499 seconds
Neutrino Oscillations for Voices
Suzie Shrubb 2018, revised 2020

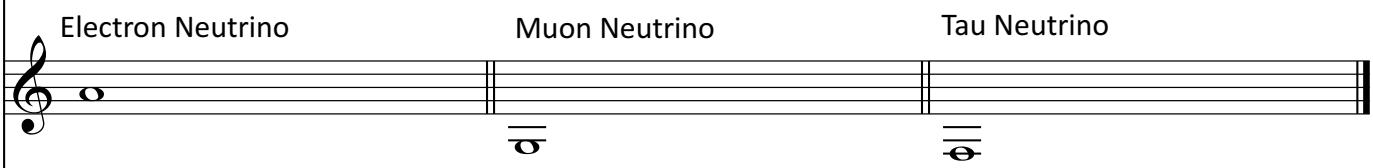
First Movement  0 seconds

The electron neutrinos leave the Sun

All vocalise the same pitch.

Second Movement  0-30 seconds onwards - 490 seconds

Neutrino Oscillations. Neutrinos travel through space to the Earth




See notes for more directions.
Vocalists become neutrinos oscillating, changing at random between these pitches.
More than one vocalist can occupy the same pitch as another.
Vocalists do not have to change at the same time.
Vocalists must be guided by the balance between their inner sense of intuition and their outer awareness of the soundscape. There is no specific duration for vocalists to remain on notes.

Third Movement 490-499 seconds
Detection on Earth

Vocalists oscillating should start to settle by the end of the piece, ideally on the last second,
creating the final chord representing the state of three flavours of solar neutrinos as detected on Earth.
These proportions are as follows:
One third of vocalists on A4 or the electron neutrino.
Two thirds of the vocalists on pitches representing the muon: G3 and tau: F3 neutrinos.

All sound must cease at exactly 499 seconds.

A few vocalists will be oscillating or moving between pitches throughout the entire piece.
This does not need to be obvious to a listener, although it may be at moments.
See notes for more directions.

Introduction

The title of this work is derived from the time it takes solar neutrinos produced in the nuclear furnace of our sun to travel to the Earth: 499.00 seconds.[1]

Neutrinos [2] are subatomic particles described as part of the standard model of particle physics.[3] There are three different types or flavours of neutrino that become progressively heavier in terms of mass/energy [4]. The particle with the smallest mass/energy is the electron neutrino; the next largest is the muon neutrino and the largest, the tau neutrino.

A distinctive feature of neutrinos is that they can change or oscillate between these different flavours. So far, no other subatomic particle has ever been observed to do this.[5]

Solar neutrinos [6] are produced as a result of nuclear processes that take place at the core of stars. The star at the centre of our solar system, our Sun, produces billions upon billions of

[1] The average distance of the Earth from the Sun is 149,597,870 km or 92,922,807 miles. Dividing this by the distance light travels in one second 299,792 km or 186,282 miles gives us our figure 499.00 seconds. Source for this data: NASA.

[2] The name "neutrino" means "little neutral one", a term coined by Italian physicist Edoardo Amaldi.

[3] Neutrinos belong to the wider group of elementary particles so far discovered and classified by the standard model that include the quark, electron, W and Z boson, photon, gluon and the Higgs boson.

[4] Mass and energy are equivalent through the famous equation discovered by Albert Einstein: $e=mc^2$ (Energy is equal to the mass times the constant squared. The constant being the speed of light.)

[5] Indeed it was experiments on solar neutrinos that first discovered and verified this.

[6] Unlike the photons from the sun that you shield from your eyes with sunglasses, that you feel warming your skin or ripening your strawberries, these ghostly particles rarely interact with matter. They are as invisible to you as you are to them and billions of these solar neutrinos stream right through you and everything around every second of every day, unfelt, unnoticed and unobserved.

neutrinos every second into space travelling at the speed of light.[7]

As far as we have discovered and confirmed so far, nuclear reactions inside the Sun produce one type of neutrino: the electron neutrino.

As these electron neutrinos travel from the Sun to our planet Earth they will oscillate or change between to different flavours of neutrino. At their detection on earth we find that two thirds of the solar neutrinos have transformed into the muon and tau neutrinos.

[7] 186,287 miles per second or 299,792 kilometers per second.

Notes on *499 Seconds Neutrino Oscillation for Voices*

For each type of neutrino: electron, muon and tau I have calculated a specific pitch which correlates directly to the mass/energy as stated by the Standard Model Of Particle Physics:[8]

Electron Neutrino = A4[9]
Muon Neutrino = G3
Tau Neutrino = F3[10]

The piece is divided into three movements. Each movement represents the state of the neutrinos as we measure them, or understand them to be behaving, at each point on their journey.

As the neutrino journey from Sun to Earth is continuous, each movement must run continuously and seamlessly into the other.

[8] Although data has been taken from The Standard Model of Particle Physics (various sources), the issue of neutrinos having mass at all is complicated and is currently an active area of research. Indeed, neutrinos are puzzling in many respects. The questions neutrinos raise offer possible solutions as to why massive particles exist at all and were not annihilated during the matter/anti-matter phase of the early universe. Neutrinos have also been proposed as candidate particles for dark matter.

