology. In this connection, I fulfilled the role and interest of the composer as well as representing the performing arts (dance and acting). The aim of my participation was to show how collaboration between music and science could result in a development of different functional approaches to compositional strategies in general and give a new perspective for the artistic thinking in music as well as in the performing arts in general.

This article is written as a part of an artistic research and the ideas, statements and conclusions presented in it are to be understood as being directly linked to creative work. But indeed, I also hope this text will provide inspiration to approach music in a new way, both for listeners, musicologists, musicians and other performing artists.

Keywords: *Quantum Music*, quantum scales, probability music, quantum narratives, choreomusicology, quantum music theory, quantum music composition

* This article was written for the project Quantum Music, co-financed by the EACEA within the programme *Creative Europe* (559695-CREA-1-2015-1-RS-CULT-COOP1).

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## Introduction

At a first glance, the term *Quantum Music* does not really make sense. It could almost be regarded as a conceptual postulate, since two different objective levels of reality are joined together and presented in coordination.

Quantum mechanics is a theory of the micro world in which no music is present; it explains the logic of atoms, particles and electrons as obeying different rules than the ones we know from the description of the classical Newtonian world, of which music is a natural part. It is clear that we must distinguish between the quantum mechanical and the classical understanding of the world to understand the relationship between music and physics. Both theories are "right" with respect to the objects they are connected to (the micro and the macro world), but problems arise when they are used at the same time to explain the world. Newtonian understanding cannot explain the strange behaviour of the smallest particles and quantum mechanics is for most people incompatible with the approach to their daily life. This is perhaps best exemplified by the fascinating quantum narrative: Schrödinger's Cat. To be alive and dead at the same time. A situation made possible by the superposition of a particle, that can influence two essential and very different outcomes. A true nightmare for a zookeeper or an undertaker. But a gift for an artist.

Here is a theory about an "organic world" that is "crazy" but real – and beyond everything that we would call classical or modern (Although only available to us through modern technology). This world has existed since the Big Bang. And it is everywhere. So, it must appear in the arts too. But how and where?

## Quantum World vs. Classical World

Let us for a moment observe the difference between the "classical (Newtonian) world" and the "quantum world." We know that classical mechanics describes nature at a macroscopic scale and Quantum mechanics describes nature at the smallest scale, but also that the relationship between the two approaches to the world are complex. It is problematic to translate the theory and history of physics into musicology. Nevertheless, in order to let the inspiration from quantum mechanics influence the compositional process in music at a full range, it is important to include these two different views on reality in a quantum music theory.

> The step from classical mechanics to quantum theory, which we assume to be revolutionary in the above sense, is obviously not a matter of adding further facts to classical mechanics, but of changing the framework of classical mechanics itself. Thus, the quantum-mechanical conception of the world ought not to rest on notions of classical mechanics. But it is difficult to decide which notions are typically germane to classical mechanics and which are not (Schommers 1998: 212).

An artistic reflection on this description could be a door opener for new possibilities of approaching music theory and history. In music history we could talk about a

classical part and a non-classical part – which, again, could be divided in two aspects: pre-classical (ritual) music and modern (post classical) music.

The term "Classical music" is used about the art music connected to the history of the western society.[2] The most important in this context is the "classical music", spanning the period from 1750 to 1820, which includes the classical forms at their peak (and including among others composers such as Mozart and Haydn). In this period, music is based on "controlled" pitches and the well-tempered tuning in the 2 tonic parallel keys of major and minor, mostly symmetrical durations (4, 8, 16 bars), symmetrical (even) measures (4/4 and 2/4), symmetrical structures (AA, ABA, AABA, ABACADA) and, not least, the clearly distinguished roles of melody, harmony and bass. These parameters are still in full use in pop, rock minimalism and other kinds of music and those styles could be seen as manifestations of a contemporary "classical" approach to music.

The classical period was prepared for a longer time. In the Baroque dance suites, we already see a strong symmetrical thinking that was surely influenced by a similar symmetrical understanding of the body.

After the classical period it did not take long before a "resistance" against symmetrical thinking arose. Already in the romantic period a "revolution" started: "Formel hält uns nicht gebunden, Unsere Kunst heißt Poesie"[3] (Uhland 1980: 35), but the basic "laws" of the classical period were more or less kept in art music until the beginning of the 20th century.

