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Abstract

Nonlinear standing waves known as Faraday waves are formed in vibrating liquids enclosed by a container. To further our understanding of the relation between frequency and wave propagation within spatial boundaries, we investigated Faraday wave phenomena utilizing the CymaScope instrument, which works by transposing sonic periodicities to water wavelet periodicities. This paper presents the resulting observations and suggests a unified language for describing sound-induced resonant wave phenomena.

Introduction

Sound-related vibratory phenomena are observed in the formation of geometric patterns of either Faraday waves formed in a vertically vibrated liquid-filled cuvette or Chladni figures formed by vibrating grains on a flat medium. The work presented here investigates Faraday waves obtained using the CymaScope instrument that was in-

vented and developed by John Stuart Reid (Web ref. 1). The trade name, "CymaScope," is derived by simply combining "kyma," meaning "wave," with the ancient Greek "skopós," meaning "watcher."

Faraday waves, first reported by Michael Faraday in an appendix to a document in 1831, are standing waves resulting from parametric instability (where a change in any parameter significantly changes the outcome) of the capillary gravity waves (where both gravity and surface tension are factors in creating the waves) (Faraday, 1831; Douady and Fauve, 1988; Fauve, 1998; Gallaire and Brun, 2017). This instability is termed the "Faraday instability" and relates to standing waves created at a critical amplitude and driving frequency of a vertically vibrated liquid-filled cuvette. When the parameters that create the instability are graphed, the shape of the unstable region in the graph can manifest in the shape of a tongue, known as an instability tongue (Benjamin and Ursell, 1954; Douady, 1990; Bechhoefer and Johnson, 1996; Perlin and Schultz,

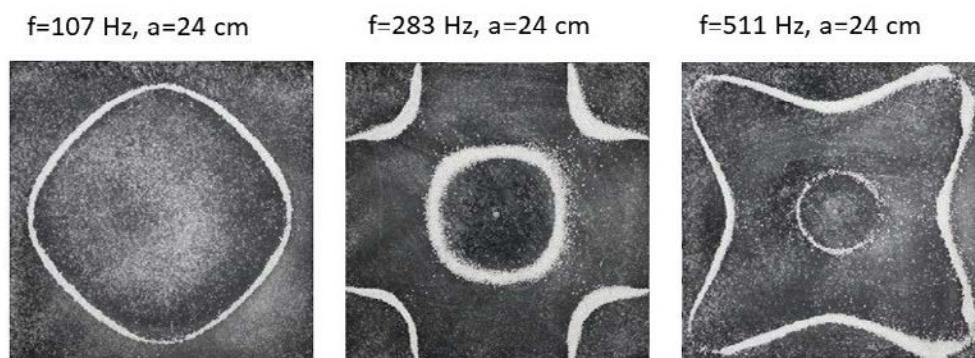


Figure 1. Chladni figures showing the nodal line patterns observed on a 24 cm square plate at a frequency of: $f = 107$ Hz; $f = 283$ Hz; and $f = 511$ Hz. Images from Val Baker *et al.*, 2024.

2000; Gallaire and Brun, 2017).

Chladni figures, also referred to as nodal patterns, are observed as emanating symmetric patterns following excitation of a flat medium sprinkled with small grains (usually sand). The patterns emerge as the granular substance sprinkled on the plate collects at the nodal points, which are the points of equilibrium or close to zero amplitude. For example, see *Figure 1*. In the wake of previous experiments, conducted in 1630 by Galileo Galilei (Galilei, 1638) and in 1680 by Robert Hooke (Andrade, 1950), the German musician and physicist Ernest Chladni observed the vibrations of matter through various experiments. Chladni documented this phenomenon of sound frequencies organizing matter in symmetric patterns and demonstrated that these patterns get more intricate as the frequency increases (Chladni, 1787). Mary Desiree Waller continued the research into Chladni figures and in her book, “Chladni Figures, a study in symmetry,” she reported observing the symmetry in Chladni figures and was the first person to deduce a law of symmetry of vibrating two-dimensional systems (Waller, 1938, 1961). Chladni figures are primarily determined by the excitation frequency, the boundary conditions and the excited medium (Escaler and De La Torre, 2018; Tuan *et al.*, 2015), inherently leading to a length-wavelength relation to the

pattern’s symmetry, allowing for the successful theoretical determination of the nodal line patterns (e.g., see Val Baker *et al.* 2024 and references therein).

While in Chladni figures the distinction is between nodes and antinodes, in Faraday wave phenomena the distinction is between the crests and troughs. The crests of the wavelets are convex and therefore diffuse light away from the eye or camera, thus appearing darker, while the concave troughs of the wavelets act as reflectors, sending light back to the eye or camera thus appearing brighter. The antinodes therefore exist as either darker crests or brighter troughs and the nodal points are the transition, or equilibrium points (e.g., see *Figure 2*).

Since their discovery, Faraday waves have been the subject of successive investigations allowing for advanced applications across a myriad of fields (Liu *et al.*, 2022). These include, for example: measuring the surface tension of soft materials (Shao *et al.*, 2018); developing new photonic devices (Tarasov *et al.*, 2016; Huang *et al.*, 2017); metamaterials (Domino *et al.*, 2016; Francois *et al.*, 2017); applications in cell culture patterns (Takagi *et al.*, 2002; Hong *et al.*, 2020); detecting physiological processes of organisms (Maksymov and Pototsky, 2020); monitoring earthworms (Mitra *et al.*, 2008); modifying soil structure to increase crop yields (Blakemore and Hochkirch, 2017; Lacoste *et al.*, 2018; Ruiz and Or, 2018); medical ultrasound and photoacoustic imaging modalities (Emelianov, 2019); Brillouin light scattering spectroscopy (Ballmann *et al.*, 2019); imaging cancer and healthy cell sounds in water (Reid *et al.*, 2019); laser vibrometry (Blamey *et al.*, 2013); liquid-based templates for directed assembly of microscale materials, including biological entities such as individual cells (Chen *et al.*, 2014); and the development of new methods for eradicating viruses and bacteria (Zinin *et al.*, 2006; Ivanova *et al.*, 2013; Boyd *et al.*, 2020). Furthermore, as noted by Sheldrake and Sheldrake (2017), the behavior of the observed resonant phenomena offers a model for analogous behavior observed in both physical (e.g., Schrödinger, 1926; Xu *et al.*, 1983; Moon *et al.*, 2008; Britton *et al.*, 2012) and biological systems, (e.g., Matsushashi *et al.*, 1998; Gruntman and Novoplansky, 2004; Gholami *et al.*, 2015; Liu *et al.*, 2017). Indeed, the similarity in the pattern morphology with both biological and physical systems is prevalent and intriguing; examples range from the structure of DNA, the trilobite, the starfish, the phyllotaxis of spiral aloe, and snowflakes, to the hexagon storm of Saturn (Web ref. 1; Gallaire and Brun, 2017). The idea that this pattern morphology is somehow inherent

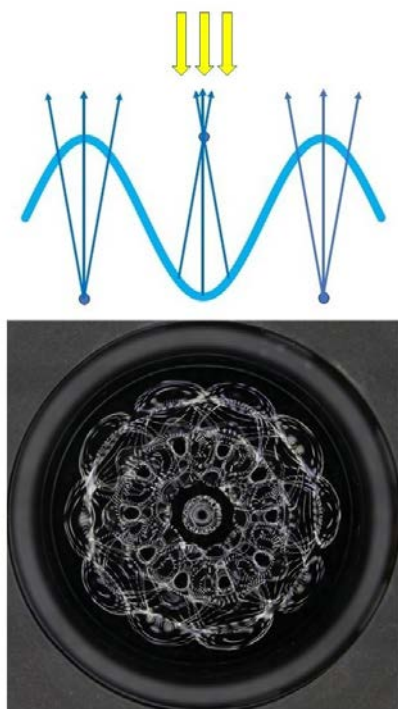


Figure 2. Diagram to show the crests and troughs in a vibrating liquid and the corresponding antinodes and nodes observed in Faraday wave phenomena at a frequency of 92 Hz.

in the universe is not new. Examples range from studies on the structure of the universe (Broadhurst *et al.*, 1990; Battaner and Florida, 1998; Eisenstein and Bennett, 2008) to studies on an archaeal virus (Rice *et al.*, 2004), where notably, in both these cases, sound is the driving force. Understanding Faraday wave phenomena and the details of their formation, morphology and dynamics therefore has huge implications for both scientific knowledge and potential applications.

Previous observations of Faraday waves in a vertically vibrated liquid-filled cuvette concluded that pattern formation is primarily determined by the excitation frequency (Abraham, 1976; Simonelli and Gollub, 1989; Kumar and Tuckerman, 1994; Sheldrake and Sheldrake, 2017), the boundary condition of the observed medium (Kumar and Tuckerman, 1994; Topaz *et al.*, 2004; Francois *et al.*, 2014; Sheldrake and Sheldrake, 2017) and the viscosity of the liquid (Escaler and De La Torre, 2018; Tuan *et al.*, 2015; Westra *et al.*, 2003), (Web ref. 1). The resulting pattern morphology, observed at different frequencies, is shown to form a myriad of patterns, e.g., lattices and stripes, hexagonal shapes, and cubes, etc. (Francois *et al.*, 2014; Topaz *et al.*, 2004). Furthermore, when excitation is by more than one frequency, akin to sounds in nature, there is an indication of pattern selection, where either one frequency pattern is more dominant or a new pattern is formed (Batson *et al.*, 2015).

However, although pattern morphology is somewhat deterministic, it is not entirely predictable (Benjamin and Ursell, 1954; Kumar and Tuckerman, 1994; Bechhoefer *et al.*, 1995). And while the seemingly unpredictable patterns observed at higher frequencies can likely be attributed to mode mixing, and the variations observed at the lower frequencies may be understood in terms of chaos theory and/or catastrophe theory, it is evident that further investigation is required (Thom, 1975; Douady and Fauve, 1988; Sheldrake and Sheldrake, 2017).

Improving our understanding of Faraday wave phenomena is therefore of great importance. Specifically, with the aim of identifying the set of initial conditions that will lead to pattern formation of a specific morphology and dynamic, *i.e.*, the inverse problem. To investigate this further and identify the inverse problem, we first need to define a unified classification language and methodology.

In this paper we report on the observations of Faraday wave phenomena following the excitation by one or more frequencies of a water-filled cuvette observed with the

CymaScope Pro Mid Frequency (MF+) instrument. This study explores the varied morphology of patterns observed for different frequencies. In each case the pattern morphology is defined, and where required, a new terminology is suggested. In this paper, we report on both new phenomena and those which were previously reported.

Methodology

The observations were conducted on the CymaScope Pro MF+ instrument that makes wave patterns visible by transforming the periodicity of audio input signals to water wavelet periodicity via acoustic excitation of a fused-quartz water-filled cuvette. The CymaScope Pro MF+ comprises a fuse-quartz cuvette direct-coupled to a Voice Coil Motor (VCM) with a vertically driven piston. The fused-quartz cuvette is acoustically excited by the VCM which, in this configuration, receives audio input signals generated by a Max/MSP patch used within Ableton Live (v11). Electronic filtering is applied in the signal path through a DBX 231 graphic equalizer to ensure that resonances inherent in the VCM-cuvette assembly are negated, resulting in a characteristic flat amplitude response curve. The resulting resonant phenomena for all audio samples were observed via direct ocular viewing while simultaneously recorded using a Canon EOS 5D Mk IV camera (see *Figures 3a-c*).

The experiments presented here used fused quartz cuvettes of the following shape and size: a triangle of 50 mm length; a rectangle of 24.25 mm length and 15 mm width; a circle of 24.25 mm diameter; and a square of 25.2 mm length. Each cuvette was filled with 2.1 ml; 1.1 ml; 2.3 ml; and 3.3 ml of distilled water, respectively (see *Figures 4a-d*).

Observations were made for each frequency in accordance with the ~ 250 Hz compatibility range of the CymaScope instrument (see Appendix 1 - 4). In each case, measurements of the wave pattern formations were made, and the following environmental factors were monitored: humidity; air pressure; water temperature; and room temperature. To account for any effects due to prior oscillation (Montagnier *et al.*, 2009), new water was used for each measurement and the order in which the different frequencies were observed was varied and random. The amplitude was manually increased using the decibel level controls and was recorded as audio input in decibel relative to full scale (dBFS). As a unit of measurement, dBFS measures amplitude levels in digi-

tal systems, where 0 dBFS is assigned to the maximum level. Throughout this paper all values in dB indicate the input amplitude in dBFS. It should be noted that the videos, and corresponding images, are only able to capture a moment in time, and thus, depending on the compatibility between the Faraday waves and the

equipment, are not always able to fully represent the wave dynamics.

