A Spectralist Approach to the Vibrations of the Universe

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A Spectralist Approach to the Vibrations of the Universe

A thesis submitted in partial fulfillment of the requirement

for the degree of Bachelor of Science

from the College of William and Mary in Virginia

by

Kevin M. Kay

Accepted for __________________________

(Honors, High Honors, Highest Honors)

________________________

Sophia Serghi

________________________

Brian Hulse

________________________

Eugene Tracy

Williamsburg, Virginia

April 24, 2017
Kevin Michael Kay

Subatomic Vibrations

for septet and live processing
**Technical Notes:**

This is a score in C. Piccolo sounds an octave higher than written.

**Instrumentation:**
- Flute/Picc.
- B♭ Clarinet/Bass Clarinet
- Alto Saxophone
- Violin
- Cello
- Piano
- Percussion
  - tom tom (Drum sticks or hard mallets)
  - bass drum (bass drum mallets and rubber mallet head)
  - tam tam, triangle, wood block (drum stick or hard mallet), maracas,
  - glockenspiel (hard mallets), crotales (Hard mallets)
  - cello bow

**Program Notes:**

I have a desire to capture the natural and physical world around me and create specific aural experiences. *Subatomic Vibrations* was created from this motivation, but had a specific purpose - to hear what nothing can. In this piece, I gathered together a soundworld made up of the frequencies of subatomic particles (fermions and bosons). These frequencies were calculated using the Compton-Wavelength Equation ($\lambda = \frac{\hbar}{mc}$) where $\lambda$ is the wavelength, $\hbar$ is the Planck constant, $m$ is the rest mass of the particle, and $c$ is the speed of light. Using the equation $v = \frac{1}{\lambda}$, where $v$ is the frequency, an equation could be derived that calculates the frequency of a particle using its rest mass ($v = \frac{(mc^2)/\hbar}{\lambda}$). The frequencies were then scaled down many, many octaves to place the pitches in our human aural range. String theory also played its role in this piece. I treated particles as bound strings, allowing each pitch associated with each particle to be thought of as a fundamental pitch, capable of vibrating at all possible harmonics. Physics lets me explore how objects in our natural and physical world create and permeate sound, and from this information, art is made.
**Extended Techniques:**

**Woodwinds - Clack keys (alternate right and left hand).**

**Feathered beaming is used to show quickening and slowing of notes.**

**Play the indicated note faster and faster.**

**Strings and percussion - Begin tremolo very slowly, then increase speed to a rapid tremolo. This can be reversed too.**

**Glissandi, (harmonic glissandi or regular glissandi) over complicated durations will include noteless stems to help indicate duration. (Do not re-articulate for each noteless stem - Always slur the entire glissando).**

In a passage like this, the glissandi happen right off of the note. There is no need for noteless stems to indicate duration.

**A triangle notehead indicates an undetermined high pitch.**
Piano extended techniques:

**Microtonality:**

- Touch the string inside the piano corresponding to the note being played. The further from the line from the note, the further down the piano on the string.

- Hit two of the wood beams inside the piano with the palms of your hands (Alternate right and left). The sustain pedal should be pressed during this.

**Live Processing**

Each instrument should have a microphone set up in front of them. For percussion, keep the microphone in front of the wood block and maracas. The signals from the 8 microphones will be routed to a laptop where someone will command a max Patch. Playback from the laptop will be routed to stereo speakers, placed on the left and right sides of the stage.

- The max patch will contain settings for each instrument (the list of settings are shown below).
- Live processing effects for each instrument are notated in the score for the person running the max patch.

**Microtonality:**

- $\sharp$ - 100 cents sharp
- $\natural$ - 50 cents sharp
- $\natural$ lower the pitch ~25 cents
- $\natural$ raise the pitch ~25 cents
- If two musicians are playing the same microtonal pitch, it is noted who to tune to.
- $b$ - 100 cents flat
- $b$ - 50 cents flat

