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What Does Quantum Music Sound Like and What Would Pierre Boulez Think of It?

Super Position (Many Worlds) by Kim Helweg (2017)*

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Abstract

Pierre Boulez (1925–2016) devoted a great deal of time and consideration to the relationship between the composer's invention and performance media, in particular those related to the application of the latest technological breakthroughs and new instruments. Boulez's famous essay "Technology and the Composer" (1977/1986) proclaims his desire to widen the range of expressive means of art music by conquering new media. Boulez's "vintage" insights are here juxtaposed with a contemporary *Quantum Music* project (2015–2018), and with one particular piece written within this project: *Super Position (Many Worlds)* by Kim Helweg (2017), commissioned by the Institute of Musicology SASA and supported by the Danish Arts Foundation (Statens Kunstfond). At least two lines

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of thinking relevant for the present discussion can be drawn from Boulez's text: the first dealing with the possible development of new musical instruments, and the other inviting a merger between music composition and science.

Keywords: Pierre Boulez, technology, new music, new instruments, Quantum Music

On Boulez, Music and Technology

A hundred years ago, Edgard Varèse (1883–1965) began his famous lecture "The liberation of sound" with a longing for new instruments which would allow him to write music as he imagined it: "Music, which should pulsate with life, needs new means of expression, and science alone can infuse it with youthful vigor" (Varèse and Chung 1966: 11). Since the beginning of the twentieth century, there have been countless modernist projects based upon an interest in the possibilities for merging modern technologies (of that time) and the arts. A fascination for technological innovations inspired artists to break from the confines of their own arts and their media and to conquer new modes of expression. As observed by Vesna Mikić, these possibilities were reflected, "on the one hand, in the inspiration for creation of certain works, originating from the urban way of life and its particularities, and on the other hand, in attempts at applying scientific discoveries to music" (Mikić 2004: 106). Two well-known examples of these possibilities are:

1) Alexander Mosolov: *Iron Foundry* – a piece inspired by the rapid development of technology and industrialization;[3]

2) Edgard Varèse: *Poème électronique* – an example of the creative application of new technologies and one of the landmarks of electronic music.[4]

Pierre Boulez (1925–2016) was one of the great avant-garde composers of the twentieth century who devoted much time and consideration to the relationship between the composer's invention and performance media, in particular those related to the application of the latest technological breakthroughs and the new instruments. One of his essays, "Technology and the Composer" (Boulez 1977/1986) is still as relevant today as it was 40 years ago, when it first appeared in print. This essay is considered a "manifesto of IRCAM"[5] (Born 1995: 97), the institute that Boulez founded that very same year, in 1977, and directed until his retirement in 1992. In a recent analysis Marija Maglov asserts that "Boulez's text remains the point of reference because of the themes it involves regarding the different institutional aspects of music organization"

3 https://www.youtube.com/watch?v=v1FotpMw46E

4 https://www.youtube.com/watch?v=iuDzSoEYixQ

5 IRCAM – Institut de Recherche et Coordination Acoustique/Musique, https://www.ircam.fr

(Maglov 2016: 63). Boulez's vision when he founded IRCAM was directed predominantly at the study of electronic and electroacoustic music, and especially the application of computers to the creation of music, which was still quite novel at that time. Just like Varèse's goal of the liberation of sound cited earlier, Boulez's text proclaims his desire to widen the range of expressive means of art music by conquering new media. Boulez's "vintage" insights will here be juxtaposed with a contemporary project that some of us have been involved with for the past three years – namely, the *Quantum Music* project, coordinated by the Institute of Musicology SASA in Belgrade, with partners from Denmark, Slovenia, Serbia, the United Kingdom and the Netherlands.[6]

At least two lines of thinking relevant for the present discussion can be drawn from Boulez's text: the first dealing with the possible development of new musical instruments, and the other inviting a merger of music composition and science. Boulez observed that, at least since the beginning of the twentieth century, Western culture had been oriented towards "historicism and conservation" (Boulez 1986: 486–487). He believed that this historicizing culture had almost completely blocked the evolution of musical instruments for both social and economic reasons:

> The great channels of musical consumption which exploit, almost exclusively, the works of the past consequently use the means of transmission appropriate to the past, when they were at their most effective. (…) The makers of musical instruments, having no vocation for economic suicide, meet the narrow demands made on them (…) and so lose all chance of inventing or transforming. (Ibid.: 487)