Before taking measurements, the following apparatus checks were made: the CymaScope instrument level check with the in-built level meter; the camera mounting

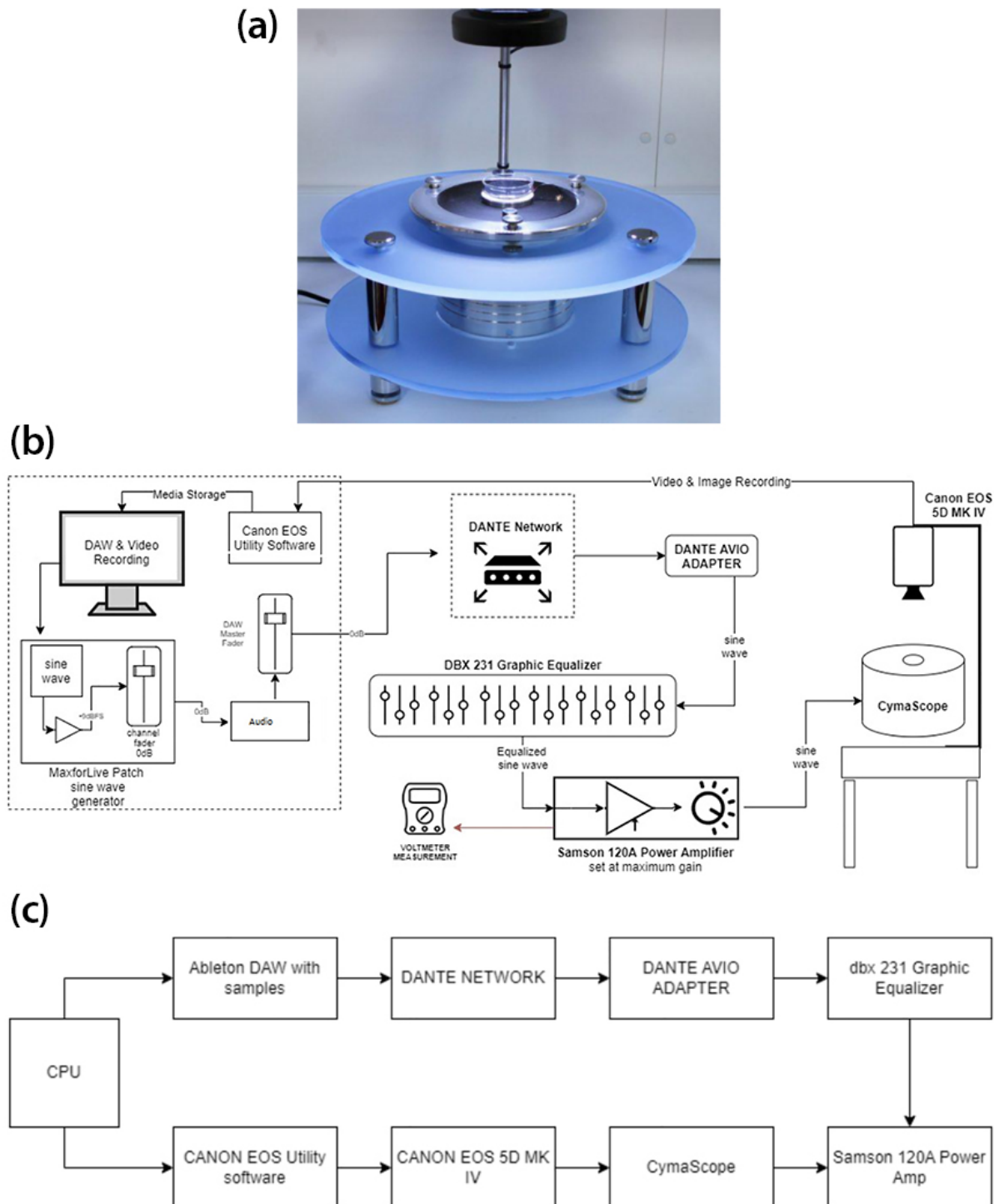


Figure 3. Experimental setup, showing: (a) the CymaScope instrument; (b) the setup configuration; and (c) the signal flow chart.

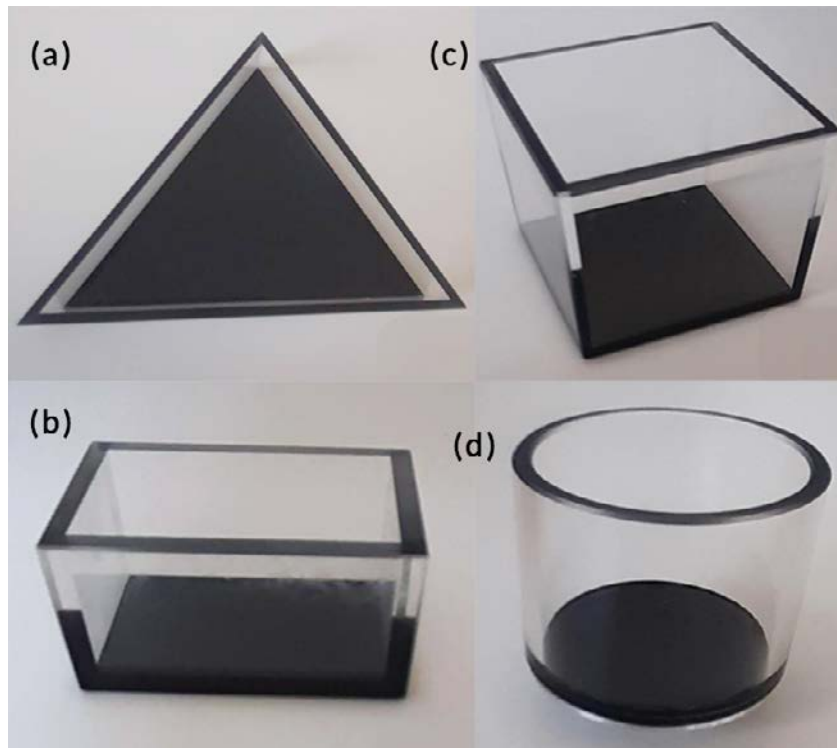


Figure 4. Images of the cuvettes for: (a) the 50 mm triangular cuvette; (b) the 24.25 x 15 mm rectangular cuvette; (c) the 25.2 mm square cuvette; and (d) the 24.25 mm circular cuvette.

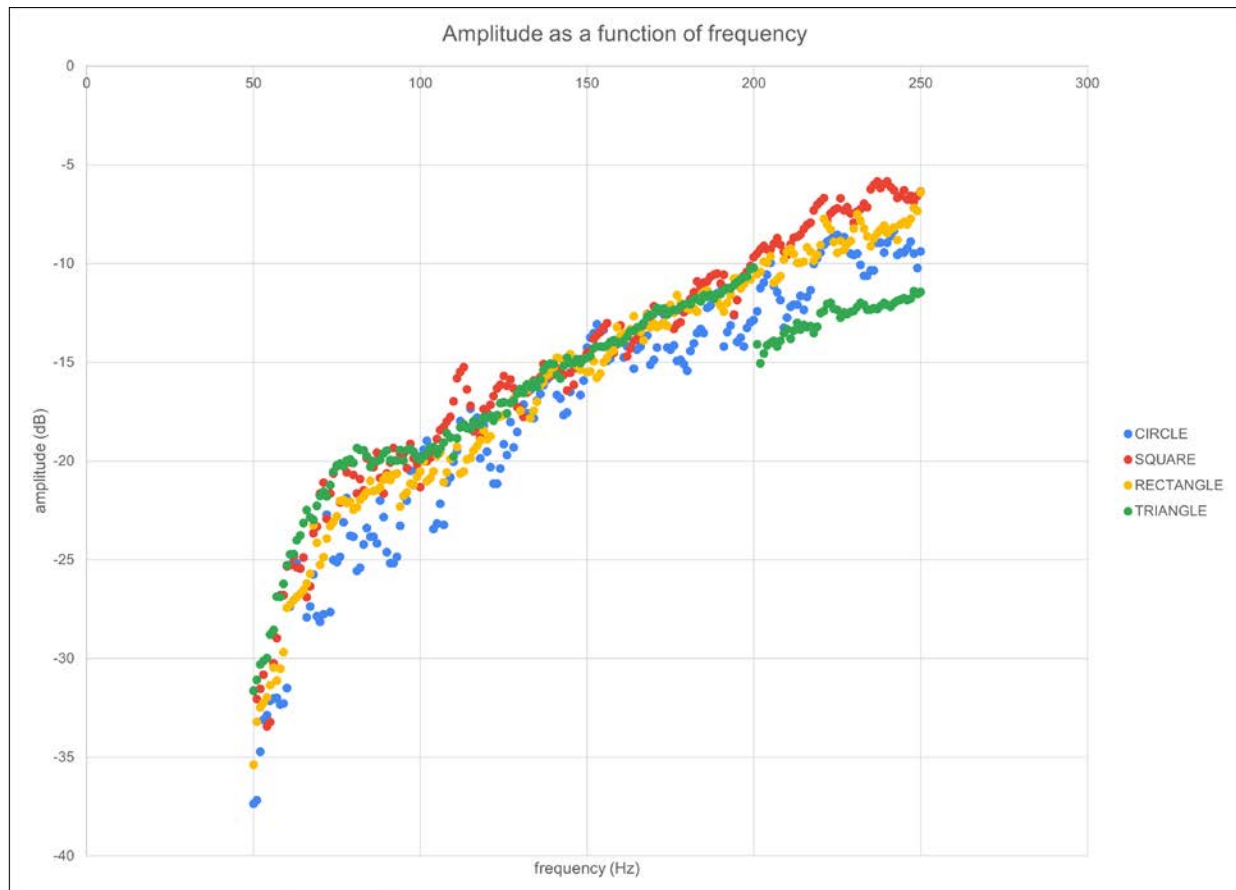


Figure 5. Plot to show amplitude as a function of frequency for the triangular, rectangular, square and circular shaped cuvettes.

level via the camera in live view with the diode reflection as a guide; dust removal from the CymaScope instrument including the cuvette and the camera lens as well as ensuring no dust remained once the cuvette had been filled with water.

Results and Discussion

The resulting observations are described in terms of: (1) pattern formation; (2) pattern morphology; and (3) pattern dynamics. In each case, existing or newly defined terminology is shown in bold.

Pattern Formation

Faraday wave phenomena formed in a vertically vibrated liquid-filled cuvette are dependent on the frequency and

the boundary conditions. Moreover, for stable pattern formation to occur: (i) The excitation frequency needs to be compatible with the boundary conditions; (ii) the amplitude needs to be of sufficient magnitude; and (iii) the required time for pattern formation to occur needs to be realized.

In this work we investigated frequencies in the range 8 - 256 Hz (see Appendix 1 - 4). The frequencies where pattern formation occurred are referred to as **reference frequencies**. Note, this does not mean that the same pattern formation will always occur at these **reference frequencies**. Sometimes the same pattern will instead be observed at a frequency of $\pm$ a few Hz of the **reference frequency** and sometimes a completely new pattern will be observed. As well, for the frequencies that showed no stable pattern formation, it does not mean that pattern

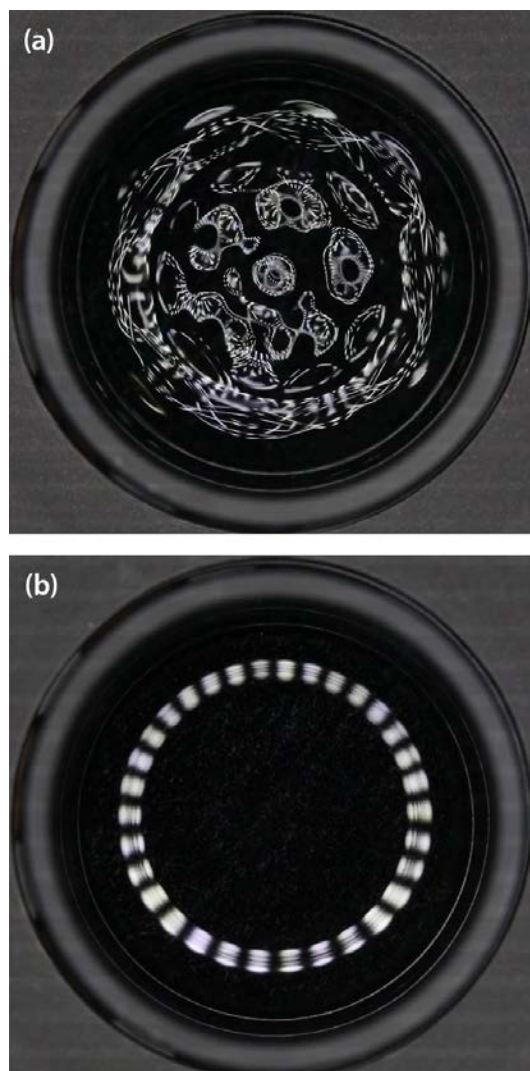


Figure 6. Pattern formation at a frequency of 128.4 Hz and an amplitude of -19.4 dB for a circular cuvette is shown to: (a) occur in one trial; and (b) not occur in another trial.