**Live Processing**

- Reverb (baseline setting, increased setting)
- Granulation (low and high density settings on a slider)
- Delay (setting 1 and setting 2)
  - Setting 1: Fast occurrence of delays, lasts ~3 seconds
  - Setting 2: One delay, begins after ~3 seconds
- Pitch shift for harmonics (settings 3, 5, 7, 9, 11)
  - Each setting adds the pitch of the harmonic assigned to that setting number (e.g. Setting 7 adds the 7th harmonic of the natural harmonic series to whatever note is being played). The 3 is not shifted any octaves, 5, 7 and 9 are shifted down 1 octave, and 11 is shifted down 2 octaves.
<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (\text{MeV})</th>
<th>Frequency (Hz)</th>
<th>Note</th>
<th>Musical Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hadrons - Baryons (3 quarks)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proton</td>
<td>938.28</td>
<td>2.269e23</td>
<td>G - 34 cents</td>
<td>G ♭</td>
</tr>
<tr>
<td>Neutron</td>
<td>939.57</td>
<td>2.272e23</td>
<td>G - 32 cents</td>
<td>G ♭</td>
</tr>
<tr>
<td><strong>Hadrons - Mesons (quark + antiquark)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\pi^0) ((\bar{u}d))</td>
<td>134.98</td>
<td>3.264e22</td>
<td>A# - 33 cents</td>
<td>A ♭</td>
</tr>
<tr>
<td>(\pi^\pm) ((u\bar{d}))</td>
<td>139.57</td>
<td>3.375e22</td>
<td>A + 9 cents</td>
<td>A ♭</td>
</tr>
<tr>
<td>(B^0) ((d\bar{b}))</td>
<td>5279.58</td>
<td>1.277e24</td>
<td>C# - 43 cents</td>
<td>C ♭</td>
</tr>
<tr>
<td>(B^{+}) ((u\bar{b}))</td>
<td>5279.26</td>
<td>1.277e24</td>
<td>C# - 43 cents</td>
<td>C ♭</td>
</tr>
<tr>
<td>(K^0) ((d\bar{s}))</td>
<td>497.61</td>
<td>1.203e23</td>
<td>G# - 32 cents</td>
<td>G ♭</td>
</tr>
<tr>
<td>(K^{+}) ((u\bar{s}))</td>
<td>493.68</td>
<td>1.194e23</td>
<td>G# - 46 cents</td>
<td>G ♭</td>
</tr>
<tr>
<td>(D^0) ((c\bar{u}))</td>
<td>1864.84</td>
<td>4.509e23</td>
<td>G - 45 cents</td>
<td>G ♭</td>
</tr>
<tr>
<td>(D^{+}) ((c\bar{d}))</td>
<td>1869.61</td>
<td>4.521e23</td>
<td>G - 41 cents</td>
<td>G ♭</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quarks</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Up (u)</strong></td>
<td>2.3</td>
<td>5.561e20</td>
<td>B - 41 cents</td>
<td>B ♭</td>
</tr>
<tr>
<td><strong>Charm (c)</strong></td>
<td>1275</td>
<td>1.161e21</td>
<td>C - 3 cents</td>
<td>C ♭</td>
</tr>
<tr>
<td><strong>Top (t)</strong></td>
<td>173210</td>
<td>4.188e24</td>
<td>C# - 2 cents</td>
<td>C ♭</td>
</tr>
<tr>
<td><strong>Down (d)</strong></td>
<td>4.8</td>
<td>1.161e23</td>
<td>B + 33 cents</td>
<td>B ♭</td>
</tr>
<tr>
<td><strong>Strange (s)</strong></td>
<td>95</td>
<td>2.297e22</td>
<td>D# + 1 cent</td>
<td>D ♭</td>
</tr>
<tr>
<td><strong>Bottom (b)</strong></td>
<td>4180</td>
<td>1.011e24</td>
<td>A - 48 cents</td>
<td>A ♭</td>
</tr>
<tr>
<td><strong>Leptons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electron</strong></td>
<td>0.511</td>
<td>1.236e20</td>
<td>A - 45 cents</td>
<td>A ♭</td>
</tr>
<tr>
<td><strong>Muon</strong></td>
<td>105.7</td>
<td>2.555e22</td>
<td>F - 15 cents</td>
<td>F ♭</td>
</tr>
<tr>
<td><strong>Tau</strong></td>
<td>1776.82</td>
<td>4.296e23</td>
<td>F# - 29 cents</td>
<td>F ♭</td>
</tr>
<tr>
<td><strong>Bosons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Z Boson</strong></td>
<td>91188</td>
<td>2.205e25</td>
<td>D - 11 cents</td>
<td>D ♭</td>
</tr>
<tr>
<td><strong>W Boson</strong></td>
<td>80385</td>
<td>1.944e25</td>
<td>C - 29 cents</td>
<td>C ♭</td>
</tr>
<tr>
<td><strong>Higgs Boson</strong></td>
<td>125090</td>
<td>3.045e25</td>
<td>G + 49 cents</td>
<td>G ♭</td>
</tr>
</tbody>
</table>
Subatomic Vibrations

Fl.

B♭Cl.

A. Sx.

Perc.

Pno.

Vln.

Vc.

tune to Vc.

Delay 1 ON
Delay 1 OFF

Delay 1 ON
Delay 1 OFF

maracas

to sul pont. sul pont. to ord. ord.

Z boson
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Perc.

Pno.

Vln.

Vc.

Reverb increase ON

Reverb increase OFF

rubber mallet head on bass drum

tune to A. Sx.

tune to A. Sx.

tune to A. Sx.

tune to A. Sx.

piccolo

to piccolo

piccolo

to molto sul pont.
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Perc.

Pno.

Vln.

Vc.

rubber mallet head on bass drum

Delay 2 ON

Delay 2 OFF

Delay 2 ON

Delay 2 OFF

Delay 2 ON

Delay 2 OFF

to sul pont. — sul pont. to ord. — ord.

to ord.

(1/2)
Subatomic Vibrations

Fl.

B. Cl.

A. Sax.

Perc.

Pno.

Vln.

Vc.
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Crt.

Pno.

Vln.

Vc.
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

crotales (bowed)

Mrcs.

Pno.