The "revolution" became more intense in some parts of the musical modernism (both the Vienna and the Darmstadt School). Music should be built on "nie zuvor gehörte Klänge."[4] Tonality, harmony and classical structures as well as sound and rhythm were deconstructed and seen in a new light. John Cage's music and Merce Cunningham's choreography broke the classical way of composing and explored randomness and silence (Cage 1961), which can now be seen from a new perspective through the knowledge of the quantum vacuum; and in György Ligeti's *Poème symphonique* (1962), John Cage's *4'33"* (1952) and Steve Reich's *Pendulum Music* (1968) we actually have some famous modern classics that include the important quantum phenomenon of probabilities (even though this was not the expressed intention of the composer).

The quantum theory gives rise to new ideas, new possibilities and new ways of understanding the musical development (history) – for example as a way of detecting sounds and forms that do not exist in the traditional (classical) approach to music. The sound of matter and anti-matter, scales built on quantum leap frequencies, music of silence, music we do not hear because of our perception of time etc. The step from "classical" understanding of music to "quantum understanding" of music could indeed change the framework of the music theory and practice itself.

2 The term "Classical music" covers two different areas: 1) Western art music (from the middle ages to today); 2) a shorter period in the music history between Baroque and Romantic periods.

3 "Formula does not keep us bound / Our art is called poetry."

4 "The sounds never heard before."

As a quantum listener you might like to listen to Richard Wagner's opera backwards (as anti-particles). Or the complete Rolling Stones records compressed to the duration of one second (as it would be "heard" from the outer universe). Or Giuseppe Verdi`s *Requiem* as a 100-year long performance (as if the atoms could listen to the music from our world). Or try to program a "probability button" on your computer that can select unexpected excerpts from different music – not to forget a journey into a Musical Hilbert Space (where we have all the existing music in the world together with all the not yet existing music).

Crazy?

I agree, but extremely inspiring for an artist… and this is perhaps the first step towards a fundamentally new relationship between the composer and her audience. In Quantum Music the listener is the observer – the scientist.

*Quantum Narratives (Quantum Chapters)*

The simplest way of drawing inspiration from Quantum Music is to use some of the theoretical texts about quantum mechanics as inspiration for titles, lyrics or program notes. Headlines from the Quantum Chapters[5] such as "Vacuum," "One particle," "Two particles," "Super position," "Entanglement" are almost like fairy tale titles in themselves. Used as musical titles, they will give the audience another aspect of approaching and understanding music, without the music necessarily being structured according to quantum theory. This has already been done many times. Some old titles seem to have been playing with our daily life logic like Keith Jarrett's "Memories of Tomorrow" from the famous *Köln Concerto*. A rather logical title when you are thinking of a particle and its anti-particle that can travel back in time. Or Ligeti`s famous piano etude "Disorder" that could be renamed "Quantum order."

*Sonifications and Frequencies*

Looking at other aspects of Quantum Music we can also include sonifications. This means that one way or another we can extract sounds from the quantum lab. Some composers have tried to use "authentic" quantum sounds as a base for music creation, from simple sonifications as done by several musicians in CERN to simple musical translations of quantum measurements.

If we understand music as any kind of organized sounds, "quantum sounds" can be provided as musical material in different ways. One is to use the frequencies that can actually be measured in the quantum lab. If the frequencies here were converted directly into the pitch of a musical note, it would be much too high for the human ear to hear. Therefore, we have to slow down the frequency millions of times in order to experience an oscillation as detectable sound. Most of the samples from CERN result in noise-like sounds almost like a very early synthesizer. However, the frequencies can also be transformed by transposition and added to a regular musical score. I will come back to this later, but I will already now underline that the main interest in this project was to see possibilities of connecting two levels of "organic information"; the

5 See Vlatko Vedral's lecture on Quantum Music: https://www.youtube.com/ watch?v=D40W3lphecg

acoustic musical instruments and the quantum world. This became possible by using the frequency tables for the quantum leaps as musical scales.

*Other possibilities*

Another way of using quantum information in a musical composition is to work with probabilities. This can be done by putting tones in quantum states in which the possibility of hearing one note and not another has to be seen as probability. This way of composing requires far more time, resources and calculations than a composer would normally consider spending in preparation of a composition. Also, the musicians will need to practice playing with unexpected changes.