In stark contrast to the 'stagnant' world of art music, Boulez notices that the situation is much better "in another sector of musical life that has little or no communication with the 'historical' sect" – that is, in non-art music, in which "the musical material (…) has formed itself into a surplus." (Ibid.) Thus Boulez notices the possibilities of enriching art music with technological means developed independently from this music's real or presumed aims:

> Aware of these forms of progress and investigation, and faced at the same time by stagnation in the world of musical instruments, the adventurous musical spirits have thought of turning the situation to their own advantage. Through an intuition (…) they have assumed that modern technology might be used in the search for a new instrumentation. (…) Oscillators, amplifiers, and computers were not invented in order to create music; however, and particularly in the case of the computer, their functions are so easily generalized, so eminently transformable, that there has been a wish to devise different objectives from the direct one. (Ibid.: 488)

Boulez remarks that technological breakthroughs were often achieved by "the scientifically minded (…) inventors, engineers and technicians" who were "admittedly interested in music but who stand outside the conventional circuit of musical education and culture."

6 http://quantummusic.org

(Ibid.: 487) Nevertheless, he is interested in applying computers and audio technologies to the composition of art music, and excited by the fact that there exists new sound material with unexpected potential for creative application (Ibid.: 489). On the other hand, he admits that "musicians, on the whole, have felt repelled by the technical and the scientific, their education and culture having in no way given them the agility or even the readiness to tackle problems of this kind" (Ibid.: 490). He believed that composers' invention and musical material should develop in parallel and concluded that *[emphasis ours]*, "**Collaboration between scientists and musicians** […] **is therefore a necessity that, seen from outside, does not appear to be inevitable.**" (Ibid.) Boulez also noticed a certain skepticism on the part of the scientific community with respect to whether musical creativity really needed technology: "They doubt whether this utopian marriage of fire and water would be likely to produce anything valid." (Ibid.) Aware of the fact that finding a common ground for music and technology would be very difficult to achieve, Boulez ultimately proclaimed that *[emphasis ours]*, "**musical invention will have somehow to learn the language of technology, and even to appropriate it.**" (Ibid.: 491)

To explain the desirable level of mastery of the technology that a composer would need to fathom, Boulez makes a very useful analogy with learning traditional orchestration (Ibid., 491–2) and concludes that **a virtual understanding of contemporary technology should form part of the musician's invention**. He expressed his belief that **the reasoned extension of the material would inspire new modes of thought** (Ibid.: 492) and illustrated this idea by making an exceptional comparison to architecture:

> … structural limitations have been radically changed by the use of new materials such as concrete, glass, and steel. (…) New possibilities triumphed over imitation and transformed architectural invention and concepts from top to bottom. These concepts had to rely much more than before on technology, with technical calculations intervening even in aesthetic choices, and engineers and architects were obliged to find a common language – which we are now about to set off to look for in the world of music. (Ibid.: 492–493)

Boulez concluded that the road ahead of composers would be long and winding, that there would be hesitation and attempts to return to the old, but that this is the price that composers would have to pay in their quest for originality.

Quantum Music and Boulez

"Think about an atom as a musical instrument."
Vlatko Vedral[7]

After reading Pierre Boulez's words written over 40 years ago, it is clear that the project Quantum Music has reinterpreted some of those modernist ideals of discovering

7 Quantum Music Project Promo, https://www.youtube.com/watch?v=PeW69lHFyEo

new ways of connecting science, music and technology. Specifically, the main idea behind the Quantum Music project was to create technological context that would enable music to "penetrate" the world of quantum particles. In a typically avant-garde manner, the project has its "manifesto" – admittedly, written as part of the funding application! – which nevertheless resembles the texts written by the great twentieth-century visionaries such as Ferruccio Busoni's treatise "Entwurf einer neuen Ästhetik der Tonkunst" [Sketch of a New Aesthetic of Music], first published in 1907 (Busoni s.a.), or Varèse's already-quoted "The Liberation of Sound" (Varese and Chung 1966):

> Quantum Music is a project with the aim to explore the connection between music and quantum physics through the creation of a new art & science experiment resulting in a live performance. The project presents quantum physics and the quantum world to a wider audience and contributes to the creation of a new musical/scientific genre – Quantum Music … [8]