Vln.

Vc.
Subatomic Vibrations

Fl.

B. Cl.

A. Sx.

Crt.

Pno.

Vln.

Vc.

\[ \text{up quark} \]
\[ \text{down quark} \]
\[ \text{charm quark} \]
\[ \text{Strange quark} \]

\[ \text{Reverb increase OFF} \]

\[ \text{Vib. as normal OFF} \]

\[ \text{Vib. as normal OFF} \]
**Subatomic Vibrations**

- **Fl.**
  - \( \text{mf} \)

- **Bb Cl.**
  - \( \text{pp} \)

- **A. Sx.**
  - \( \text{pp} \)

- **Crt.**
  - \( \text{pp} \)

- **Pno.**
  - \( \text{f} \)

- **Vln.**
  - \( \text{mf} \)

- **Vc.**
  - \( \text{pp} \)

- **Higgs harmonic series**
  - \( \text{to molto sul pont.} \)
  - \( \text{molto sul pont.} \)
  - \( \text{to ord.} \)

- **to ord.**
  - \( \text{to ord.} \)

- **Peck shift**
  - \( \text{ON} \)
Fl.

B♭ Cl.

A. Sx.

Crt.

Pno.

Vln.

Vc.

Subatomic Vibrations

strange quark

legato

with bow

Poch shift

5 OFF

Pitch shift
Subatomic Vibrations

Fl. legato

B♭ Cl. mp

A. Sx. mp

Crt.

Pno. rubber mallet head on bass drum

Vln. legato

Vc. mf
Subatomic Vibrations

Fl. legato

B♭ Cl. legato

A. Sx. legato

Perc.

Pro. Reverb increase

Vln.

Vc. Reverb increase
Subatomic Vibrations

\textsf{a tempo}

\textsf{rit.}

\textbf{Fl.}

\textbf{Bb Cl.}

\textbf{A. Sx.}

\textbf{Perc.}

\textbf{Pno.}

\textbf{Vln.}

\textbf{Vc.}

\textbf{bass drum mallets}

\textit{to bass clarinet}

\textit{press finger and drag down the string, activating various harmonics...and back up the string...}

\textit{...continue...}

\textit{move muting finger beyond the damper}

\textit{(pedal full depressed)
Subatomic Vibrations
Subatomic Vibrations

Fl.  

B. Cl.  

A. Sx.  

glockenspiel with bow  

Perc.  

Pno.  

Vln.  

Vc.  

tau  

electron  

tau  

electron  

muon  

muon (half)  

Vln.  

Vc.
Subatomic Vibrations
Subatomic Vibrations

Fl.

B® Cl.

A. Sx.

glockenspiel

Glk.

Pno.

Vln.

Vc.
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Glk.

Pno.

Vln.

Vc.

Delay 2 ON

Delay 2 ON

In four different sections, the notation includes musical elements such as clefs, bar lines, and dynamics (mp, mf, p). The sections are labeled as Fl., B♭ Cl., A. Sx., Glk., Pno., Vln., and Vc. The notation includes references to quarks and mesons, and there are indications for delays and onsets.
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Glk.

Pno.

Vln.

Vc.

K⁺/⁻ meson

D⁺/⁻ meson

π⁺ meson

Reverb increase ON

π⁺/⁻ meson

Delay 2 OFF

Delay 2 OFF

up quark

down quark

Subatomic Vibrations
Subatomic Vibrations


Pitch shift 7 ON

Pitch shift 7 OFF

Pitch shift 9 ON

Pitch shift 9 OFF

with bow
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Glk.

Pno.

Vln.

Vc.

Pitch shift
11 ON

Pitch shift
11 OFF

sul pont.
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Glk.

Pno.

Vln.

Vc.

Delay 2 ON

leptons

quarks

tam-tam

(bowed)

Delay 2 ON

quarks

leptons

Delay 2 ON

leptons

Delay 2 ON

leptons
Subatomic Vibrations

Picc.

B. Cl.

A. Sx.

Perc.

Pno.

Vln.

Vc.

muon, tau, electron (leptons)
Subatomic Vibrations

Picc.

B. Cl.

A. Sx.

Pno.

Vln.

Vc.
Subatomic Vibrations

Picc.

Reverb increase
ON

B. Cl.

Reverb increase
ON

A. Sx.

Reverb increase
ON

Perc.

Pno.

Reverb increase
ON

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
ON

Vln.

Reverb increase
ON

Vc.

Reverb increase
ON

tune to Vln.

flute

Reverb increase
OFF

tune to A. Sx.

tune to Hn.

tune to flute

(3/8) (half)

sul tasto

sul tasto

sul tasto

Reverb increase
ON

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
ON

Reverb increase
OFF

Higgs Boson
harmonic series

Reverb increase
OFF

Subatomic Vibrations
Subatomic Vibrations

Fl.

B. Cl.

A. Sx.

Perc.

Pno.

Vln.

Vc.

Reverb increase OFF

Reverb increase OFF
Subatomic Vibrations
Subatomic Vibrations

electron harmonic series

Fl.

B. Cl.

A. Sx.

Perc.