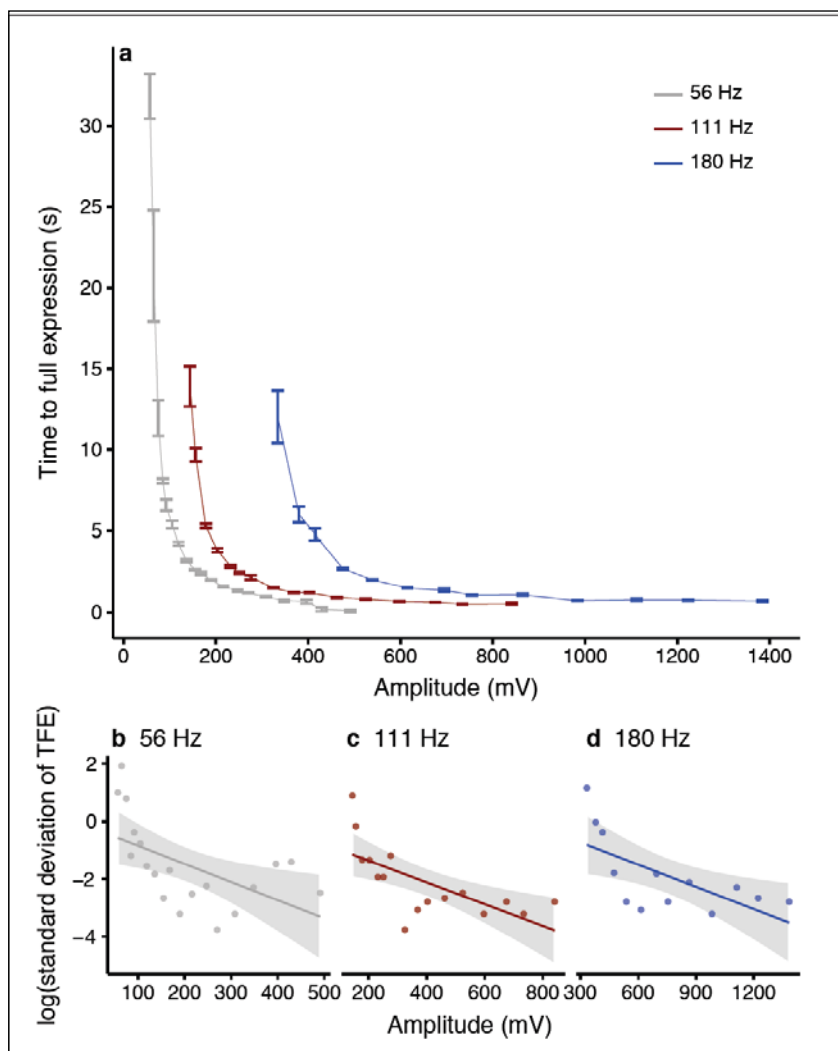


Figure 7. Plot from Sheldrake and Sheldrake (2017) showing the TFE as a function of frequency for three frequencies: 56; 111; and 180 Hz. The top plot shows how the TFE decreases with increasing amplitude and frequency, and the bottom plot shows the variation between trials. (Figure 5, Sheldrake and Sheldrake, 2017).

formation will never occur and/or that the same pattern will occur. The results presented here and in previous work (Sheldrake and Sheldrake, 2017) showed that other factors, internal and external, could affect the occurrence of pattern formation. For example, we see that pattern formation occurs at a specific amplitude, which we refer to as the **reference amplitude**. This **reference amplitude** was observed to increase with frequency, for every shape of cuvette investigated, e.g., see *Figure 5*. However, it should be noted that the pattern morphology, observed under the same conditions, for a given **reference amplitude** and **reference frequency**, exhibits variations. For example, at a frequency of 128.4 Hz and an amplitude of -19.4 dB, we see pattern formation occurs in one trial (see *Figure 6a*) and does not occur in another trial, apparently under the same conditions (see *Figure 6b*), but clearly an unidentified parameter change was responsible for this anomaly. We refer to this as an **unidentified anomaly** and to identify the cause of such variations further investigations are required where both internal and external factors are monitored in more detail.

We also see that for pattern formation to occur, a specific time needs to be realized. This time is referred to as the **Time to Full Expression (TFE)** and was originally defined in 2017 by Sheldrake and Sheldrake. Pattern formation can

be observed either by the naked eye, or more quantitatively determined from the grey pixel count (see Sheldrake and Sheldrake, 2017, for a detailed explanation of the grey pixel count methodology). Sheldrake and Sheldrake also note that the **TFE** varies with a dependence on the frequency and amplitude, e.g., see *Figure 7*, which shows the **TFE** decreases with both amplitude and frequency.

Pattern Morphology

Faraday wave phenomena exhibit various pattern morphologies, depending on the driving frequency and boundary conditions of the excited medium. This morphology will vary with time due to changes in both external and internal parameters. We can therefore view the pattern morphology as individual moments in time, which are referred to as **cymaglyphs**. The term **cymaglyph** was coined by CymaScope inventor John Stuart Reid and is defined as a cymatic representation of a moment of sound. For example, see *Figure 8*.

Cymaglyphs can show different degrees of expression of wave pattern formation that we identify and outline below:

Fully expressed cymaglyph – shows a wave pattern morphology with visible crests and troughs. The observed patterns can exhibit either a symmetric wave pattern for-

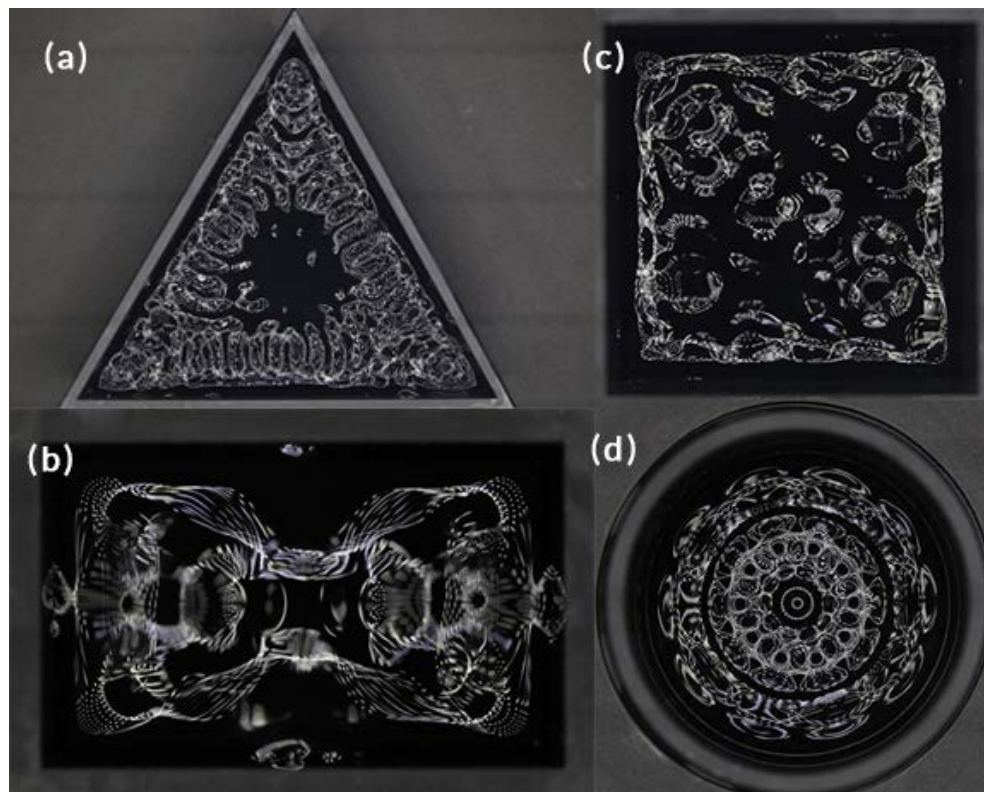


Figure 8. Cymaglyphs from: (a) a triangular cuvette at 103 Hz; (b) a rectangular cuvette at 40 Hz; (c) a square cuvette at 100 Hz; and (d) a circular cuvette at 124 Hz.

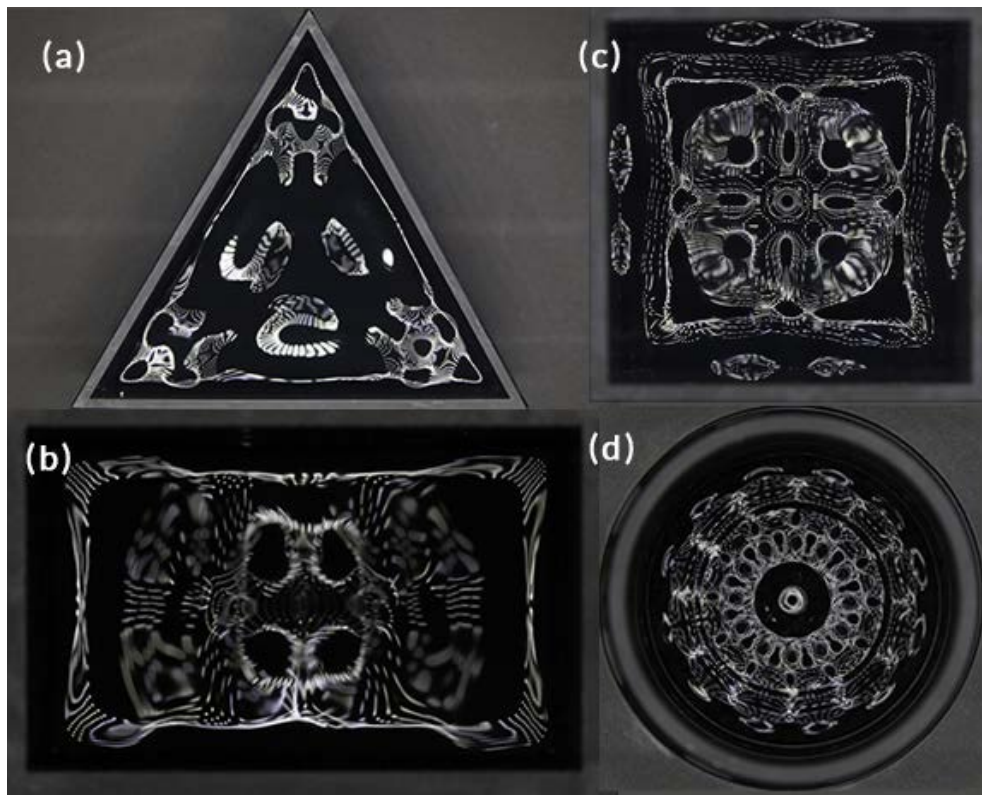


Figure 9. Coherent cymaglyphs for: (a) a triangular cuvette at a frequency of 12 Hz; (b) a rectangular cuvette at a frequency of 18 Hz; (c) a square cuvette at a frequency of 56 Hz; and (d) a circular cuvette at a frequency of 144 Hz.

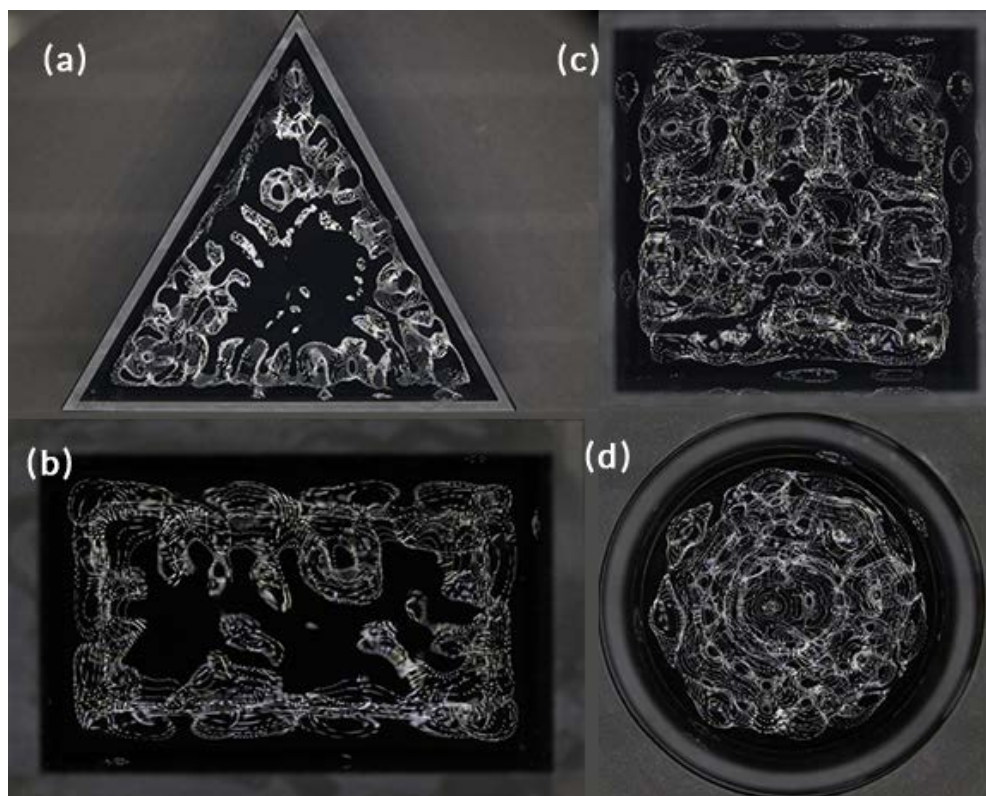


Figure 10. Incoherent cymaglyphs for: (a) a triangular cuvette at a frequency of 62 Hz; (b) a rectangular cuvette at a frequency of 116 Hz; (c) a square cuvette at a frequency of 84 Hz; and (d) a circular cuvette at a frequency of 99 Hz.

mation, referred to as a **coherent cymaglyph** (e.g., see *Figure 9*), or a non-symmetric, irregular wave pattern formation, referred to as an **incoherent cymaglyph** (e.g., see *Figure 10*). In some cases, the wave pattern morphology forms a complex and dynamic structure, which shows a winding and twisting pattern (e.g., see *Figure 11*).