As described in the "manifesto", the main objective of this project was to bring the imaginary principles of quantum physics closer to a wide audience by means of the most imaginative of all arts – music – and to investigate and demonstrate how the laws of quantum physics and the aesthetics of music could interact. This research took the team in several directions simultaneously. The first direction was the technological one, which led to a creation of a new hardware that transformed the classical piano (be it grand or upright piano) into a hybrid analogue-digital instrument (Lončar and Pavlović 2018). This was complemented by a creation of a new software interface for this new hardware, as well as soundbanks synthesized on the basis of quantum equations (Mølmer 2018; Novković et al. 2018). The next direction was artistic and involved composing new music and rearranging pre-existing music for the new hybrid instrument (Lončar and Pavlović 2018; Helweg 2018). Finally, the project involved creating an audio-visual narrative that would accompany concert performances of these newly composed or newly-rearranged quantum music pieces, in order to present and explain to the audiences some phenomena from the quantum world.

Whilst creating the hybrid piano and soundbanks for it, the scientists, engineers and musicians found themselves "on the same wavelength" – just as we imagine Boulez would have desired – 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. The members of the LP Duo, Sonja Lončar and Andrija Pavlović, saw this new hybrid piano as a fulfilment of their dream: a merger of an acoustic piano and analogue and digital synthesisers, i.e., the creation of an electronic instrument that has genuine piano mechanics and that enables the demonstration of the entire range of pianistic virtuosity – which had never been possible with other electronic synthesisers, no matter how well they were made (Lončar and Pavlović 2016: 61–69). The development of this prototype is still on-going, although even in its present form it is fully operational.

8 Quantum Music – About Us, http://quantummusic.org/about-us/

Kim Helweg: *Super Position (Many Worlds)*

In May 2017 the first new musical piece that resulted from the Quantum Music project was composed – *Super Position (Many Worlds)* for two hybrid/quantum pianos, by Danish composer Kim Helweg, born in 1956, with whom the LP Duo have had a long and very fruitful collaboration (Helweg 2018). At the outset of the project Helweg observed that, "this project moves the boundaries quite a bit. We are still very 'classical' in the way we approach music, how we organize it – this is still pretty much the same as it was done in Mozart's time."[9] While these words echo Boulez's own, they must have sounded unusual coming from Helweg, because, for several decades, especially in his native Denmark, he was considered a composer of not-very-serious, postmodern music with influences from popular music genres – jazz, rock, punk, etc. For example, in the early 1980s he wrote two jazz/rock symphonies and the rock-operas *Ulysses* (1982) and *Black Mass* (1983); he also wrote an anti-musical, *The Kreutzer Sonata*, as well as works such as *Variations on Chick Corea's 'La Fiesta'* for two pianos, *Shlag* for punk singer and orchestra, and so on. Yet in 2015 he was ready for a new challenge and gladly accepted the invitation to became part of the (neo-) avant-garde Quantum Music project, thus revisiting some of those modernist ideas that he would have probably dismissed in his rebellious youth. Wishing to depart from "musical historicism" and to step into an unprobed field of musical invention, Helweg wrote *Super Position*, the first musical piece inspired by the hydrogen atom. Here we can think of parallels with Varèse's experiments from a hundred years ago (for example in his works such as *Ionisation* [1929–1931], *Hyperprism* [1923], *Density 21.5* [1936] and so on), or more recently, with similar endeavours undertaken by another prominent European avant-gardist, Iannis Xenakis (1922–2001), for instance in his seminal piece *Pithoprakta* composed in 1955–1956 – to name but two composers who in their own time also used the phenomena of physics as a source of extramusical inspiration.

In his *Super Position*, Helweg depicts the quantum world by using traditional Western European compositional devices. *Super Position* and its subtitle *Many Worlds* refer to one of the characteristic phenomena of the quantum universe – the fact that particles can exist simultaneously in different states. A wave function in quantum physics is a mathematical description of the state of a system, a complex-valued probability amplitude. As explained by Vlatko Vedral, wave function collapse is said to occur when a wave function appears to reduce to a single state (by "observation"). Namely: when it is not observed, the particle does not exist; there is only the wave probability function expressing the likelihood of finding it. However, as soon as a particle is located in the quantum space, the "superposition" is lost and it "collapses" into a single, defined state.[10] Quantum Superposition is another fundamental principle of quantum mechanics; much like waves in classical physics, any two (or more) quantum states can be added together ('superposed') and the result will be another

9 Quantum Music Project Promo, https://www.youtube.com/watch?v=PeW69lHFyEo

10 "The Quantum Music Project presents Quantum Mechanics with Vlatko Vedral," Quantum Music 2016, https://www.youtube.com/watch?v=D40W3lphecg.

valid quantum state; and conversely, every quantum state can be represented as a sum of two or more other distinct states (Vedral 2018).