Pno.

Vln.

Vc.
Subatomic Vibrations

Fl.

B. Cl.

A. Sx.

Perc.

Pno.

Vln.

Vc.
Subatomic Vibrations

Fl.

B♭ Clarinet

A. Sx.

Perc.

Pno.

Vln.

Vc.

Higgs Boson harmonic series

M 2 above Vc.

M 3 above Vc.

(P 5 above Vc.)

tam-tam (bowed)

(charm harmonic)

J

subatomic vibrations

B meson

strange quark

electron

K± meson

bottom quark

down quark

tau

top quark

charm quark

charm quark

D ±± meson

down quark

pitch shift 3 ON

charm harmonic

charm harmonic

charm harmonic
**Subatomic Vibrations**

Fl.

<table>
<thead>
<tr>
<th>357</th>
<th>Higgs Boson harmonic series</th>
</tr>
</thead>
</table>

B♭ Cl.

<table>
<thead>
<tr>
<th>357</th>
<th></th>
</tr>
</thead>
</table>

A. Sx.

<table>
<thead>
<tr>
<th>357</th>
<th>glockenspiel (bowed) to crotales</th>
</tr>
</thead>
</table>

Perc.

<table>
<thead>
<tr>
<th>357</th>
<th>Reverb increase ON</th>
</tr>
</thead>
</table>

Pno.

<table>
<thead>
<tr>
<th>357</th>
<th>press finger and drag down the string, activating various harmonics</th>
</tr>
</thead>
</table>

Vln.

<table>
<thead>
<tr>
<th>357</th>
<th>Pitch shift ON</th>
</tr>
</thead>
</table>

Vc.

<table>
<thead>
<tr>
<th>357</th>
<th>Pitch shift OFF</th>
</tr>
</thead>
</table>

63
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Crt.

Pno.

Vln.

Vc.

Reverb increase
ON

Reverb increase
OFF

Reverb increase
ON

Reverb increase
OFF

Reverb increase
ON

Reverb increase
OFF

Audibly

(bowed)

Audibly

Subatomic Vibrations
Subatomic Vibrations

Fl.

B♭ Cl.

A. Sx.

Perc.

Pno.

Vln.

Vc.

Reverb increase
OFF

pizz.

scordatura (while playing)
G to G

(match violin)

III. (open G)
Subatomic Vibrations

Fl.
B♭ Cl.
A. Sx.
Perc.
Pno.
Vln.
Vc.

Reverb increase
ON
pizz. slap

Reverb increase
OFF

Reverb increase
ON

Reverb increase
ON

Reverb increase
OFF

Reverb increase
ON

Reverb increase
ON

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
ON

Reverb increase
ON

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
ON

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
OFF

Reverb increase
OFF
Subatomic Vibrations

Fl.  408
B♭Cl.  mf  n
A. Sx.  mf  n  crotale
(rolled)
Glk.  mf
Pno.  mf  (half)
Vln.  mf
Vc.  mf  sul III.

a tempo

bass clarinet

crotale
(bowed)
audibly

Granulation ON
(high density)
tune to Vln.

Granulation ON
(low density)

Subatomic Vibrations
Subatomic Vibrations

Fl.

B. Cl.

A. Sx.

Crt.

Pno.

Vln.

Vc.
“I have a desire to capture the natural and physical world around me and create specific aural experiences. Subatomic vibrations was created from this motivation, but had a specific purpose - to hear what nothing can. In this piece, I gathered together a soundworld made up of the frequencies of subatomic particles (fermions and bosons). These frequencies were calculated using the Compton-Wavelength Equation \((\lambda = \frac{h}{mc})\) where \(\lambda\) is the wavelength, \(h\) is the Planck constant, \(m\) is the rest mass of the particle, and \(c\) is the speed of light. Using the equation \(c = v\lambda\), where \(v\) is the frequency, an equation could be derived that calculates the frequency of a particle using its rest mass \((v = \frac{mc^2}{h})\). The frequencies were then scaled down many, many octaves to place the pitches in our human aural range. String theory also played its role in this piece. I treated particles as bound strings, allowing each pitch associated with each particle to be thought of as a fundamental pitch, capable of vibrating at all possible harmonics. Physics lets me explore how objects in our natural and physical world create and permeate sound, and from this information, art is made.”
Spectral music, or spectralism, is a sub-genre of classical music that emerged during the 1970s primarily out of IRCAM (Institute for Research and Coordination in Acoustics/Music). However, “the origins of spectral music are so diverse and numerous that no single survey can pretend to be exhaustive. The attempt to relate musicocultural activity to (supposedly) natural laws of acoustics has been a mainstay of musical theory since the time of the ancient Greeks.”

While the definition of spectral music tends to be malleable, most spectral composers tend to agree that the primary focus is sound evolving in time, with emphasis on timbre, or the sound quality of a tone. Spectral music is created usually by a formal organization of sonic material that comes directly from the physics of sound, allowed through the advancement in microphonic access. This music is heavily informed by the calculation and manipulation of sound spectra from the world around us. Sound spectra can be captured and utilized from musical instruments, although anything that produces noise could be recorded and analyzed. Computer software in the 21st century is able to easily analyze a sound sample and tell you the most prominent frequencies in the sound spectra. This is done by a process called a FFT (Fast Fourier Transform), which converts a signal from time to a representation into a frequency representation, and vice versa.