However, to try this out in a tonal system without too many notes is an interesting research project and the staggering logistic calculations of finding a way to perform the piece should not be underestimated.

Maybe some jazz styles can bring some experience to develop this very interesting Quantum Music genre.

Added to this, using quantum information from graphics and pictures and rewriting them as musical scores is an exciting possibility.

## Approaches and Strategies

Quantum Music can be understood in many different ways. As already mentioned the term connects two different ways of understanding the world and on top of that even two different ways of interacting with the world: measuring or creating. This is a very important fact to consider before attempting to define what Quantum Music is or could be.

Quantum Music is not in any way an established part of the scientific study of physics, and Quantum Music is not yet a part of the study and research of musicology. At this point in time, Quantum Music is only a pilot project looking into the potential relevance and the possibilities that arise from this combination or collaboration between an art form and science.

The effect of this collaboration may result in many successful outcomes on many levels. However, it is important to understand that the result of such a collaboration will be understood and evaluated under the same conditions as any other artistic crossover, depending on matters of style, taste and individual experience. In other words, a subjective evaluation or what John Cage called "likes" and "dislikes". The true enemies of the arts.

The nature of such collaboration may be a musical or scientific outreach, meaning that either the music or the science "uses" the other part to make itself more visible and hereby reaching a different and broader audience. The collaboration can also be used to research and combine two different ways of working and interpreting the physical reality. The latter could create a platform for new artistic work and perhaps even new scientific work.

If we look at music as one partner (or level) in a collaborative project, we can borrow some techniques from choreomusicology and the choreomusical practice.

This collaboration spans 400 years of research into the relationship between movement and music, including the exploration of an unlimited number of relations. Choreomusicology is a new science that was launched in response to an increasing understanding that the art forms dance and music were becoming more and more independent of each other (not including ballet, early modern dance and most of all folk dance/music). The introduction of this term made it possible to understand music and dance as one, once again. An understanding that many famous choreographers, such as Theresa De Keersmaeker and Pina Bausch have used in their works.

In collaboration with other art forms (or science), music can interact in accordance with different techniques. The following techniques are derived from the relationship between dance and music, but are very useful for other interactive collaborations.

*1) Illustrating*
The music illustrates a given subject. In Quantum Mechanics a simple illustration could for instance be a super position pictured by two musicians playing the same material on the same instrument. Obviously, this would not be a super position but an illustration. This technique has been used a lot in cartoons and films and may be helpful in a pedagogic process. Sonifications, transforming quantum events into sound, also belong to this category.

*2) Complementarity*
One way of getting into an interactive state between two elements, for instance, is by filling out the gaps between each element in the binary information stream. In the case of dance and music, this could be a coupling of slow music with fast movements or vice versa. However, in the case of music and physics that appear to be in a complementary relationship from the beginning, this option is simpler. The "concert lecture" is an example of a format that can easily connect music and science into one event.

*3) Impulse*
Here, either the quantum information or the musical information provides an impulse to go in whatever direction. The impulses are beginnings, meeting points and endings. This was the case in the performance of the *BEC Music* where Klaus Mølmer formed a "Sentence that triggered a musical passage" in his lecture. One example of this is a "wave," which as we all know plays a very important role in both music and quantum physics. Or the sound of matter and anti-matter.

*4) Symbiosis*
Here the music and the quantum information should appear as one and the same. A rather challenging task. For example, this could mean that the music is built on quantum information. This counts for musical parameters such as melody, harmony

and rhythm, as well as time and space (structure and sound). At the same time, the sound of music will have a natural presence in the quantum mechanical context. Ballet is an example of a symbiotic relationship between dance and music.

*5) Chance operation*
In this case, we would look at the relationship between music and quantum mechanics by letting the two levels meet without any prepared connection, relation or interaction whatsoever, besides the time frame. Like putting any music to a superposition lecture without any preparation and observing the outcome. This was the technique of the Cunningham-Cage collaboration.

*6) Other techniques and more*
A lot of other techniques are available like "foreground and background," "going against," soundscape and more.

Although the choreomusical technique is formulated in a relationship with performing arts and/or film, the tools are also relevant in other constellations such as music and architecture, music and literature, music and biology. The method simply provides a strategy to work from, depending on the expected outcome.