Chaotically expressed cymaglyph – shows a chaotic wave pattern morphology and occurs when a critically high excitation amplitude is applied. Eventually, as the amplitude is further increased, this chaotic behavior will result in water droplets jumping out of the cuvette (e.g., see *Figure 12*).

Pre-cymaglyph – shows no visible wave movement to the naked eye, even when the water is optimally excited or overexcited (e.g., see *Figure 13*). However, in such cases the presence of wave formation within the system cannot be ruled out. Further research investigating the system, from different angles, rather than the surface, may reveal the system morphology in greater detail.

Underexpressed cymaglyph – shows either no wave pattern formation or an incomplete pattern morphology, *i.e.*, a lower degree of expression of the pattern than previously observed. For example, see *Figures 14* and *15*.

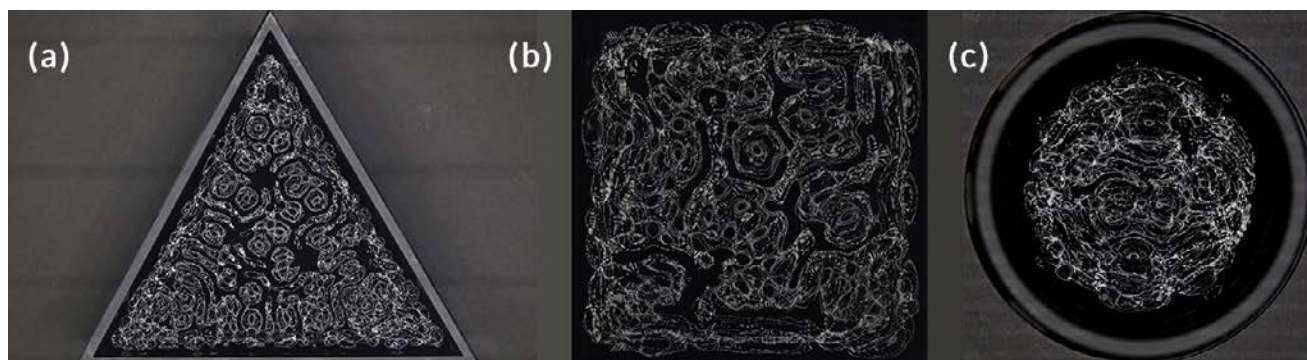


Figure 11. Incoherent cymaglyphs showing a winding and twisting pattern observed in: (a) a triangular cuvette at 201 Hz; (b) a square cuvette at 160 Hz; and (c) a circular cuvette at 179 Hz.

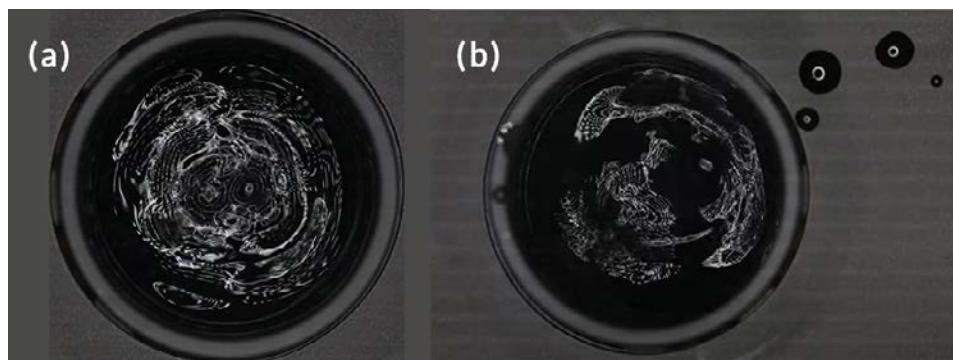


Figure 12. Chaotically expressed cymaglyph observed in a circular cuvette, showing: (a) a distorted pattern at 99 Hz, where a wobble can be seen [here](#); and (b) water droplets jumping out of the cuvette at 26.5 Hz.



Figure 13. Pre-cymaglyph from a circular cuvette at a frequency of 214 Hz.

Various aspects of the pattern morphology can also be described by means of the radial symmetry. For example, we can see radial symmetry of 180 degrees, defined as 2-fold or bilateral symmetry; 120 degrees, defined as 3-fold or trilateral symmetry; 90 degrees, defined as 4-fold or quadrilateral symmetry; etc. (e.g., see *Figure 16*). Sheldrake and Sheldrake (2017) refer to the radial symmetry as **n-fold symmetry**. We adopt this terminology throughout this paper and any subsequent papers on this topic of research. This radial symmetry pattern morphology is also observed in the triangular, square and rectangular cuvettes, e.g., see *Figure 17*.

Another aspect of the pattern morphology is a ring pattern, which is usually observed in the center of the cuvette (e.g., see *Figure 9c* and *9d*). For the circular cuvettes we also observe **concentric rings**. These **concentric rings** are typically observed in **pre-cymaglyphs** (e.g., see *Figure 13*) before sufficient amplitude has been reached to form a **cymaglyph** and are due to reflections of the CymaScope's light ring, which consists of 32 diodes. For example, see *Figure 18*, which shows: the reflection of the light ring before excitation; concentric rings after initial

excitation, lower than the critical amount; and the 4-fold pattern formation after sufficient excitation (critical) has been reached. However, in some cases we see a **cymaglyph** with **concentric rings**, which can also be referred to as 1-fold symmetry (e.g., see *Figure 19*). For the square and rectangular cuvettes, we also see patterns of parallel and perpendicular lines; e.g., see *Figure 20*. We refer to this as a **grid cymaglyph**.

The variety of observed pattern morphologies is dependent on the frequency, amplitude and boundary conditions. However, due to the complex and delicate nature of Faraday waves we cannot confidently attribute pattern morphologies to specific parameters. For example, for specific frequencies measured under the same conditions, including amplitude conditions, a variety of cymaglyphs are produced (*i.e.*, different symmetry fold, pattern morphology, etc.). For example, see *Figure 21*, which for a circular cuvette at a frequency of 40 Hz, shows a 14-fold symmetry pattern formation in one trial and a 4-fold symmetry pattern in another trial. We refer to this as an **unidentified anomaly** and, to identify the cause of such variations in the manifestation of cymaglyphs, further in-

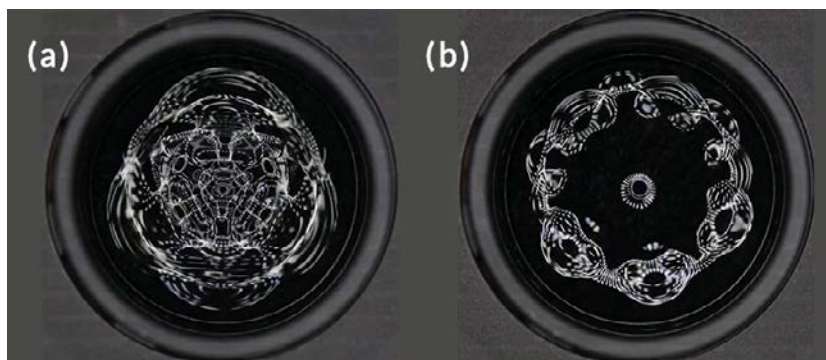


Figure 14. Cymaglyphs observed in a circular cuvette at a frequency of 80 Hz, showing: (a) a fully expressed pattern; and (b) an underexpressed pattern.

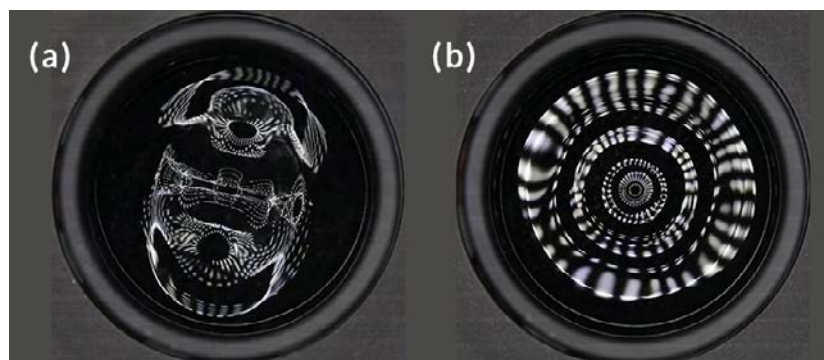


Figure 15. Cymaglyphs observed in a circular cuvette at a frequency of 43.0625 Hz, showing (a) a fully expressed pattern; and (b) an underexpressed pattern.

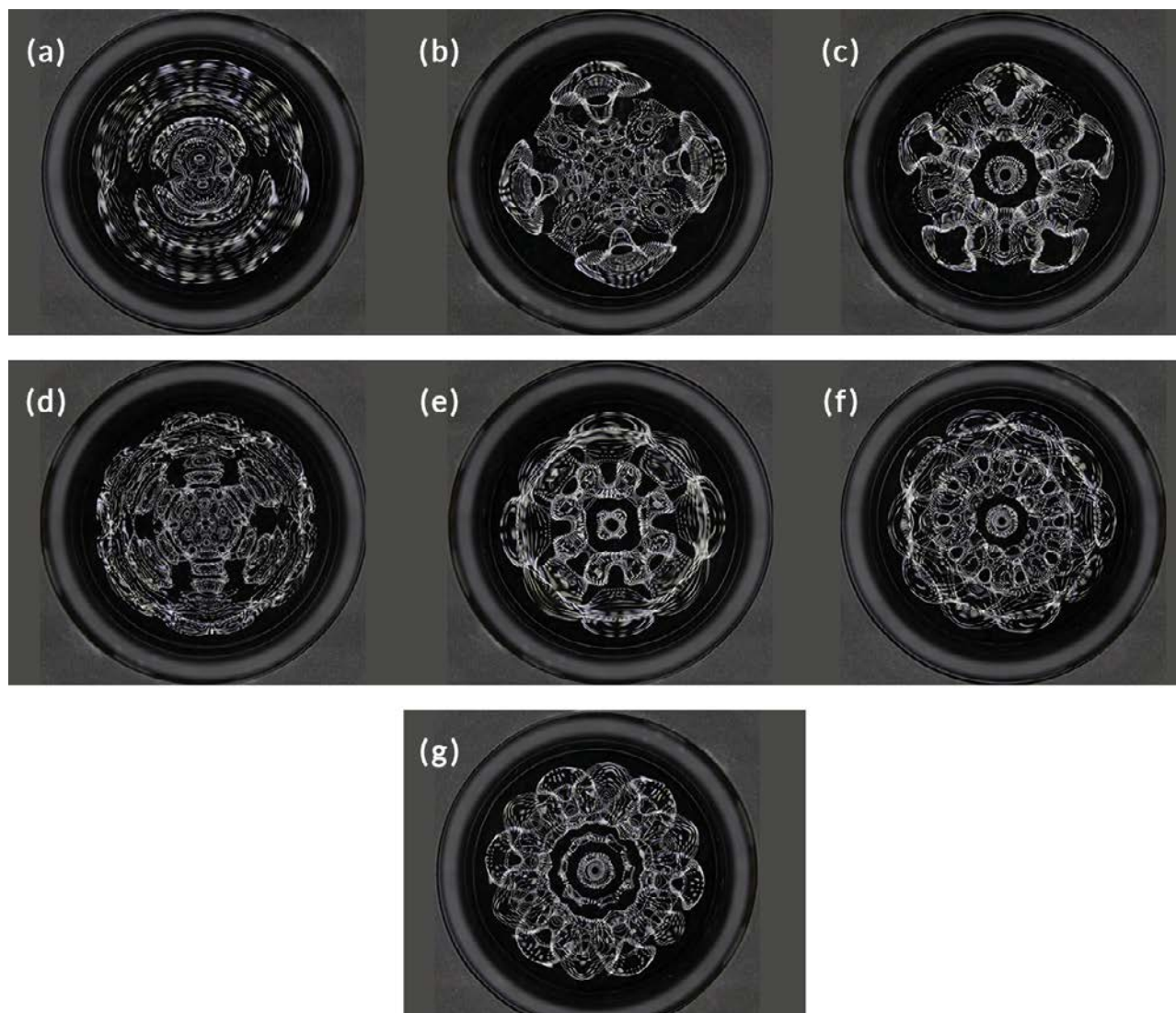


Figure 16. Cymaglyphs from a circular cuvette showing symmetry folds of: (a) 2-fold at a frequency of 129 Hz; (b) 4-fold at a frequency of 56 Hz; (c) 5-fold at a frequency of 66 Hz; (d) 6-fold at a frequency of 238 Hz; (e) 8-fold at a frequency of 82 Hz; (f) 10-fold at a frequency of 73 Hz; and (g) 12-fold at a frequency of 78 Hz.