Most sounds we hear, whether it’s your voice, the dog barking, or the car horn, consists of a complex system of tones. The simplest harmonic spectrum is just a sine tone, in which one fundamental pitch is heard without any partials. However, I find simplicity and beauty to things found in our world that contain ordered harmonic spectra, such as the strings on a violin or cello.

---

When a string on a violin is played, the note contains more than just the fundamental pitch (the pitch of the note you are playing); contained within its sound are overtones. For a violin, these overtones (or partials as they are often called), act in a rigid mathematical way called the harmonic series, meaning that each partial is an integer value of the frequency of the fundamental. For example, if you play the G string on a violin (196 Hz), this note includes the partials 2f, 3f, 4f, 5f, …, nf, where f is the fundamental pitch (196 Hz in this case), and n is an integer (see the figure below). There is no need to run an FFT on a sound sample of the violin because we know how it will behave, as shown below.

Subatomic Vibrations began as a piece for 10 instruments and live processing. However, mid-way through composing, I decided to scale the instrumentation back to 7 instruments so that the piece had a foreseeable future performance. While the Max MSP patch for handling live electronics will not be created until closer to the premiere of the piece, I have gone through the piece and given cues for where and how the electronics will be used. The instrumentation is as follows: flute/piccolo, Bb clarinet/bass clarinet, alto saxophone, violin, cello, piano, percussion. The electronic effects are summarized below:

<table>
<thead>
<tr>
<th>Live Processing Effect</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverb</td>
<td>Standard reverb is added to every instrument to fill the room with sound, has a more natural effect</td>
</tr>
<tr>
<td>Increased Reverb</td>
<td>Creates a larger and fuller sound, is clearly electronically manufactured</td>
</tr>
<tr>
<td>Delay Setting 1</td>
<td>A quick occurrence of delays that lasts ~3 seconds</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>Delay Setting 2</td>
<td>One delay that begins after ~3 seconds</td>
</tr>
<tr>
<td>Pitch Shift (Settings 3, 5, 7, 9, 11)</td>
<td>Each setting adds the pitch of the harmonic assigned to that setting number (e.g. Setting 7 adds the 7th harmonic of the natural harmonic series to whatever note is being played). The 3 is not shifted any octaves, 5, 7 and 9 are shifted down 1 octave, and 11 is shifted down 2 octaves.</td>
</tr>
<tr>
<td>Granulation (Low and High Density)</td>
<td>This effect takes the incoming signal and turns it into small grains that overlap each other. There is a high and low density option, as well as the capability to slide from one to the other.</td>
</tr>
</tbody>
</table>

When starting *Subatomic Vibrations*, I needed to decide on the harmonic language of the piece. I have a fascination for string theory, as this theory, if true, would have really amazing implications for the world of music. If the fundamental particles of the universe were vibrating strings, couldn’t we calculate the frequency of these strings and exploit their musical properties? This was the starting inspiration for this project. I decided that with this inspiration in mind, I would focus my attention on fundamental particles that physicists have discovered, and calculate the frequencies at which these these particles are vibrating. The Compton Wavelength equation was the primary equation used, which calculates the Compton Wavelength, a quantum mechanical property, of a particle. The equation is:

\[
\lambda = \frac{\hbar}{mc}
\]

where \(\lambda\) is the wavelength, \(\hbar\) is the Planck constant, \(m\) is the mass of the particle, and \(c\) is the speed of light. By using the relationship of the speed of light to frequency and wavelength,

\[
c = v\lambda
\]
where $v$ is the frequency of the particle, a relationship between frequency and the mass of the particle could be derived:

$$v = \frac{mc^2}{h}$$

Below is a chart of the masses and frequencies of the particles used in *Subatomic Vibrations*. To go from Frequency to musical note, the frequencies were scaled down many octaves (by dividing by $2^n$) and then put into a frequency-to-musical note converter. The assigned musical notes are approximations of the frequencies to the nearest musical note, and not as a result of tuning or scales built from frequency rations, which is an important concept for spectral composition. Note that between two chromatic pitches (e.g. C and C sharp) is 100 cents.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass ($\frac{MeV}{c^2}$)</th>
<th>Frequency (Hz)</th>
<th>Note</th>
<th>Musical Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hadrons - Baryons (3 quarks)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proton</td>
<td>938.28</td>
<td>2.269e23</td>
<td>G - 34 cents</td>
<td>G ♭</td>
</tr>
<tr>
<td>Neutron</td>
<td>939.57</td>
<td>2.272e23</td>
<td>G - 32 cents</td>
<td>G ♭</td>
</tr>
<tr>
<td><strong>Hadrons - Mesons (quark + antiquark)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\pi,^0$</td>
<td>( $\uparrow\uparrow\uparrow - \downarrow\downarrow$ )</td>
<td>134.98</td>
<td>3.264e22</td>
<td>A# - 33 cents</td>
</tr>
<tr>
<td>$\pi,^{+/−}$</td>
<td></td>
<td>139.57</td>
<td>3.375e22</td>
<td>A +9 cents</td>
</tr>
<tr>
<td>$B,!^{0}$</td>
<td>( $\uparrow\downarrow$ )</td>
<td>5279.58</td>
<td>1.277e24</td>
<td>C# - 43 cents</td>
</tr>
<tr>
<td>$B,^{+/−}$</td>
<td>( $\uparrow\downarrow$ )</td>
<td>5279.26</td>
<td>1.277e24</td>
<td>C# - 43 cents</td>
</tr>
<tr>
<td>$K,^{0}$</td>
<td>( $\uparrow\downarrow$ )</td>
<td>497.61</td>
<td>1.203e23</td>
<td>G# - 32 cents</td>
</tr>
<tr>
<td>$K,^{+/−}$</td>
<td>( $\uparrow\downarrow$ )</td>
<td>493.68</td>
<td>1.194e23</td>
<td>G# - 46 cents</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
<th>Mass (MeV/c^2)</th>
<th>Energy (GeV)</th>
<th>Difference (cents)</th>
<th>Octave</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0$ (c̅u)</td>
<td>1864.84</td>
<td>4.509e23</td>
<td>G - 45 cents</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>$D^{+/-}$ (c̅d)</td>
<td>1869.61</td>
<td>4.521e23</td>
<td>G - 41 cents</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Quarks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up (u)</td>
<td>2.3</td>
<td>5.561e20</td>
<td>B - 41 cents</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Charm (c)</td>
<td>1275</td>
<td>1.161e21</td>
<td>C - 3 cents</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Top (t)</td>
<td>173210</td>
<td>4.188e24</td>
<td>C# - 2 cents</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Down (d)</td>
<td>4.8</td>
<td>1.161e23</td>
<td>B + 33 cents</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Strange (s)</td>
<td>95</td>
<td>2.297e22</td>
<td>D# + 1 cent</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Bottom (b)</td>
<td>4180</td>
<td>1.011e24</td>
<td>A - 48 cents</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Leptons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electron</td>
<td>0.511</td>
<td>1.236e20</td>
<td>A - 45 cents</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Muon</td>
<td>105.7</td>
<td>2.555e22</td>
<td>F - 15 cents</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Tau</td>
<td>1776.82</td>
<td>4.296e23</td>
<td>F# - 29 cents</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Bosons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z Boson</td>
<td>91188</td>
<td>2.205e25</td>
<td>D - 11 cents</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>W Boson</td>
<td>80385</td>
<td>1.944e25</td>
<td>C - 29 cents</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Higgs Boson</td>
<td>125090</td>
<td>3.045e25</td>
<td>G + 49 cents</td>
<td>G</td>
<td></td>
</tr>
</tbody>
</table>

After creating a collection of pitches, I wanted to bring the inspiration from string theory into the piece. I imagined each particle as a vibrating string, capable of producing all of its harmonics. Therefore, at certain moments in the piece, I explored the harmonic series of
particular particles. The collection of the up, charm, and top quarks are referred to as the up-type quarks, and the down, strange, and bottom quarks as the down-type quarks. With the up-type quarks, the up quark is first generation, the charm quark is second generation, and the top quark is third generation. All three of these quarks have a charge of $+\frac{2}{3}$, but they differ in mass (causing higher generation quarks to decay into lower generation ones), and by their flavour quantum number (a way of parameterizing quarks). The story is similar to the down-like quarks; the down quark is first generation, the strange quark is second generation, and the bottom quark is third generation. They all have a charge of $-\frac{1}{3}$, and they differ for the same reasons as the up-type quarks.

I began composing the piece at the place that feels like the most natural place to start - the beginning. When creating music, I always want to immediately place the listeners into the particular world of sound. For methods of grabbing attention, my mind went to Anders Hillborg’s *Celestial Mechanics*, where he used a wood block for moments of quick changes. With this in mind, the piece starts with a fortissimo wood block hit followed by a sustained pitch of the W boson. My idea for this is almost like the big bang just happened, and the world is coming to fruition. The opening of the piece uses the 3 boson pitches pitches. By the end of the exposition, I stabilized on octave Ds. Throughout the exposition, I used short bursts of percussive rattling through a combination of maracas, key clacking on the woodwinds, and tapping the wood frames inside the piano. This percussive motive acts as a sort of glue throughout the piece. In a way, it can be thought of as the whizzing of neutrinos, as the unpitched nature of the percussion is similar to the massless quality of the neutrinos. Cues for the live
processing electronic were added after the piece was fully composed. An excerpt of the percussive motive is shown below:

Percussive motive for *Subatomic Vibrations*.

After settling on the boson pitches, I wanted to find a transition that was cohesive with particle physics. “The W & Z particles are the massive exchange particles which are involved in the nuclear weak interaction, the weak force between electrons and neutrinos.” The W boson can decay by the following processes:

\[
W^+ \rightarrow e^+ + \nu_e \\
W^+ \rightarrow \mu^+ + \nu_\mu \\
W^+ \rightarrow \tau^+ + \nu_\tau
\]

Decay of the W boson.