Quantum Music is not a science and not even a musical style (at least not yet). It would have to establish itself as a powerful wave in the public world and for this purpose we will need many experiments resulting in powerful music. However, Quantum Music will probably not be considered a musical style in the future. It is far more likely that it will be perceived as a new way of approaching music and arts. Even the classical works can be understood from a new perspective. Think of a Shostakovich Symphony in a relationship with a Hilbert space, in which all possible variations are present. A rather astonishing thought. The quantum state of a simple melody where all possible variations seem to be present at the same time. The concept of music as a bigger particle that collapses when it is measured (heard). These reflections do not change the music but they do change the way we approach it.

In the following I will present my pieces composed during the *Quantum Music* project. The emphasis will be on the two major works: The *BEC cello concerto* and the *Super Position*.

## Quantum Works 2016–2018

***1) Research: Sound and visual etudes***
As a beginning of this artistic research project, it was obvious to start by working on some basic experiments with sound and quantum information. The first elements of quantum information to be figured out musically were those from the Quantum Chapter video with Vlatko Vedral, especially created for the Quantum Music project. Starting with...

*a) Vacuum*

For music this would mean silence or a blank score paper. But with a quantum approach to music we know that silence does not exist and that a blank score paper is not an empty page. There will always be something there. Amplify the silence and there will be new sounds from the "nothingness." Enlarge a blank paper and there will be a lot of graphic information. This is an interesting new aspect to my own "The Whiteness and the Stillness" which was conceptualised as a "Tabula rasa." But "Tabula rasa" is only a philosophic or imaginative term and does not exist as a reality in either physics or music.

*b) Particles*

At this stage of the project, I was already collaborating closely with Klaus Mølmer, Århus University. Some fascinating drawings provided a visual entrance to the quantum world that could be seen as musical graphic notation. Klaus suggested just adding some score lines to open up the possibility of creating musical phrases from the Quantum information. All of the graphics worked with time (forwards and backwards) and space. This led me to the following exercises:

**Figure 1 (a, b, c, d, e)** – Drawings by Klaus Mølmer and Kim Helweg. Captions by Klaus Mølmer.

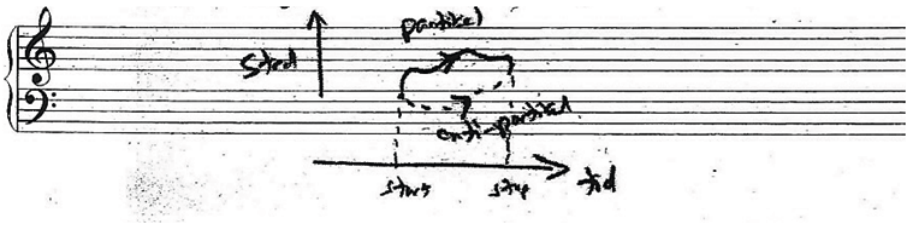

***Figure 1a.*** *The simultaneous creation of a particle and an anti-particle from nothing violates conservation of energy, but may occur for very short periods of time in quantum mechanics due to Heisenberg's uncertainty principle. The illustration thus shows how such a pair is formed and propagates in space as the solid and dashed arrows until they meet again and disappear. Even the emptiest of spaces is a constant coming and going of such pairs of all kinds of physical particles.*

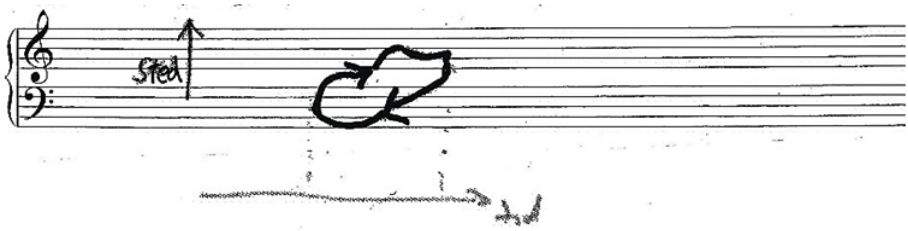

***Figure 1b.*** *The dashed anti-particle arrow beginning and ending its existence together with its particle partner in Fig. A., may also be thought of as being one and the same particle, shown with the solid arrow, moving forward and backwards in time. This is like the audience at a concert: when the spectators move left, one by one, to fill an empty seat, "the empty seat moves right" in the opposite direction.*