Inspiration in quantum phenomena is also revealed by the titles of movements in Helweg's composition, because they correspond to the titles of the series of spectral lines of the hydrogen atom. Namely, the emission spectrum of atomic hydrogen is divided into a number of spectral series. A hydrogen atom consists of an electron orbiting its nucleus. The electromagnetic force between the electron and the nuclear proton leads to a set of quantum states for the electron, each with its own energy.

Spectral emission occurs when an electron transitions, or jumps, from a higher energy state (***n***) to a lower energy state (***n'***). The energy of an emitted photon corresponds to the energy difference between the two states. The spectral lines are grouped into series according to ***n'***. Lines are named sequentially starting from the longest wavelength/lowest frequency of the series, using Greek letters within each series. The first six series were named after the scientists who discovered them, while the last ones do not have names, but they follow the same Rydberg formula, devised by Johannes Rydberg in 1888.

A Bose–Einstein condensate (BEC) is a state of matter of a dilute gas of bosons cooled to temperatures very close to absolute zero. Under such conditions, a large fraction of bosons occupy the lowest quantum state, at which point microscopic quantum phenomena, particularly wavefunction interference, become apparent. In such conditions, a change in a certain feature of one atom (e.g. its velocity) immediately changes the same feature in all other atoms, even if these atoms do not interact. Thus all wave functions of single atoms "collapse" into a single wavefunction because of the low temperature and pressure (*Wave Function Overlap*) (cf. Rančić 2011).

Even an initial glance at Helweg's score allows us to establish a metaphorical analogy between the repetitive models of postminimalist provenance and the "waves of energy" in the quantum world. These "waves" are actually the images of the "superposition" of particles, because they are "neither here nor there" – they belong to all possible worlds, until the moment when they "collapse" into "here and now." We shall now overview these nine series and their eponymous musical outcomes, highlighting some specific procedures implemented in the selected movements.

Prelude I, series 1 "Lyman": The Lyman series is a hydrogen spectral series of transitions and resulting ultraviolet emission lines of the hydrogen atom as an electron goes from $n \geq 2$ to $n = 1$ (where n is the principal quantum number), the lowest energy level of the electron. The transitions are named sequentially by Greek letters: from $n = 2$ to $n = 1$ is called Lyman-alpha, 3 to 1 is Lyman-beta, 4 to 1 is Lyman-gamma, and so on. The series is named after Theodore Lyman (1874–1954), who discovered the spectral lines from 1906–1914 (Lyman 1906, 1914; see also Bridgman 1957). All the wavelengths in the Lyman series are in the ultraviolet band.

This prelude is based on a short chromatic motif consisting of four notes; at its first repeat it is expanded to five. Constant repetitions with minor modifications of this motif create a "trembling" musical line in the first piano, while the second one remains silent, until it is "awakened". It is as if the movement of the first "particle" in the first piano has kick-started the second particle to react in the exact same way

– hence at its first entry the second piano faithfully copies what the first one did. The two pianos, i.e., particles, then start to interact and continue to do so until the end of the movement. The introduction of a new motif in bar 6 provides a counterpoint and apparently opens up a new realm; as the composer piles on and sustains the layers, it is as if we can witness the transitions and emission lines of the hydrogen atom (Figure 1).