Figure 17. Cymaglyphs showing different symmetry folds for: (a) a triangular cuvette at a frequency of 45 Hz showing 3-fold symmetry; (b) a rectangular cuvette at a frequency of 36 Hz showing 2-fold symmetry; and (c) a square cuvette at a frequency of 89 Hz showing 4-fold symmetry.

vestigations are required where both internal and external factors are monitored in more detail.

Pattern Dynamics

When investigating how the pattern morphology changes with time, we observed both stable and unstable pattern morphology. In the cases with stable pattern morphology, a coherent and steady wave formation is observed, resulting in a series of **stable cymaglyphs** (e.g., see *Figure 22*). However, unstable pattern morphology shows a dy-

namic and changing wave formation, resulting in a series of **unstable cymaglyphs** (e.g., see *Figures 23-28*). Note, these unstable cymaglyphs can be coherent and incoherent.

In some cases, this unstable pattern morphology could be due to the fact that no standing wave formation is compatible within the boundary conditions at that specific frequency. For example, see *Figure 23*, which shows an incoherent morphing pattern in a series of unstable cymaglyphs.



Figure 18. Ring patterns in a circular cuvette at a frequency of 64 Hz, showing: (a) one ring pattern of 32 dashes corresponding to the 32 diodes in the CymaScope light ring; (b) concentric rings due to an amplitude increase; and (c) the 4-fold pattern formation after sufficient (critical) amplitude has been applied.



Figure 19. Cymaglyph showing concentric rings in a circular cuvette at a frequency of 183.428 Hz.

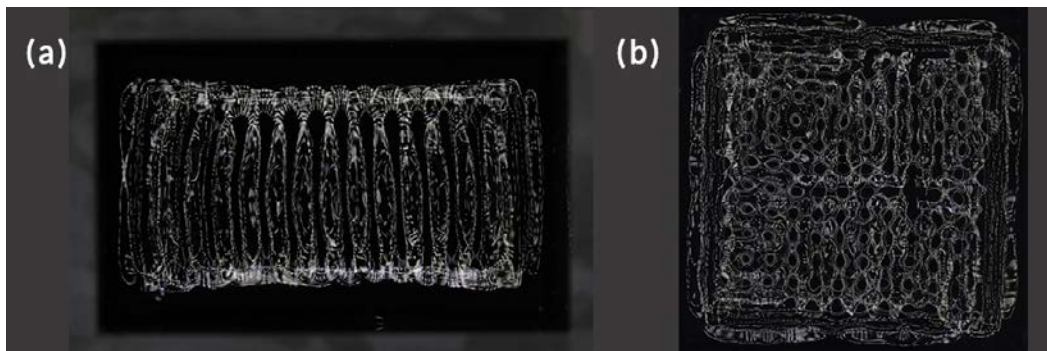


Figure 20. Grid cymaglyph from: (a) a rectangular cuvette at a frequency of 221 Hz; and (b) a square cuvette at a frequency of 180 Hz.

In other cases, it could be that the specific frequency is between two stable pattern formation frequencies and thus oscillations between alternate patterns occur. This is referred to by Sheldrake and Sheldrake as a transition between stability points and addressed by Thom as a “competition of resonance” (Sheldrake and Sheldrake, 2017; Thom, 1975). In the latter case, where the patterns appear to oscillate between two or more alternating symmetry folds, the resulting series of **unstable cymaglyphs** may appear as a combination of two or more symmetry folds, e.g., see *Figures 24 and 25*. Sheldrake and Sheldrake observed such a phenomenon and referred to it

as a **composite** of two alternating phases of oscillation, whereby crests become troughs and troughs become crests (Sheldrake and Sheldrake, 2017).

However, these oscillations could also be alternating between the same pattern but of different degrees of expression (e.g., see *Figure 26*) and/or morphing between different patterns (e.g., see *Figure 27*). Note these oscillations between alternating patterns are not necessarily regular in time and can instead exhibit an irregular dynamic.

We also see coherent dynamics such as rotation where clear circular motions are visible, either clockwise, coun-

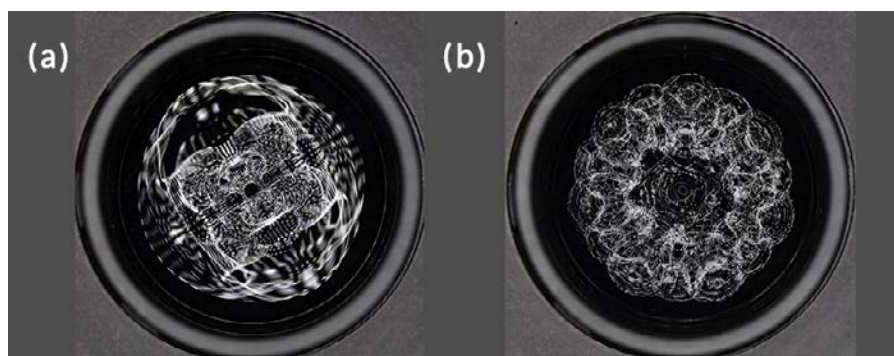


Figure 21. Cymaglyph from a circular cuvette at a frequency of 40 Hz showing: (a) a 4-fold pattern; and (b) a 14-fold pattern.

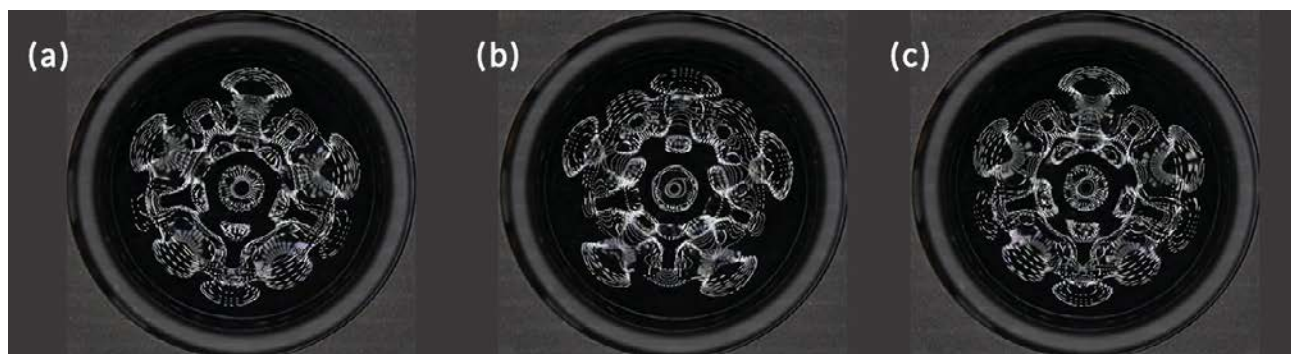


Figure 22. A series of stable cymaglyphs from a circular cuvette at a frequency of 69 Hz showing a 10-fold pattern at: (a) 2 seconds; (b) 5 seconds; and (c) 10 seconds.

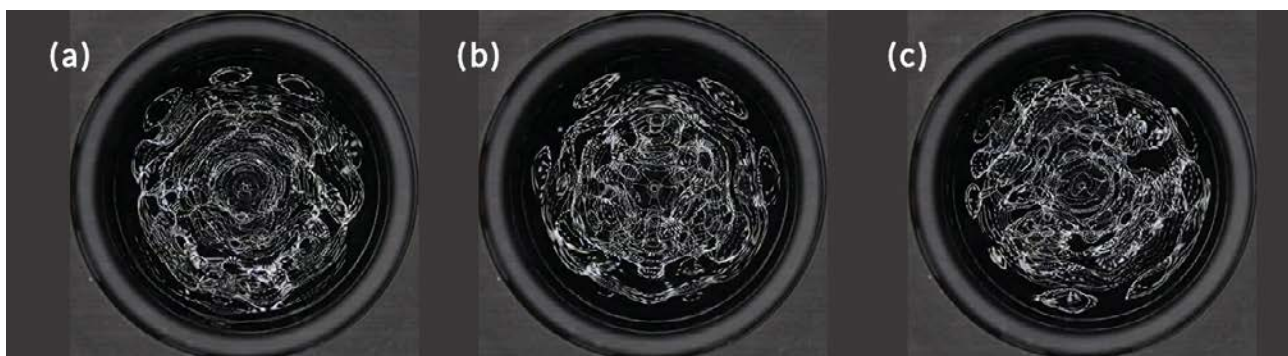


Figure 23. A series of unstable cymaglyphs from a circular cuvette at a frequency of 114.134 Hz that shows an incoherent morphing pattern at: (a) 4 seconds; (b) 8 seconds; and (c) 17 seconds.

terclockwise, or both, and for varying degrees of rotation, *i.e.*, 10 degrees, 45 degrees, 360+ degrees (see *Figures 28-30*). We conjecture that the observed rotational effects are produced by interference between the sinusoidal driving frequency and inherent resonances in the CymaScope instrument's fused quartz cuvette. The quartz resonances cause reflections of acoustic energy into the water that are out of phase with the driving frequency, causing a type of beat frequency effect that manifests as hunting rotational effects in the cymaglyph. Although the natural resonances in the characteristic frequency response curve of the CymaScope are identified by a calibrated ac-

celerometer system and tuned out by the graphic equaliser, this form of frequency response correction cannot take account of dynamic resonances inherent within the fused quartz of the cuvette. Interference between the opposing waveforms, *i.e.*, those emanating from the centre outwards and those reflected from the outer boundary and directed inwards, will also contribute to the observed rotational effects. Further investigation of these rotations and the system dynamics in general, could yield insights on similar systems seen in nature, such as whirlpools.

In other cases, we observed the pattern morphology to

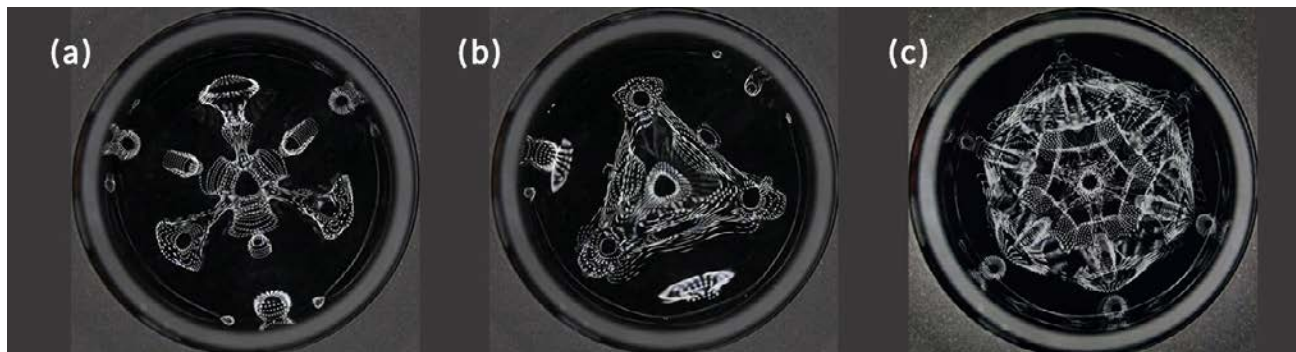


Figure 24. A series of unstable cymaglyphs from a circular cuvette at a frequency of [26.5 Hz](#) showing: (a) 3-fold symmetry; (b) the opposite 3-fold symmetry; and (c) the composite 6-fold symmetry.



Figure 25. A series of unstable cymaglyphs from a circular cuvette at a frequency of [35.34 Hz](#) showing: (a) 4-fold symmetry; (b) the opposite 4-fold symmetry; and (c) the composite 8-fold symmetry.

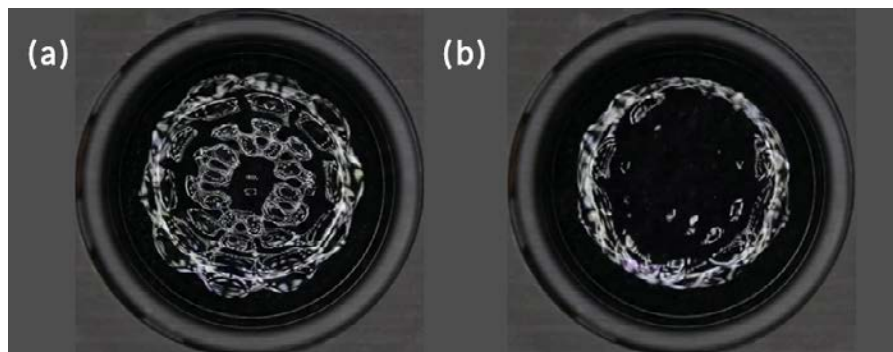


Figure 26. A series of unstable cymaglyphs from a circular cuvette at a frequency of [171.2 Hz](#) showing different degrees of expression with: (a) showing a fully expressed 10-fold symmetry at 7 seconds; and (b) showing an underexpressed pattern at 13 seconds.

change in such a way that it appeared as a toroidal dynamic, *i.e.*, a spherical inwards and outwards dynamic, which is visible on the water surface, either observed in parts or in the entire wave formation (e.g., see *Figure 31*). It would be interesting to investigate this further and verify if such a toroidal movement is indeed occurring. This would require a new methodology that allows for 3D viewing, as well as a suspension of particles that could be used to track the motion. Again, like rotational dynamics, improving our understanding of the observed toroidal

dynamics could yield insights on similar systems seen in nature.