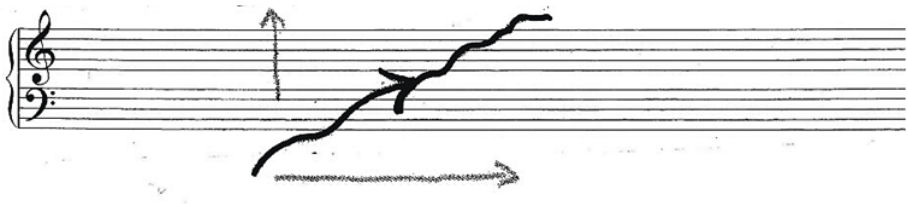

***Figure 1c.*** *A single particle flying through space.*

***Figure 1d.*** *Particles such as electrons inside an atom or a molecule, experience forces from each other. The particles and anti-particles, ever present in the empty space, contribute to these forces by a process called vacuum polarization.*

***Figure 1e.*** *A simple motion of a single particle is not so simple. It may meet an anti-particle from a pair previously emerging out of vacuum, and the two may vanish together, while the remaining partner particle continues its journey. In the picture of Fig. 1b, we would alternatively say that the incident particle in the lower figure turns around and goes back in time and then turns and moves forward in time again.*

*c) Time and space*

Another early idea of working with Quantum information was to stretch time. Musical time. There is no music in the quantum world – meant for our ears at least. An obvious step to take, is to stretch time (slow down or transpose) as suggested earlier. Thus, the quantum frequencies become within reach. Alternatively, one could follow the opposite approach. Take any famous piece of music from our classical world and stretch it so it becomes 10, 20, 30 or 50 times longer, thus becoming new music. Not empty gaps, which one might think would be the case, but new information coming from the emptiness.

**2) Compositions:**
***Quantum Leaves***
**for cello and guitar**
1st performance, Hendrikholms Kirke, Copenhagen, Denmark.
September 2016
*Colour scale frequencies*
This is my first piece involving some quantum mechanical thinking. It is inspired by the photosynthesis that happens all the time in the nature around us. From a Quantum Mechanical point of view, the light, which is essential for the process, has to be in all possible places at the same time to make the process possible and happen. This is a very clear example of super position or rather a kind of multi-position. For the purposes of composition, I used a translation of the colour frequency scale into an octave. And to create a funny link to the classical work, I used the Jazz Standard Tune "Autumn Leaves" as reference. This standard is extremely classical in both the melody and the harmonies, with the characteristic descending fifths.

For me the exciting conflict here appears in the border line between classical music and quantum frequencies. Between classical melodies and frequencies of colour as a mixture of dynamics and probabilities.

***BEC Music - Cello Concerto no. 3***
**for cello solo and sinfonietta**
1st performance, dokk1, Århus and The Opera, Copenhagen, March 2017.
John Ehde, Klaus Mølmer, Kaare Hansen, Aarhus Sinfonietta,
*BEC frequency chord*
The process of this work began at the same time as the *Quantum Music* project was launched but was not intended to be related to this. However, as I reached the middle of the composition, I realized that the piece did reflect many of the musical thoughts connected with my meeting with quantum information. The piece contains 15 movements of different characters, melted together as one long piece, like the particles in the Bose-Einstein Condensate. This made me use the frequencies of the condensate to construct a chord (*corda misterioso*) that I would use as an "idée fixe," appearing in different important places throughout the piece. Additionally, the noise of black matter was used as a percussive instrumental sound in the middle of the highly clean acoustic orchestra. The entire piece has an overall structure going from fast notes to slow, like zooming into the micro world. And also zooming into a world defined by a non-classical logic. The usual conflict between the individual soloist (cello) and the collective (orchestra) here reflects the relationship between the particles in the condensate, as they all end up by behaving like one big particle. Here understood in the sense that the soloist is swallowed up by the condensate and time. The concert ends with anti-matter noise, giving the impression that not only time has passed but also the music is going to collapse since we have now measured (heard) the piece.

During the 15 smaller movements, I also worked with super position as a way to see the relationship between the cello solo and the cello in the orchestra. Sometimes they play exactly the same and it is unclear which of them has the leading voice. While

this would be a disturbing element in a classical concerto, this is not at all the case in a concerto inspired by quantum mechanics. In addition to this, cello plays a chord with 8 notes on 4 strings. The super position reaches its extreme in the last movement when all the instruments play the same tune slightly staggered, almost like a multiple world experience.