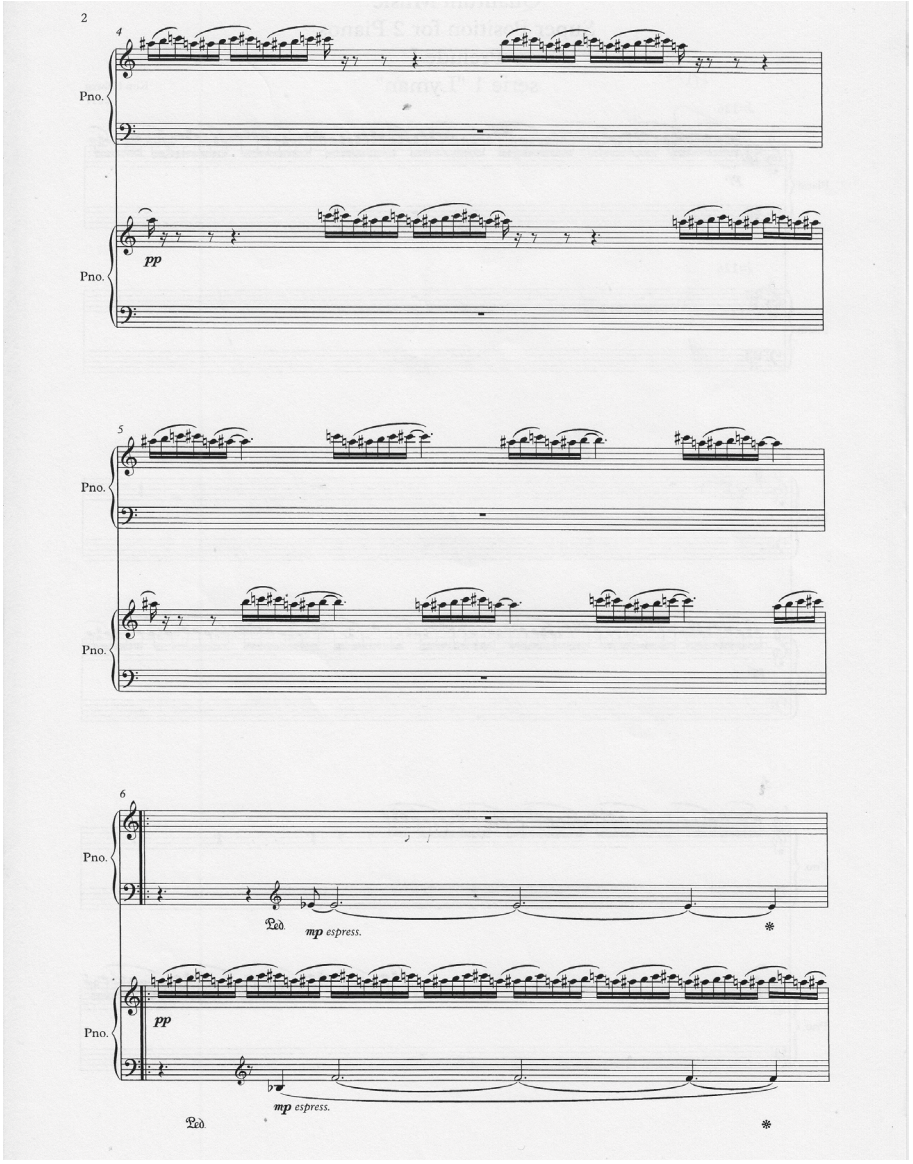

Figure 1. *Kim Helweg, Super Position (Many Worlds), Prelude 1 "Lyman", bars 4–6*

Prelude II, series 2 – "Johann Balmers lustige Streiche": Balmer's series, named after Johann Jakob Balmer (1825–1898), is the only one that belongs to the visible part of the spectrum (Balmer 1885/1966). Using Anders Jonas Ångström's measurements of the hydrogen lines, he arrived at a formula for computing the wavelength. Balmer's formula was later found to be a special case of the Rydberg formula (formulated by Johannes [Janne] Rydberg). Not only is this the only "visible" series, but only in this movement does Helweg employ a familiar musical motif – a theme from Richard Strauss's programmatic symphonic poem *Till Eulenspiegels lustige Streiche* [Till Eulenspiegel's Merry Pranks]. As explained by Helweg himself, the fact that the Balmers scale replicates Till Eulenspiegel's Leitmotif is a coincidence (Helweg 2018), but one that he was happy to utilize, thus evoking the (auto)referentiality of his earlier, pre-Quantum music.