So far, we have described the resulting Faraday wave phenomena when a liquid-filled cuvette is excited by a single frequency. However, it is known that distinct phenomena are observed when two or more frequencies are applied mechanically; for example, Topaz *et al.*, (2004), Francois *et al.* (2014), and Batson *et al.* (2015) report such distinct behaviors. Furthermore, natural sounds are made up of

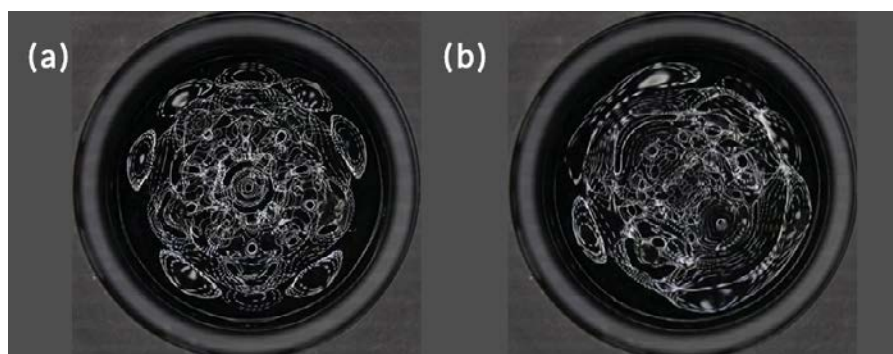


Figure 27. A series of unstable cymaglyphs from a circular cuvette at a frequency of [96 Hz](#) showing morphing between different patterns with: (a) showing a 10-fold symmetry at 2 seconds; and (b) showing a 2-fold symmetry at 10 seconds. Note, the symmetry fold of these cymaglyphs is more apparent when viewed in the video.



Figure 28. A series of cymaglyphs showing counterclockwise rotation in a circular cuvette at a frequency of [74.76 Hz](#). We can see at a time of: (a) 7 seconds, the reference point; (b) 13 seconds, a rotation of approximately 45 degrees; and (c) 18 seconds, a further rotation of 45 degrees.



Figure 29. A series of cymaglyphs showing clockwise rotation in a circular cuvette at a frequency of [26.5 Hz](#). We can see at a time of: (a) 7 seconds, the reference point; (b) 9 seconds, a rotation of approximately 30 degrees; and (c) 18 seconds, a further rotation of 30 degrees.

multiple frequencies, so studying cymaglyphs created by two or more frequencies is of great interest and a first step toward understanding more complex sounds akin to nature. As well, such investigations can reveal how interference leads to pulsating and/or rotational effects, which has numerous applications, from cell manipulation to water containment and filtration methods. To investigate this further, we simultaneously applied dyad frequencies of different ratios. We refer to the resulting cymaglyph as an **interference cymaglyph**. In each case

we observe a morphing of the respective patterns to various degrees where the wave pattern will settle into either: a summation pattern; a new pattern, which in some cases incorporates elements from patterns associated with the individual frequencies; or one of the individual frequency patterns (e.g., see *Figures 32-34*). However, it should be noted, the distinction between patterns is not always obvious and highly subjective. For example, *Figure 32c* and *33c* could both be exhibiting either a summation pattern or a new pattern. To investigate this further, more data is need-

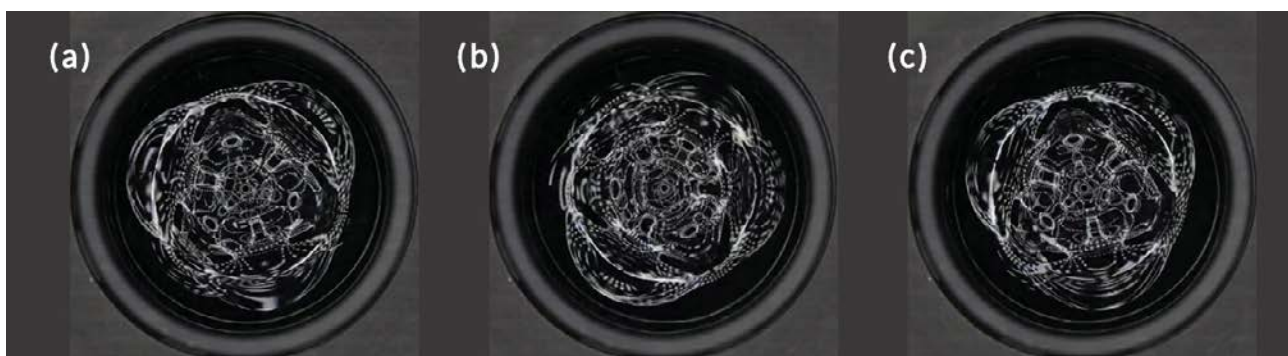


Figure 30. A series of cymaglyphs showing both clockwise and counterclockwise rotation in a circular cuvette at a frequency of [74.67 Hz](#). We can see at a time of: (a) 5 seconds, the reference point; (b) 12 seconds, a clockwise rotation of approximately 30 degrees; and (c) 23 seconds, a counterclockwise rotation of 30 degrees.

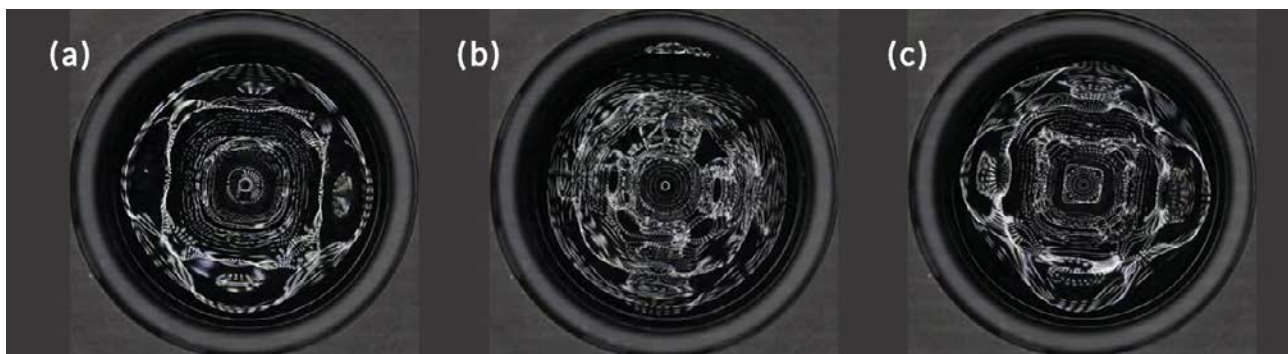


Figure 31. A series of cymaglyphs showing toroidal dynamics in a circular cuvette at a frequency of [64 Hz](#). We can see at a time of: (a) 3 seconds, the reference point; (b) 4 seconds, the inwards dynamic; and (c) 5 seconds, the outwards dynamic. Note, a toroidal dynamic is often easier to identify when playing the videos at slower speeds.

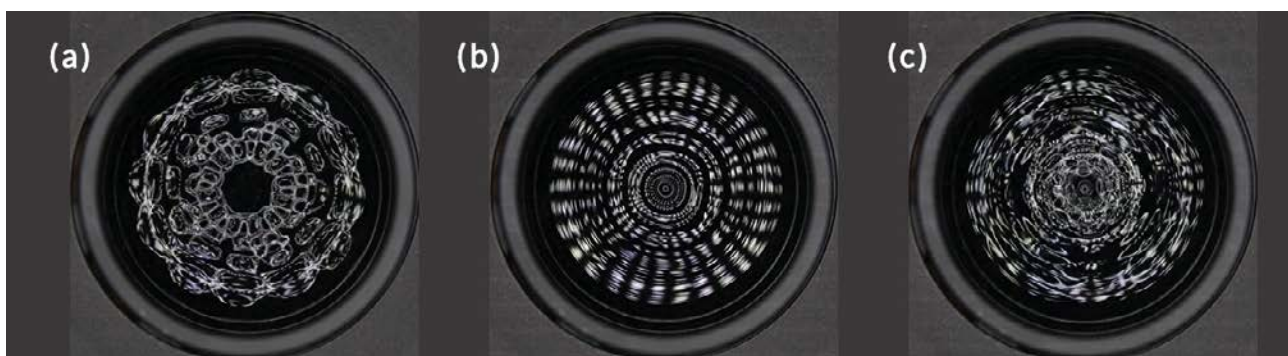


Figure 32. A cymaglyph observed in a circular cuvette at: (a) a frequency of [214 Hz](#); (b) the corresponding 6:7 (minor 3rd) ratio frequency of [183.428 Hz](#); and (c) both frequencies [214 and 183.428 Hz](#), resulting in an interference cymaglyph showing a new pattern.

ed as well as the utilisation of image analysis software.

Summary

In this paper we identified different phenomena in Faraday wave formation following sound excitation as observed with the CymaScope instrument. We suggest a unified terminology of classification to describe these phenomena, solidifying previously coined and newly defined vocabulary. Notably, an observed pattern can be defined with multiple terms describing every aspect of the pattern formation, morphology and dynamics. For example, *Figure 22* can be described as a fully expressed coherent cymaglyph of 10-fold symmetry at a reference frequency of 69 Hz with a stable dynamic showing both clockwise and counterclockwise rotation.

Faraday wave phenomena are intrinsically delicate and susceptible to variations, yet we also observe consistency in pattern formation determined by frequency and boundary conditions. However, variation in pattern formation and morphology are observed, which we refer to as an un-

identified anomaly. Further investigations with the aim of identifying the inverse problem are therefore needed.

With the help of a unified terminology and methodology, future studies can be improved and yield further insights on Faraday wave phenomena.

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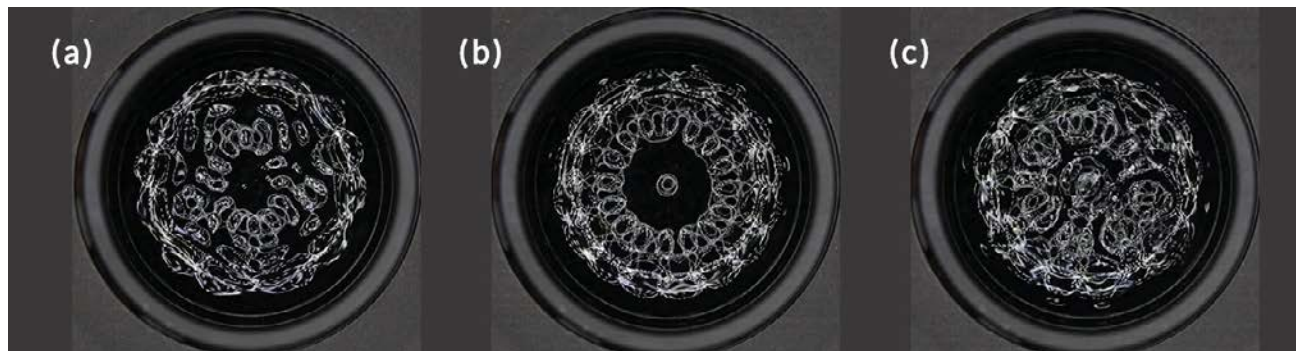


Figure 33. A cymaglyph observed in a circular cuvette at: (a) a frequency of [214 Hz](#); (b) the corresponding 4:5 (major 3rd) ratio frequency of [171.2 Hz](#); and (c) both frequencies [214 and 171.2 Hz](#), resulting in an interference cymaglyph showing a summation pattern.



Figure 34. A cymaglyph observed in a circular cuvette at: (a) a frequency of [26.5 Hz](#); (b) the corresponding 4:3 (perfect 4th) ratio frequency of [35.34 Hz](#); and (c) both frequencies [26.5 and 35.34 Hz](#), resulting in an interference cymaglyph showing the dominant characteristics of the 26.5 Hz frequency pattern.

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Discussion with Reviewers

Reviewer 1: In your manuscript, you describe a “toroidal wave,” but it is not clear to me from looking at the figures and videos that there is a toroidal dynamic or that there is any such thing as a toroidal “wave.” This throw-away term, toroidal wave, needs unpacking in much more detail if you want to describe the wave patterns in the CymaScope in terms of toroids.

Please also explain how this might relate to the diagrams in *Figures 8a and b* and discuss whether these patterns of flow are in fact happening in the CymaScope, giving more evidence than an uninterpreted video.

Authors: The images, and their corresponding descriptions, have now been amended to clarify the observations presented. As well, the suggestion to observe the videos at a slow speed has been included. However, as you say, without further investigations we cannot be sure that what we are observing is a toroidal dynamic. We have therefore amended this to read as, ‘... appeared as a toroidal dynamic ...’ and included a sentence that suggests a potential experimental verification. Furthermore, this definition has been moved to the new section, Pattern Dynamics.

Reviewer 1: *When describing pattern morphology and a ring pattern, you say that the concentric rings may not necessarily orbit in the same direction or at the same speed, but do not give examples to support this assertion. You also say they may be a result of concentric ripples in the cuvette. Surely, they must be a result of concentric ripples or standing waves.*

Authors: This definition has now been amended for clarification and moved to the new section, Pattern Morphology. In this section we describe ring patterns and make the distinction between ring patterns observed in the center of the cuvette; “concentric rings” observed due to reflections of the CymaScope light ring; and concentric rings observed as a 1-fold symmetry pattern.