The concerts with the concerto were structured as a half hour Quantum Mechanics lecture by Klaus Mølmer followed by a half-hour performance. Some parts of the lecture reflected specific musical samples played by the orchestra during the lecture.

***Quantum Fantasy***
**Suite for Guitar solo**
1st performance, Carnegie Hall, New York, DAP Festival Pietrasanta Italy, Ophelia Beach, The Royal Theatre, Copenhagen.

*Schrödingers cat and other narratives*

This piece was spontaneously inspired by some of the popular quantum narratives, ending up with Schrödingers Cat. Here as a new way of understanding Scarlatti's Cat fugue.

***Super Position* for 2 pianos**
***Many Worlds*. The first piece without a final structure; not being performed the same way twice; existing in an endless number of variations.**
Composed for the LP Duo. Ljubljana, Aarhus, Copenhagen, Belgrade, Autumn 2017
*The first 9 series of Quantum frequencies (Lyman, Balmer.....)*

This is the first work based on scales measured from the frequencies of the quantum leaps of a helium atom, which was worked out by Klaus Mølmer. The work has nine movements, each using one of the first nine series as musical scales, made possible by transpositions. The title refers to the double image of one instrument (Piano Duo) and works with the double image as the basic technique of the musical setting, such as micro canons, stereo, cross lines and so on. Also, the double image of tonality and atonality. The first version performed was for two pianos in traditional tuning. To give an impression of a more fluctual tuning, a recording of a Sheppard's harmony was used in some of the movements as pre-recorded background sound.

This version also includes the possibility of new piano techniques built on probabilities.

The idea of the title is to create a piece of music that exists in a kind of super position or rather in a multiple world position. The piece should never be the same from performance to performance. Every time it is performed, it must be slightly changed and at a sudden point radically changed. The music or the composition so to speak, is supposed to move into a parallel world every time it is performed.

Since the micro intervals had not yet been developed on the hybrid piano, the first versions provided a traditional classical well-tempered sound image of two pianos.

Even so, it already seems very possible to connect the micro tonality to the acoustic pianos and hereby reach the quantum frequencies.

Here are some descriptions of the use of the quantum scales in some of the movements:

**1st prelude, The Lyman series**

The first prelude is built on the Lyman series.

This scale, as well as the following Balmer series had a very limited range of notes. This means that after transposing the series into the audible area, a stretching of the scale is also done. This prelude is built on a chorographical technique called stacking, in which a full phrase is built up by releasing just a small part of it until it appears in full shape. The middle part of the scale (the "tonal part") presents the scale as a melody starting with the middle note and adding the previous and the following note, every time repeated. The piece also uses the horizontal aspect as well as the vertical (harmony) of the series. The prelude concludes when all the notes are presented, with microtonal stop notes ending in vacuum.

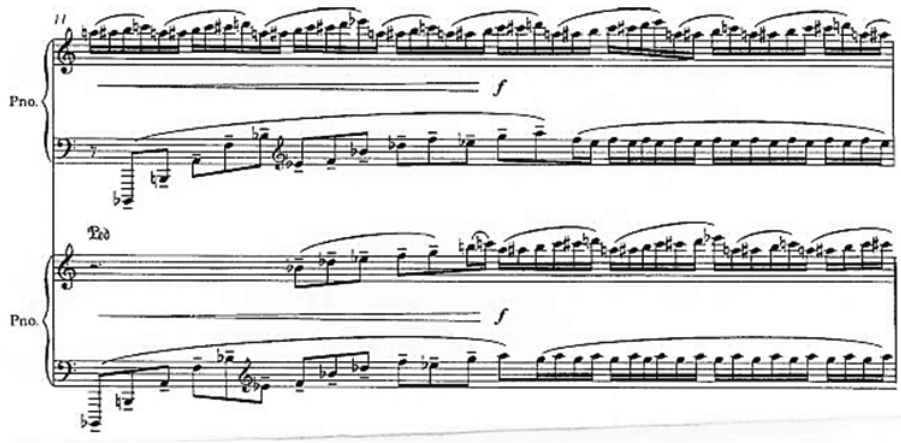


***Figure 2.*** *Super Position, Prelude 1 "Lyman" – bar 11 where the entire Lyman scale is presented*

**2nd prelude, "Johann Balmer's Lustige Streiche"**

This prelude presents the "original" compressed scale in the A part and uses the stretched one as the middle section. From below, the scale is actually the theme from Richard Strauss' *Till Eulenspiegel*, which is easily recognizable in this scherzo-like piece. The middle section (the trio) consists of the extended scale played forwards and backwards at the same time with sustain pedal throughout, presenting the sense of melody and harmony at the same time as seen in the first prelude.