In Richard Strauss's work, the German folk hero Till is represented by two themes. The first, played by the horn, is a lilting melody that reaches a peak, falls downward, and ends in three long, loud notes, each progressively lower (Figure 2):

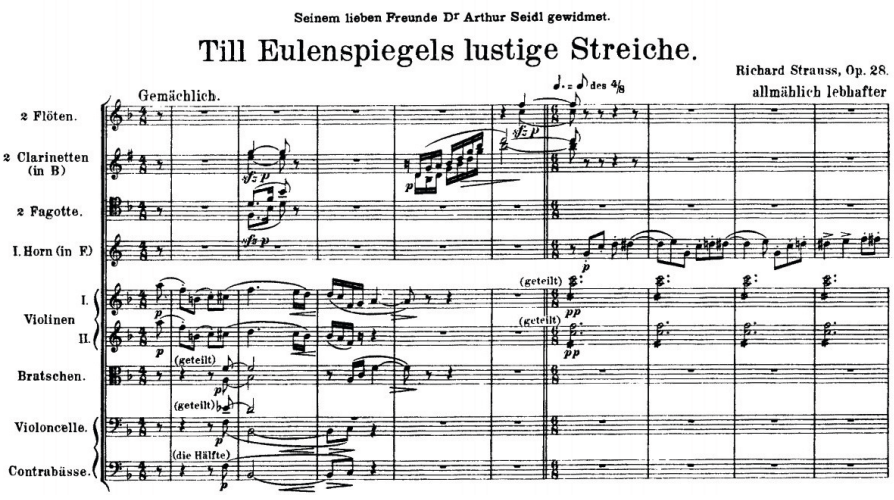

Figure 2. *Richard Strauss, Till Eulenspiegels lustige Streiche, Sinfonische Dichtung Op. 28, Edition Eulenburg No. 443, bars 6–9 – Till's first theme*

Helweg subjects the first Till theme to wave-like repetitions and transformations (although the theme itself is repeated multiple times in Strauss's piece, only in a completely different, romantic context). Instead of depicting Till, here the theme depicts the "familiar", visible part of the spectrum and its "playfulness" (Figure 3):