Reviewer 1: *You describe the effects of playing two frequencies at the same time, compared with the patterns produced by the single frequencies, or what I refer to as the “interference cymaglyph.” This would be a good subject for systematic investigation rather than giving random examples. For example, you refer to patterns from video 18 (see Appendix). The first shows a 3/6-fold pattern and the second shows a 4-fold pattern. When combined they give a 3/6-fold pattern. Here, one of the two patterns seems to predominate over the other. By contrast, video 19 combines two patterns, the first of which shows a 2/4-fold pattern and the second a 1/2-fold pattern that, when combined, produce a ring pattern.*

Here is an opportunity for you to provide a systematic investigation of the interaction of different frequencies, rather than just a few random examples. It would be good to insert a systematic study of these frequency combinations illustrating in how many cases one pattern predominates over the other, in how many cases both are combined in unstable mixtures,

and in which cases the two patterns produce something that is different from both of these, like the rings in video 19.

Authors: This definition has now been amended for clarity and moved to the new section, Pattern Dynamics. It is noted, as well, that these are just preliminary observations and that an in-depth study on this topic should be done in the future. However, we decided to keep the name interference cymaglyph for both harmonic and in-harmonic frequencies to distinguish between cymaglyphs that are from single frequencies and those that are from multiple frequencies.

Reviewer 1: *In your paper, “Amplitude anomaly” hardly required an entry in a taxonomy. They would simply observe that sometimes it requires a higher amplitude to elicit a pattern than others. It is also not clear why decibel readings have been given here as negatives, e.g. – 23.3dB and -17.8dB.*

In your paper, “cymaglyph anomaly” hardly merits a separate taxonomic entry. You could simply mention that sometimes under those same conditions different patterns formed. However, the conditions might not be the same because the atmospheric pressure varies from day to day and there are other variables that affect the expression of the pattern. In Sheldrake and Sheldrake (2017), Figure 11 shows 3 replicates at every frequency between 50 and 199 Hz, observed on three different days. On some days the patterns appeared at slightly different frequencies for unknown reasons. But one uncontrolled variable was atmospheric pressure, which could have had some effect and accounted for these “cymaglyph anomalies.” However, the discussion that follows sheds no light on the reason for these anomalies and tells us nothing more than can already be observed from Sheldrake and Sheldrake (2017), Figure 11. This kind of variation is one of the main features discussed that simply makes the point that several different factors could affect these discrepancies, without illuminating what is going on any further.

Authors: The term amplitude anomaly describes the observed variation in pattern formation for a specific amplitude, despite being under the same conditions. For example, for a given amplitude, pattern formation occurs in one trial and not in another. This has now been moved to the new section, Pattern Formation, and is referred to as an unidentified anomaly. Regarding the decibel readings being negative, this is due to the signal level in the audio system being lower than the 0 dB full scale. A note to clarify this has now been included in the Methodology section. The term cymaglyph anomaly describes the ob-

served variation in cymaglyphs (i.e., different symmetry fold, pattern morphology, etc.) for specific frequencies measured under the same conditions, including amplitude. For example, for a given frequency a multitude of pattern morphologies can be observed, even for the same amplitude. This has now been moved to the new section, Pattern Morphology, and is referred to as an unidentified anomaly.

Reviewer 1: *You do not refer in this paper to a key paper on Faraday waves that gives a far more systematic understanding of the patterns formed and the radial and circumferential modes, together with a mathematical analysis in terms of Bessel functions, namely Shao et al., (2021). Surface pattern wave formation in a cylindrical container. Journal of Fluid Mechanics, Vol. 915, A19. Reading this paper, you will be able to make more sense of your observations and produce a description of them that is less confused and confusing.*

Authors: After reading the suggested paper, and others, 12 new references have been added: Abraham, 1976; Bechlofer, 1995; 1996; Benjamin and Ursell, 1954; Douady, 1988; Fauve, 1998; Gallaire and Brun, 2017; Kumar and Tuckerman, 1994; Perlin and Schultz, 2000; Simonelli and Gollub, 1989; Val Baker, 2024, and Montagnier, 2009. We've also referred to multiple studies and applications in our paper and referenced them accordingly.

Reviewer 2: *The rotation "Rotation" is interesting. Is there any physical explanation behind or beyond simple chance?*

Authors: The rotation is interesting and something that we hope to investigate further. We don't think the rotational effects are simply chance. Instead, it is likely the result of the resonant characteristics of the mechanical system as well as interference effects between the driving wave and the reflected wave. These rotational effects, along with a note on the possible causes has now been moved to the new section, Pattern Dynamics.

Reviewer 2: *The key question for me is whether these have any relevance to pattern formation in biology or are just interesting patterns. The motivation of this taxonomy paper is to try and unify the terms that are used, which is well worthwhile as it can be confusing if different papers use the different terminologies to refer to the same thing, and the taxonomy discussion appears to be a welcome contribution to the field. I think that the paper might be improved if the Taxonomy section was more clearly identified as the results section as the results of your experiments are clearly described in this section. The taxonomic terms only refer to*

where such effects are seen, but most of them have already been reported by other authors, so the results section should also note, with references, specific examples where the effect being described has been seen by others. It may then be possible to more clearly tie together the discussion and the results, perhaps by using bold font whenever a specific taxonomic term was used so that it is easier to see the terms being used and easier to go back to the results section and identify the more detailed results that are being discussed.

Authors: The Taxonomy section has now been updated to the Results and Discussion section. The terminology is now clearly shown in bold and in cases where the definition has previously been used, we refer to the relevant reference. As well we have now noted the connection between biology and the patterns observed.

Reviewer 3: *What is the rationale for experimenting with triangular, square, and rectangular cuvettes? For instance, is it to reveal forms not visible or possible in circular configurations, to study them as biological analogues, or to go beyond what math or simulation can show us? Do we gain any understanding, or can we go on simply trying things and describing them without providing insights or understanding? I would appreciate a systematic study of a triangular boundary as a function of frequency (like what Sheldrake and Sheldrake, 2017, did for circular cuvettes) or a systematic study of rectangular shapes as the sides are progressively changed from a square into a straighter rectangle.*

Authors: The rationale for experimenting with different shaped cuvettes is to investigate the effects of boundary conditions on resonant wave phenomena. The work presented in this paper is qualitative and shows the resulting resonant phenomena for a broad range of frequencies for 4 different shaped cuvettes. We hope that these observations will be the basis to build upon when future work allows us to investigate further, gaining understanding of their behavior and ultimately describing them mathematically.

Reviewer 3: *What is the rationale for using two frequencies? Again, a systematic study of frequencies, rather than "being all over the place," would be valuable.*

Authors: The rationale for using two frequencies is to observe the resulting effects on the resonant wave phenomena. How do the frequencies interact with each other? What other effects does it lead to? Again, this paper is qualitative and looks at a broad range of parameters that can affect the observed resonant phenomena. We identi-

fied 3 different effects observed when using two frequencies instead of one. We hope that this can be investigated further in future and more insights can be gained. Understanding resonant wave phenomena, especially with water, has huge implications ranging from water containment, manipulation, and understanding how biological forms take hold.

Reviewer 4: *What I found most interesting in this paper was the different Taxonomies and especially "Over Excited Water" and "Toroidal Rotation." From my point of view the method is rather flat, i.e., 2-dimensional and the Taxonomy of Over Excited Water gives a thought that there is something happening in 3-dimensions as well. The Taxonomy of Toroidal Rotation gives the idea of using sound as a means for propulsion. If we can get the correct combination of frequencies, we can get the water or maybe air to shape a rotating torus to have a new type of propulsion for airplanes.*

Authors: The cymaglyphs show the surface morphology, so indeed, it would be interesting to observe the pattern morphology and dynamics from all angles and within the container so that the full 3D aspect of these phenomena can be observed. To achieve this, a new methodology

that allows for 3D viewing would be required. As well, the suspension of particles within the liquid could be utilized so that the motion could be tracked. This is a great idea for a future study and has now been mentioned in the new section, Pattern Dynamics. As you mention, a future study that can help us better understand toroidal dynamics could not only yield insights on similar systems seen in nature, but could also help us design systems such as propulsion systems.

Reviewer 5: *A key question for me is whether these have any relevance to pattern formation in biology or are just interesting patterns; a question that has been raised at the water conference.*

Authors: Yes, the pattern morphologies we observe with the CymaScope are relevant to biology and one of the driving factors in studying them. This has been the case since Faraday waves have been studied and has yielded myriad applications across all fields of science, including biology. We have now included this in the introduction, where an extensive list of potential applications is given. Throughout the paper, when relevant, the similarity to biological or physical systems and dynamics is mentioned.

APPENDIX 1

Resonant wave phenomena in a 50 mm triangular cuvette for frequencies 8 – 256 Hz.