**3rd prelude, "Paschen"**

A piano playing back in time creates a tone with the quality of a string instrument ending with an accent. This technique was dedicated to the 3rd prelude due to the live

performance being replaced by E Bows, evoking the feeling of a rewound piano note. The quarter notes were marked with grace notes like in blues piano style.

**5th prelude, "Pfund"**

This piece was inspired by rock music (to be more accurate the guitar ostinato from The Police's song "Message in a Bottle"). The two pianos are playing the same. However, one piano is playing on the beat and the other off the beat, resulting in a feeling of swinging syncopation. Played very mechanically, the piece can be heard in two different ways depending on which piano part the listener's ears choose to perceive as being played on the beat.

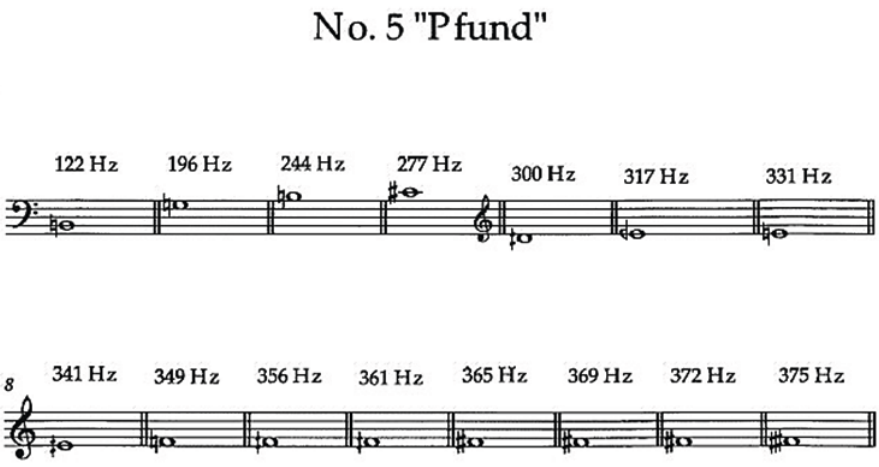


***Figure 3.*** *Super Position – The "Pfund" Series*

**6th prelude, Humphrey**

This prelude is built on the 6th series which in its strong chromatic like structure gives an impressionistic sound that inspired me to create a meditative and atmospheric prelude similar to film music. Perhaps the beginning of a "quantum frequencies healing system".

**8th prelude, Series 8**

This prelude is inspired by free jazz. However, the material constantly repeats syncopated figures, expected and unexpected at the same time, like watching the light glimmers from the quantum leaps.

**9th Prelude, Series 9**

The scales consist mostly of micro tonal intervals (in between the notes on the piano). The piece plays with the possibility to replace the note with the nearest note beneath it, resulting in chromatic intervals or to replace the note with the nearest note

above, which results in a Lydian like scale. In the end, the vision of a musical Hilbert Space is presented with pre-recorded pianos. The 2 pianos become 18.

***Balmer stretched Balmer* – Piano Sonata no. 3**
**for an imaginary quantum piano**

Dance performance, The U-boat Copenhagen, January 2018

For this piece, I used the music program Logic to manipulate piano sounds according to the quantum concepts. The idea of going backwards in time and stretching the time was the main thought as earlier presented in the drawings by Klaus Mølmer. Actually, the B part of the 2nd prelude of the Super Position piece for 2 pianos, which is more or less 40 seconds of music, is used as the only material for this 40-minute piece.

It is now possible to perform this piece live on the Yamaha DIS Klavier and hopefully soon on the Quantum piano.