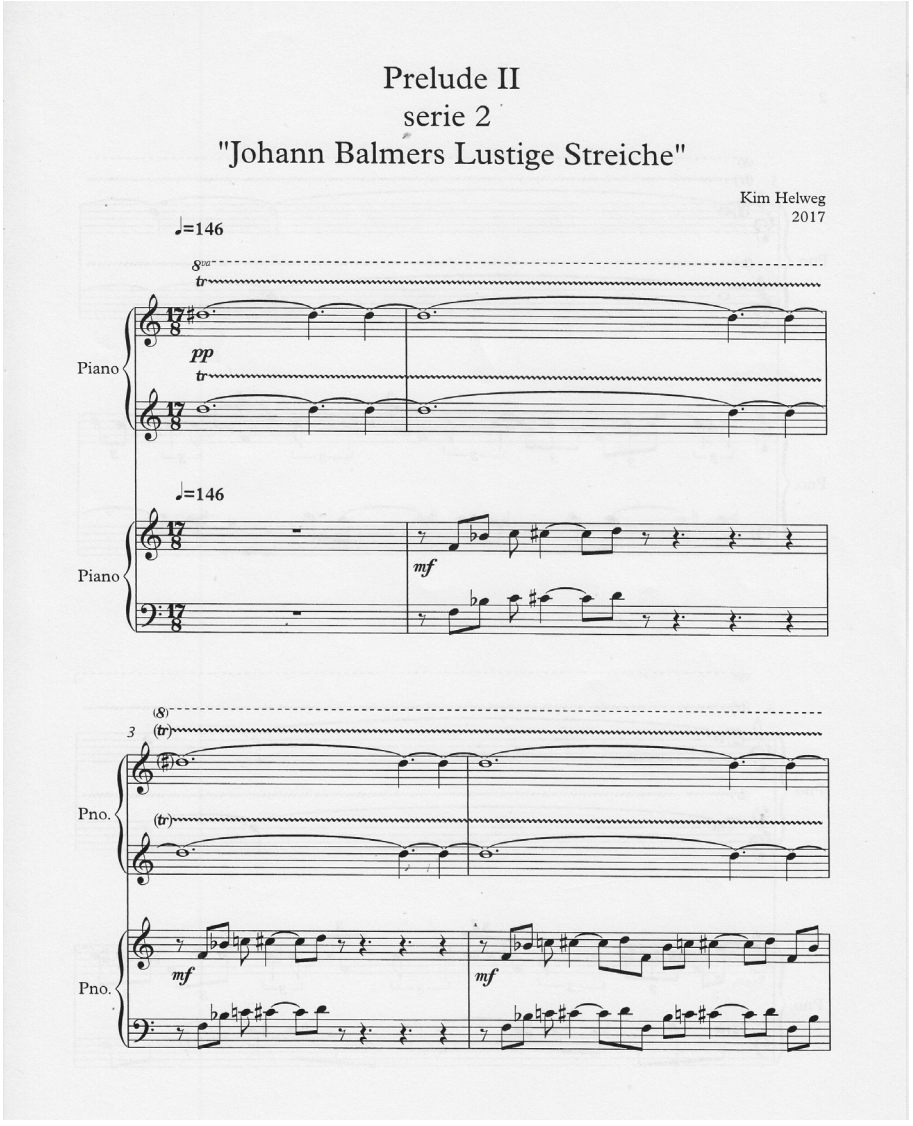

Figure 3. *Kim Helweg, Super Position (Many Worlds), Prelude 2 "Johann Balmers Lustige Streiche", bars 1–4*

Prelude III, series 3 – "Paschen": Paschen series are the series of lines in the spectrum of the hydrogen atom which corresponds to transitions between the state with the principal quantum number n = 3 and successive higher states. They are named after the German physicist Friedrich Paschen (1865–1947) who first observed them (Paschen 1908). The Paschen lines all lie in the infrared band. This series overlaps with the next (Brackett) series, i.e. the shortest line in the Brackett series has a wavelength that falls among the Paschen series. All subsequent series overlap.

Prelude IV, series 4 – "Brackett": This series is named after the American physicist Frederick Sumner Brackett (1896–1988), who first observed the spectral lines (Brackett 1922). The musical motif on which this movement is based is an inversion of the motif from the first movement. As Helweg's composition progresses and the movements depict higher states, the rhythmic and intervallic patterns become increasingly complex.

Prelude V, series 5 – "Pfund": Experimentally discovered in 1924 (Pfund 1924) by the American physicist August Herman Pfund (1879–1949), in Helweg's piece the fifth series is depicted by a canon in two pianos rhythmically separated by just one quaver, thus producing the effect of particles copying or chasing one another. The same principle is used consistently in Prelude VII.

Prelude VI, series 6 – "Humphreys": This series was discovered by the American physicist Curtis J. Humphreys (1898–1986) (Humphreys 1953).

Further series are unnamed, but follow the same pattern, as dictated by the Rydberg equation. Series are increasingly spread out and occur in increasing wavelengths. The lines are also increasingly faint, corresponding to increasingly rare atomic events. The seventh series of atomic hydrogen was first demonstrated experimentally at infrared wavelengths in 1972 by John Strong and Peter Hansen at the University of Massachusetts Amherst.

Prelude VII, series 7, repeats the canonic imitation as seen in the Prelude V.

At the beginning, **Prelude VIII, series 8** features two pianos in unison, depicting particles that share the exact same movement, velocity and other characteristics, as if it were the situation happening in the Bose-Einstein condensate. And even after they are separated at bar 7, they remain in a canon imitation.

Finally, **Prelude IX, series 9** presents a similar idea; however a carefully calculated rhythmic "mismatch" or "reverb" of the two pianos here produces seemingly irregular "twinkling" musical waves.

Conclusion

Kim Helweg's composition *Super Position (Many Worlds)* presents just the first attempt – and by no means the only possible one – at finding a "common ground" for quantum mechanics and art music. Helweg's composition does not introduce a completely new musical language in comparison with his earlier pieces, which could be understood in the context of a broadly-defined postmodernism and postminimalism. Instead, Helweg here finds a way to bring his already established musical language logically and unforcedly into a relationship with the new source of inspiration – the quantum world. Moreover, the transformation of the piano sound, although achieved by means of an innovative technology (the hybrid pianos and the accompanying interface and soundbanks) also does not represent a complete novelty in the field of electroacoustic music – although it does change the way of transporting acoustic information into the digital world. Hence, what is truly new and original in Helweg's piece, aside from the use of the hybrid piano prototype, is the penetration of music into the world of experimental physics, both as a new source of inspiration

for composers, and as an outcome of the physicists' desire to "musicalize" i.e. make audible this distant subatomic world. Due to the extreme difficulty and "unplayability" of some parts of Helweg's score, but also due to the fact that the tempered tuning of the piano (which has been preserved even with the hybrid mechanism) makes it impossible to reproduce the exact pitches of the quantum scales, the version of *Super Position (Many Worlds)* that LP Duo performed during the Quantum Music Tour in September and October 2017 is by no means the only possible one, but just one of the "many worlds" that the composer has envisioned. Moreover, as of March 2018 there have already been four updates to the score; should the future development of the hybrid piano enable the performance of quarter-notes, it would necessitate further revisions of the piece.