---

With this physics in mind, I introduced the electron, muon, and tau pitches into the harmonic fabric of my piece. I begin to build some interesting cluster chords with the pitches using the muon pitch as the base pitch since it is a stable pitch (F, with no microtonal fluctuation). After introducing these notes, a pulsing on these pitches was created with feathered beaming (allowing the musicians to increase speed and decrease speed in a non-rigid way). This motive was used lightly in the beginning of the piece, but is more dense here.

The next group of pitches I added were the up-type quarks (up, charm, top), followed not-so arbitrarily by the Strange quark (D#). The reason for this chosen quark from the collection of down-type quarks is for my desire to focus on a group of non-microtonal pitches (Charm-C, Top-C#, Strange-D#), for the first “micropolyphonic” section of the piece. György Ligeti’s coined the term micropolyphony, which is “a technique of assembling large masses of sound from multiple layers of minute contrapuntal activity, with many different instruments playing the same material at different speeds.”8 Ligeti used this technique in his large textural works in the 60s and 70s, and has been a tremendous influence on my music. I used the term micropolyphonic in quotes, because what I have done with these quark pitches is not micropolyphony in the strict sense of Ligeti’s music, but the technique is still the same. A small motive was created from these quark pitches and given to several instruments, overlapping at different speeds. Later in the creative process, when I went through the piece and added notation for electronics, I included in this passage (and all of the micropolyphonic passages I composed), a delay effect. An excerpt from this passage is shown below:

---

8 Alex Ross, The rest is noise: listening to the twentieth century (New York: Picador, 2013).
Excerpt of the “micropolyphonic” section involving quark pitches.

After this section, I allowed for the feathered beaming pulsing to come back, which I used as a method adding the pions (\(\pi^0\) meson and the \(\pi^{\pm/0}\)) into the texture. Adding these pitches was a little presumptuous since I had not yet fully introduced the down-type quarks (pions are made from up and down quarks/antiquarks). However, very quickly following this, the violin and cello enter with pizzicato on strictly rhythmic tuplets that gliss to closely related quarks (by pitch), and by this process, all of the down-type quark pitches have finally entered the piece. The piano enters as well, allowing for more complex overlapping of rhythm. The proton/neutron then is introduced by the bass clarinet, which felt like a necessary climax of pitch content after the quarks exploration. A proton is made from 2 up quarks and 1 down quark, and a neutron is made from 1 up quark and 2 down quarks. Although not truly a climax of the piece, I felt it necessary to include a softer, more delicate section of meditation on the quarks and the proton/neutron, as to fully allow our ears to become acquainted to the harmonic language that I have developed. Electronic cues for granulation were added to these sustained pitches to add a
second layer of delicacy. This lighter section leads to a very pivotal moment within the work: the first introduction of steady pulsing 16th notes and the inspiration of string theory.

Because the steady Z Boson pitch (D) has been a crucial pitch of the work thus far, I felt it important to begin the 16th note pulse with this, starting in measure 141. I began to expand into the first harmonic series of the piece, drawing inspiration from string theory as I previously explained. I did so with overlapping duple and tuplet rhythms, which is something that I have seen in the textural works of Iannis Xenakis. Overlapping rhythms is a crucial idea for this work, and it is used several times throughout the piece. An excerpt is shown below:

Excerpt of overlapping rhythmic entities based on the harmonic series of the Z Boson.

I had this section die down, and make way for a rather flowing melody within the violin and cello. This melody acts as a brief sigh in the piece - an escape from the surrounding
microtonality. Inspiration for this idea came from the composer Anna Thorvaldsdottir. On top of this melody I added electronics notation for increased reverberation, so that this melody can really fill the room. With a couple of the pitches from the harmonic series of the Z Boson still pulsing, I proceeded to play with the changing of quark flavors, as I had done earlier in the piece. “By emitting an electrically charged W boson, the weak force can cause a particle such as the proton to change its charge by changing the flavour of its quarks. In 1958, Sidney Bludman suggested that there might be another arm of the weak force, the so-called ‘weak neutral current,’ mediated by an uncharged partner of the W bosons, which later became known as the Z boson.”

While it is not the Z boson that enacts in the changing of quark flavors, but its partner the W boson, my intent was that the weak force in general is changing the quark flavors here. It was also convenient that the W boson pitch, C (slightly flat), is the 7th partial of the Z boson harmonic series.

The 11th partial of the Z boson is a G quarter-tone sharp, which is conveniently the same pitch as the Higgs boson. These two pitches have several partials in their harmonic series that are the same (such as E: the 9th partial of the Z boson harmonic series, and the 13th partial of the Higgs boson harmonic series). The piece shifts back to the Z boson harmonic series, which I explored in two sections. Afterwards, there is not a major shift in harmonic language until measure 197, where I re-introduce the quarks. In measure 205, I introduced pulsing 16th notes within the quarks which fade in and out with dynamics. Pulsing 16th note electrons emerge, following by pulsing muons and pulsing taus. I represented musically the fact that the tau and muon particles are not stable, as seen below:

---

Decay of the tau particle, expressed musically.