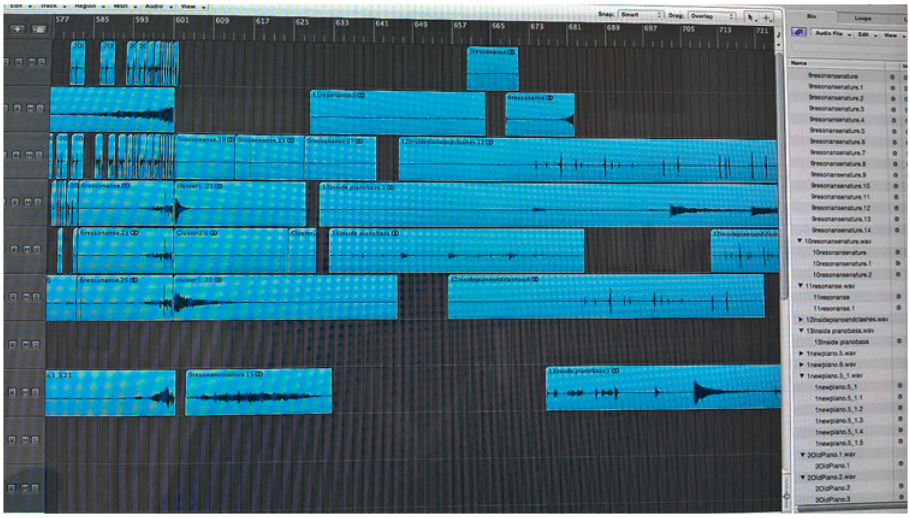

***Figure 4.*** *Balmer stretched Balmer (an extract)*

## Conclusion

This article and the thoughts about dealing with quantum information in a compositional way is just the beginning. Exploring the scales for different types of musical instruments needs much more time and experimentation than what is possible within the 3-year Quantum Music pilot project. What has been proven throughout this project, is that quantum information is indeed viable as a way of generating musical material. As shown in the composition *Super Position*, it is possible to create melodies, harmonies and rhythmical patterns based on quantum leap frequencies as well as using the information as a time structuring element and in *Balmer stretched Balmer* the idea of the piano as an instrument that can sound like an orchestra just manipulating its own sounds according to the movements of particles and anti-particles. Yes, the doors have been opened into other ways of approaching music composition.

## Additional Acknowledgements

I would like to thank: Klaus Mølmer for the essential information that made this project and all my compositions possible; Claire Percy Smith for critical advices and translations in connection with this article; The Danish National School of Performing Arts for supporting this project in all aspects (research, workshops, concerts, lectures, promotion); The Royal Danish Theatre for providing space for concerts and lectures; The Danish Arts Foundation and Creative Europe for supporting my compositions and artistic research.

I entered the Quantum Music project in its planning phase; it was an extension of a long, fruitful collaboration with the Serbian piano duo Sonja Lončar and Andrija Pavlović (LP Duo). Together we made a recording of my complete works for 2 pianos and some years later the first recording of my jazz-rock symphony *Mechanical Destruction* (1977) arranged for 2 pianos and synthesizers. This collaboration also encompassed a series of memorable concerts in Europe and the United States.

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# Компоновање на основу квантних информација: аспекти квантне музике у теорији и пракси

## (Сажетак)

Квантна музика *(Quantum Music)* је назив пројекта кофинансираног од стране Европске Уније у оквиру програма Креативна Европа. Овај пројекат је отворио могућност да се истражује однос између уметности и науке — прецизније, између музике и квантне физике. Идеја партнера окупљених на овом пројекту била је да се креира нови музички стил инспирисан теоријским поставкама квантне механике, као и да се развије нов хибридни клавијатурни инструмент. Развој је био пажљиво планиран и распоређен на различите учеснике пројекта, у складу са њиховом експертизом, било да су у питању дизајнери звука, физичари, музички извођачи или музиколози. Мени је, као композитору, било поверено компоновање прве квантне композиције (*Супер позиција [Много светова]* за два хибридна клавира, 2017), али и повезивање музике са другим извођачким уметностима (плес, глума) путем мог педагошког рада у оквиру Данске националне школе за извођачке уметности. Циљ мог учешћа у овом пројекту био је да установим на који начин спој музике и науке може резултовати развојем нових композиторских стратегија и понудити нову перспективу за промишљање музике и извођачких уметности данас.

Кључне речи: Квантна музика, квантне скале, музика вероватноће, квантни наративи, кореомузикологија, теорија квантне музике, компоновање квантне музике.