If one now returns to Boulez's aims with respect to the development and progress of music as expressed in the text "Technology and the Composer," one might establish many meeting points with the Quantum Music project, including: a close collaboration between scientists, engineers and musicians; the development and production of new instruments; the musicians' (both composers' and performers') efforts aimed at learning and mastering the new technology; and, finally, finding a common language for music and cutting-edge technology. One may conclude that the Quantum Music project opens a new chapter in the relationship between science, technology and music, which has the potential to lead to the discovery of new sound worlds – while, simultaneously, music is given the opportunity to contribute to science by partaking in experiments in the field of quantum mechanics. In the final analysis, we are certain that Boulez would have been quite eager to compose music for hybrid pianos, "pianos of the future," because they embody the symbiosis of science, technology and music about which Boulez dreamed and which he himself aimed to accomplish.

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Како звучи квантна музика и шта би Пјер Булез мислио о томе? *Супер позиција (много светова)* Кима Хелвега (2017)

(Сажетак)

Француски авангардни композитор Пјер Булез (1925–2016) посветио је пуно пажње спрези између композиторске инвенције и извођачког медија, посебно у вези са применом најновијих (у то време) технолошких достигнућа и нових (превасходно електроакустичких) инструмената. У чувеном есеју из 1977. године „Технологија и композитор" Булез је прокламовао своју жељу за проширењем опсега изражајних средстава уметничке музике путем освајања нових медија. У овом раду Булезова запажања сагледавамо у паралели са резултатима савременог пројекта *Квантна музика (Quantum Music)*, реализованог у оквиру програма *Креативна Европа* (2015–2018). Након разматрања Булезових теоријских поставки, превасходно оних које се односе на развој нових инструмената и на спој музике и науке, као и њихових савремених реперкусија, анализирамо композицију *Супер позиција (Много светова)* за два хибридна (квантна) клавира данског композитора Кима Хелвега, насталу 2017. године у оквиру пројекта *Квантна музика*. Ова композиција представља тек први покушај – свакако не и једини могући – повезивања квантне механике и савремене уметничке музике.

У поређењу са ранијим Хелвеговим остварењима, композиција *Супер позиција (Много светова)* не одступа превише од његовог уобичајеног израза, који се креће у координатама постмодернизма и постминимализма. Међутим, Хелвег проналази начин да свој препознатљив музички рукопис неусиљено и логично доведе у везу са новим извором инспирације – квантним светом. Поред тога, трансформација клавирског звука, премда остварена употребом иновативне технологије (хибридних клавира и пратећег компјутерског интерфејса и банке звукова, специјално развијених за овај пројекат) такође не представља апсолутну новину у домену електроакустичке музике – мада де факто мења начин преноса акустичких информација у дигитални свет. Оно што је заиста ново и оригинално у Хелвеговом остварењу, поред чињенице да је у питању прва композиција за хибридне клавире, јесте продор уметничке музике у свет експерименталне физике, као резултат сусрета композитора у потрази за новим изворима инспирације и физичара који су желели да свет мајушних квантних честица приближе људском уху.

Као заједничке црте Булезовог есеја "Технологија и композитор" и пројекта *Квантна музика* издвојиле смо: тесну сарадњу између научника, инжењера и музичара; развој и производњу нових инструмената; напор музичара (како композитора, тако и извођача) да овладају најсавременијим технологијама; најзад, проналажење заједничког језика за музику и нове технолошке продоре. Пројекат *Квантна музика* отвара ново поглавље у односу између науке, технологије и музике, које има потенцијала да доведе до открића нових звучних светова – док је, у исто време, музици дата прилика да допринесе науци путем учествовања у експериментима на пољу квантне механике. Сигурне смо да би Булез одушевљено прихватио да компонује музику за квантне инструменте, јер ови "клавири будућности" отелотворују симбиозу науке, технологије и музике о којој је овај великан авангарде сањао и коју је и сам желео да оствари.

Кључне речи: Пјер Булез, технологија, нова музика, нови инструменти, *Квантна музика*