A passage utilizing the electron harmonic series takes over, building in rhythmic overlapping pulses, which then transitions to the work’s second passage exploring micropolyphony, beginning in measure 236. Two pitches of the electron harmonic series (partials 7 and 13) are conveniently the same pitches as the muon and tau, and these two pitches are initiated within the clarinet and saxophone part and then passed to the violin and cello. The piano and glockenspiel also emerge with passages involving the muon and the tau, connecting in material to the strings. Above the strings, the flute, clarinet, and saxophone begin their own distinct micropolyphonic section using pitches of the electron harmonic series, but later switch the a scale of the 6 quarks. The violin joins in with this as well, but the cello introduces new pitch information: the mesons. With this section, I approximated some of the microtonal pitches to their nearest chromatic pitch for playability purposes. The excerpt below shows the progression of events I just described:
Progression of the second section of micropolyphony in *Subatomic Vibrations*.

This large-scale micropolyphonic section acts as a pre-climax. With the introduction of the meson pitches (snuck in with a passage of micropolyphony), I followed with a more ordered passage of pulsing 16th notes involving mesons and their respective quark makeup and then a calm section of sustained harmonic series pitches before the actual climax begins. Below is a chart of the mesons and the quark makeup. A bar over the quark indicates that it is an antiquark.

<table>
<thead>
<tr>
<th>Meson</th>
<th>Pitch</th>
<th>Quarks</th>
<th>Pitches</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+$</td>
<td>A</td>
<td>$ud$</td>
<td>B quarter flat, B natural +</td>
</tr>
<tr>
<td>$\pi^0$</td>
<td>A sharp -</td>
<td>$\frac{m - \sqrt{2}}{\sqrt{2}}$</td>
<td>B quarter flat, B natural +</td>
</tr>
<tr>
<td>$K^+$</td>
<td>G quarter sharp</td>
<td>$\bar{u}s$</td>
<td>B quarter flat, D sharp</td>
</tr>
<tr>
<td>$K^0$</td>
<td>G sharp -</td>
<td>$d\bar{s}$</td>
<td>B natural +, D sharp</td>
</tr>
<tr>
<td>$D^+$</td>
<td>G quarter flat</td>
<td>$\bar{c}d$</td>
<td>C natural, B natural +</td>
</tr>
</tbody>
</table>
Musically, I expressed this by having the meson pulsing 16th notes, and overtop in a shorter segment, I had the two quarks pulsing as well. This is shown below:
saxophone and cello as the flute and clarinet change to micropolyphonic passages on the quarks (with the violin as well). Like the previous micropolyphonic section, I approximated some microtonal pitches to the nearest chromatic pitch for playability purposes. I composed quick runs for the piano using any of the non-microtonal subatomic particle pitches, which had been a staple use of the piano throughout the entire piece. The progression of the micropolyphony can be seen below:

Use of micropolyphony in the climax of Subatomic Vibrations.

I proceeded to introducing shorter pulsing of 3 notes, either assigned to an on-beat or an off-beat. These pitches cycle through the mesons and also the quarks. To make this more cacophonous, I changed these short bursts to higher octaves occasionally, and sometimes let them last for a full beat, displacing the rhythm. This is shown below:
Use of on-beat and off-beat bursts as means of cacophony during the climax.

The climax of the piece finishes at measure 311. The piece quickly evolves into a passage involving the Higgs boson harmonic series. Following this, several more harmonic series are established, which all include pulsing 16th notes as the piece moves towards a more calm nature. There is some slight increase in tension in measure 346, as cluster chords emerge based on leptons, mesons, and quarks. This is shown below:

Cluster chords during the de-escalation of *Subatomic Vibrations.*
A small passage follows with chords based on the harmonic series of quarks phasing through each other, which precedes another passage of utilizing the harmonic series of the three bosons. I placed specific emphasis on the Higgs boson, as its discovery has been extremely important in recent particle physics research. At this point in the piece I provided instruction for the cello and violin to re-tune some of the strings of their instruments (scordatura). Specifically, the C string on the cello is re-tuned to a C slightly flat (W boson pitch), and the G string on both the violin and cello are re-tuned to a G quarter-sharp (Higgs boson pitch). Due to this, the cello and violin are capable of playing harmonic glissandi for all of the boson pitches, and play specific natural harmonics. The piece continues to wind down as the piece shifts full attention to the harmonic series of the Higgs boson. Other instruments begin to play G naturals and G sharps, which is literally representative of the uncertainty of the Higgs boson mass. (I hope at this point in the analysis it has not been forgotten that particle mass is used to equate their Compton Wavelength and therefore their pitch!) The piece ends with the sustained Higgs boson pitch in a high register of the violin and flute, followed by a wood block hit and shaking maracas which slowly fade away.


Ross, Alex. The rest is noise: listening to the twentieth century. New York: Picador, 2013.