[9] Scientific pitch notation

[10] I used a logarithmic scaling to correlate the vastly different energy scale of the neutrinos with the scale of notes attainable by the human voice. I also reversed the relationship of energy/mass because it feels counterintuitive to me musically speaking to have heavy particles as high notes, which is what would result if no reversal took place. The mass/energy as well as the relationship between neutrino mass/energy has been maintained and preserved in their translation to the western chromatic scale.

*First Movement*
*The electron neutrinos leave the Sun*
*0-30 seconds*

Voices sing one note: A4.

Jumping between pitches starts in a small and inaudible way.

The start of the piece, the First Movement we find to neutrino electrons emitted by the Sun. The Sun is singing at one specific note.

*Second Movement*
*Neutrino Oscillations. Neutrinos travel through space to the Earth.*
*30-490 seconds*

Neutrinos oscillating.

Voices jump, shift, change, and move between the three different assigned pitches: A4, G3, F3.

As solar neutrinos travel the distance from the Sun to the Earth over a duration of 499 seconds they constantly change or oscillate between the three possible types: electron, muon or tau. In this movement voices jump, shift, change, move between the three different assigned pitches.

Neutrinos are sub-atomic phenomena and as such are subject to the rules governing these phenomena, namely Quantum Theory. The behaviour of these particles therefore looks to us completely random, governed by chance and statistics. We cannot say for sure which specific particles are going to change into muons or taus or electron neutrinos or when they are

going to do it. We can only say that they will and we know that when we measure them on Earth an exact proportion of them will have transformed from the electron type into the muon and tau type. This exact proportion has been measured as 34%[11] of the neutrinos of the electron type with the remaining 66% made up of the muon and tau type. For the purposes of this piece a third (1/3) of the ensemble stays with the corresponding electron neutrino pitch and the remaining two thirds (2/3) organised into muon and tau pitches.

*Third Movement*
*Detection on Earth*
*490-499 seconds*

A chord comprised of 1/3 ensemble singing A4 and 2/3 of the ensemble singing G3 and F3.

At their point of detection on Earth 1/3 of the neutrinos will be of the electron type with the remaining 2/3 made up of the muon and tau type.

Proportions of muon and tau neutrinos have not been measured exactly. Therefore performers can follow whatever proportions emerge, so long as a two-thirds of the ensemble are doing so.

Ideally the final chord should come to settle with almost no oscillating from performers at the absolute last second of the piece. 10 seconds before the end of the piece, voices may start to settle into their relevant configurations and maintain some jumping between pitches here.

[11] By the Sudbury Neutrino Observatory.

This final movement represents the neutrino detection on Earth. The neutrinos do not know this and they keep going, oscillating and travelling beyond Earth and out into the vastness of the Universe forever. Neutrinos have been found to be oscillating in the Sun itself.[12] Some voices will oscillate through out the whole piece.

In this piece performers become the neutrinos journeying from the Sun to the Earth. In rehearsal and performance the invitation is for vocalists to cultivate a connection to their deepest inner selves and instinct as well as to the outer sound world and connection to others in the space. Performers need to spend time developing something akin to a telepathic link to the voices inside them and outside them in the ensemble in order to connect to the desire for change, not for changes sake, but change fostered by a deep awareness of the space-time continuum of which we are all embedded and a part, along with the neutrinos.

[12] Discovered by the Sudbury Neutrino Observatory.

*499.00 Seconds Neutrino Oscillations for Voices*

Performance directions:

Time will need to be measured using a stopwatch or other device.

The composer recommends one person nominated to direct or communicate the passing of time to other performers.

There is no minimum or maximum number of voices specified. Performers are free to decide for themselves what will work for them. I specify no maximum number of voices since this could be in the billions if we wanted it to be.

Different pitches may be chosen to suit the voice range of the ensemble. To preserve the note relationship to neutrino energy/mass ***the interval distance or relationship between pitches must be maintained as set out in this piece.***

Arrangement of the final chord can be managed in various ways. Performers can decide in advance who will take which note to express the desired proportions. Performers may choose to do this in the moment of the piece using their instinct and ears and hearts. Although I have nothing against deciding in advance as a strategy, my preferred option as a performer and composer would always be to explore the latter option.

Given timings are approximate guides. Vocalists must allow themselves to follow their own intuitive senses and awareness of the inner sense and outer soundscape when shaping the piece. The neutrinos will be constantly oscillating as soon as they are produced inside Sun. They will never stop oscillating.

Therefore some voices continue to oscillate throughout the whole piece. This does not need to be audible to the outside world but nonetheless needs to happen within the ensemble.

The time frame of the piece is non-negotiable. It is vital that the piece ends and everyone ceases to produce sound with their voice at exactly 499 seconds.

Sound ceases abruptly at the end of the piece.

The action of starting on the same pitch, and ending on the chord comprised of specific ratios: 1/3's on A4, 2/3 on G3 and F3 is also non-negotiable.

The following are at the discretion of performers:
Dynamics
Embouchure shapes
Length of notes
Although sound must be continuous within the durational frame of the piece vocalists can stagger entries and thus take breaks to rest as needed.
Vocal expression i.e. whispering, vibrato, nasal tones etc.
Anything else that feels right to be expressed within the confines of the piece,
Use your collective imaginations, playfulness and curiosity to discover what happens in this piece. Allow what happens in the moment to happen.