8 Hz



9 Hz



10 Hz



11 Hz



12 Hz



13 Hz



14 Hz



15 Hz



16 Hz



17 Hz



18 Hz



19 Hz



20 Hz



21 Hz



22 Hz



23 Hz



24 Hz



25 Hz



26 Hz



27 Hz



28 Hz



29 Hz



30 Hz



31 Hz



32 Hz



33 Hz



34 Hz



35 Hz



36 Hz



37 Hz



38 Hz



39 Hz



40 Hz



41 Hz



42 Hz



43 Hz



44 Hz



45 Hz



46 Hz



47 Hz



48 Hz



49 Hz



50 Hz



51 Hz



52 Hz



53 Hz



54 Hz



55 Hz



56 Hz



57 Hz



58 Hz



59 Hz



60 Hz



61 Hz



62 Hz



63 Hz



64 Hz



65 Hz



66 Hz



67 Hz



68 Hz



69 Hz



70 Hz



71 Hz



72 Hz



73 Hz



74 Hz



75 Hz



76 Hz



77 Hz



78 Hz



79 Hz



80 Hz



81 Hz



82 Hz



83 Hz



84 Hz



85 Hz



86 Hz



87 Hz



88 Hz



89 Hz



90 Hz



91 Hz



92 Hz



93 Hz



94 Hz



95 Hz



96 Hz



97 Hz



98 Hz



99 Hz



100 Hz



101 Hz



102 Hz



103 Hz



104 Hz



105 Hz



106 Hz



107 Hz



108 Hz



109 Hz



110 Hz



111 Hz



112 Hz



113 Hz



114 Hz



115 Hz



116 Hz



117 Hz



118 Hz



119 Hz



120 Hz



121 Hz



122 Hz



123 Hz



124 Hz



125 Hz



126 Hz



127 Hz



128 Hz



129 Hz



130 Hz



131 Hz



132 Hz



133 Hz



134 Hz



135 Hz



136 Hz



137 Hz



138 Hz



139 Hz



140 Hz



141 Hz



142 Hz



143 Hz



144 Hz



145 Hz



146 Hz



147 Hz



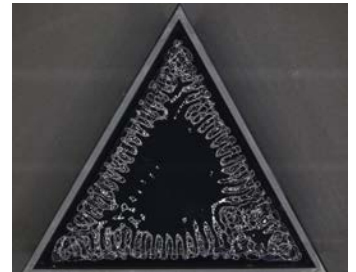
148 Hz



149 Hz



150 Hz



151 Hz



152 Hz



153 Hz



154 Hz



155 Hz



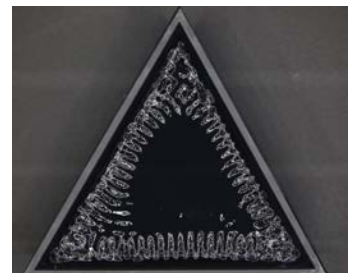
156 Hz



157 Hz



158 Hz



159 Hz



160 Hz



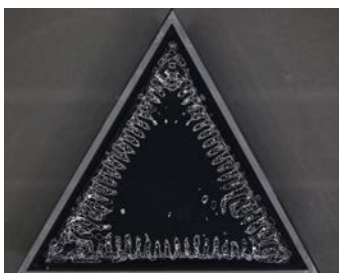
161 Hz



162 Hz



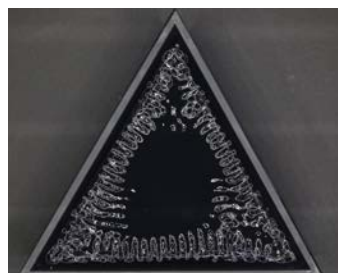
163 Hz



164 Hz



165 Hz



166 Hz



167 Hz



168 Hz



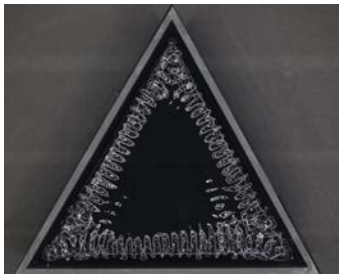
169 Hz



170 Hz



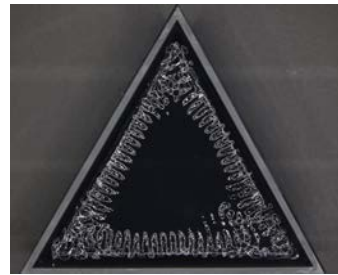
171 Hz



172 Hz



173 Hz



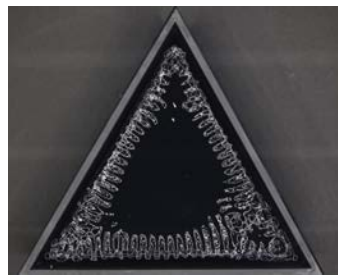
174 Hz



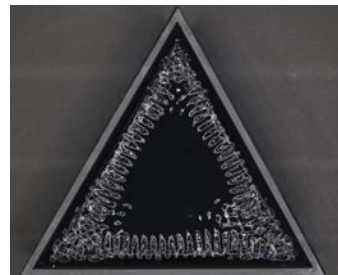
175 Hz



176 Hz



177 Hz



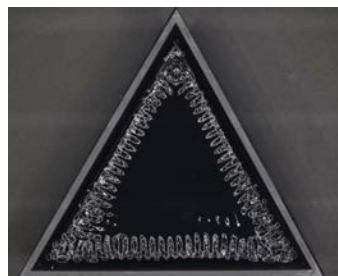
178 Hz



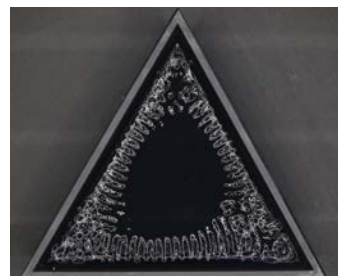
179 Hz



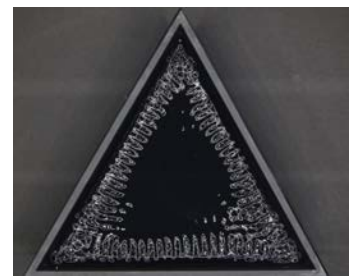
180 Hz



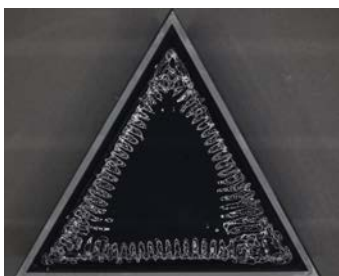
181 Hz



182 Hz



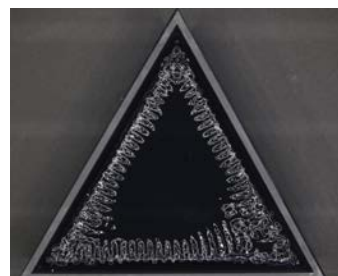
183 Hz



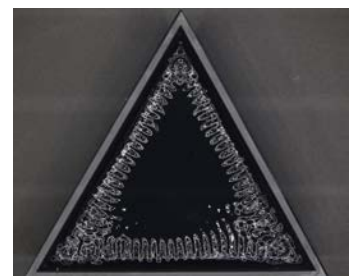
184 Hz



185 Hz



186 Hz



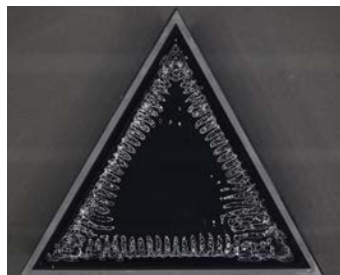
187 Hz



188 Hz



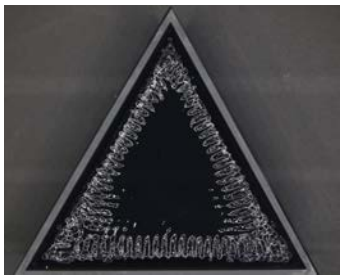
189 Hz



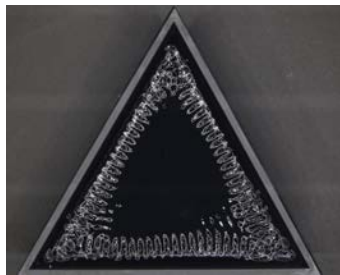
190 Hz



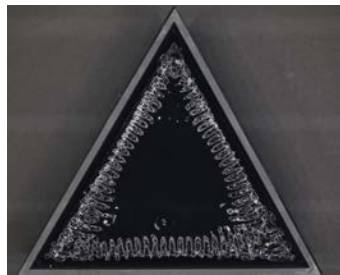
191 Hz



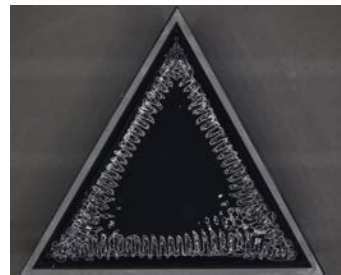
192 Hz



193 Hz



194 Hz



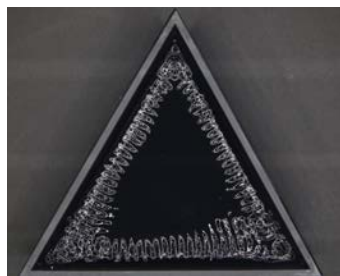
195 Hz



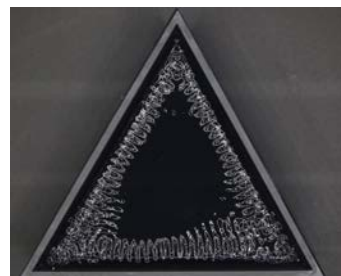
196 Hz



197 Hz



198 Hz



199 Hz



200 Hz



201 Hz



202 Hz



203 Hz



204 Hz



205 Hz



206 Hz



207 Hz



208 Hz



209 Hz



210 Hz



211 Hz



212 Hz



213 Hz



214 Hz



215 Hz



216 Hz



217 Hz



218 Hz



219 Hz



220 Hz



221 Hz



222 Hz



223 Hz



224 Hz



225 Hz



226 Hz



227 Hz



228 Hz



229 Hz



230 Hz



231 Hz



232 Hz



233 Hz



234 Hz



235 Hz



236 Hz



237 Hz



238 Hz



239 Hz



240 Hz



241 Hz



242 Hz



243 Hz



244 Hz



245 Hz



246 Hz



247 Hz



248 Hz



249 Hz



250 Hz



251 Hz



252 Hz



253 Hz



254 Hz



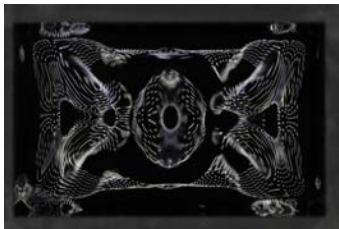
255 Hz



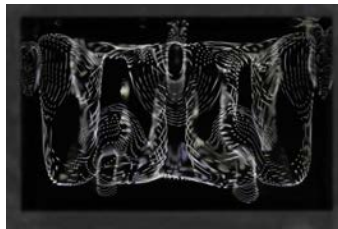
256 Hz

Resonant wave phenomena in a 24.25 x 15 mm rectangular cuvette for frequencies 16 – 256 Hz.

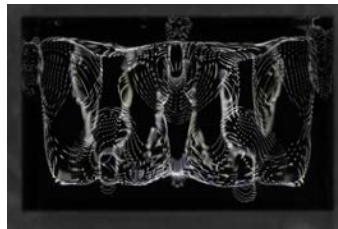




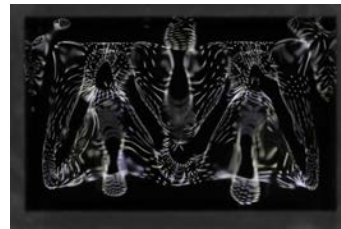
40 Hz



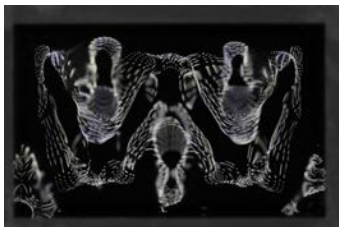
41 Hz



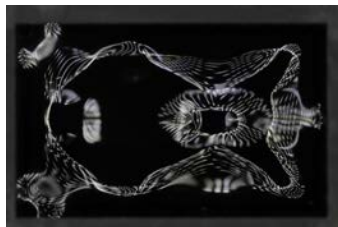
42 Hz



43 Hz



44 Hz



45 Hz



46 Hz



47 Hz



48 Hz



49 Hz



50 Hz



51 Hz



52 Hz



53 Hz



54 Hz



55 Hz



56 Hz



57 Hz



58 Hz



59 Hz



60 Hz



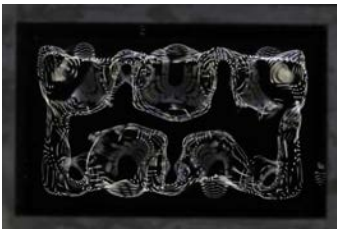
61 Hz



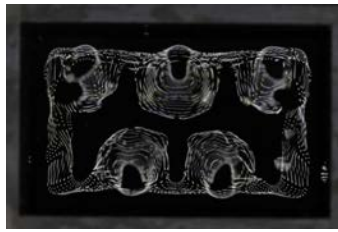
62 Hz



63 Hz



64 Hz



65 Hz



66 Hz



67 Hz



68 Hz



69 Hz



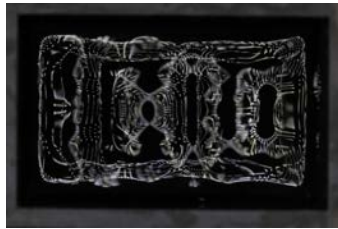
70 Hz



71 Hz



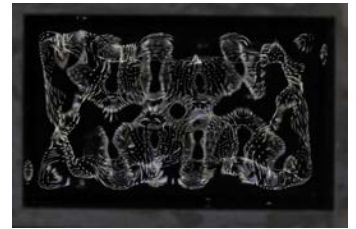
72 Hz



73 Hz



74 Hz



75 Hz



76 Hz



77 Hz



78 Hz



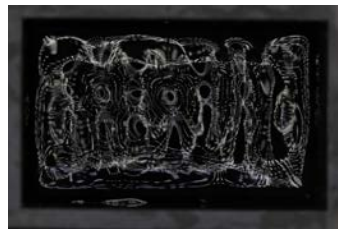
79 Hz



80 Hz



81 Hz



82 Hz



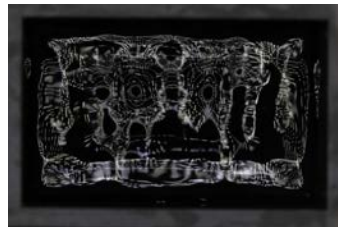
83 Hz



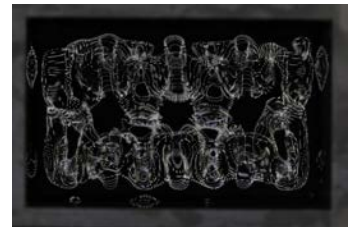
84 Hz



85 Hz



86 Hz



87 Hz



88 Hz



89 Hz



90 Hz



91 Hz



92 Hz



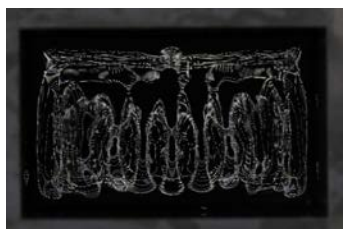
93 Hz



94 Hz



95 Hz



96 Hz



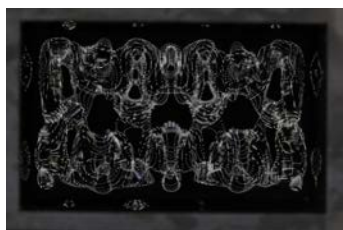
97 Hz



98 Hz



99 Hz



100 Hz



101 Hz



102 Hz



103 Hz



104 Hz



105 Hz



106 Hz



107 Hz



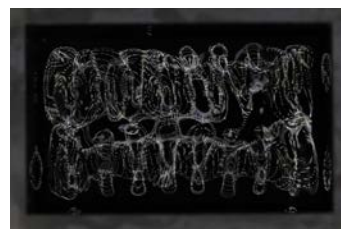
108 Hz



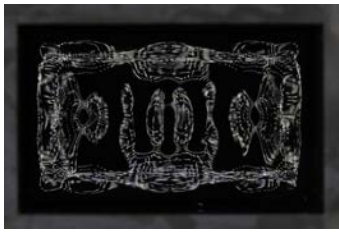
109 Hz



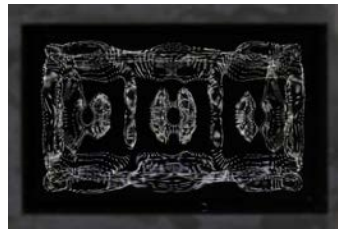
110 Hz



111 Hz



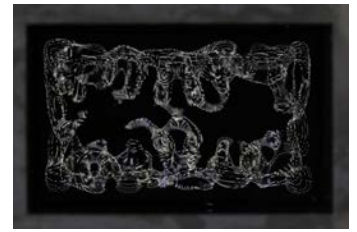
112 Hz



113 Hz



114 Hz



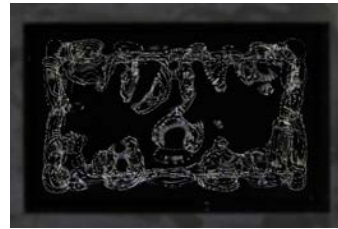
115 Hz



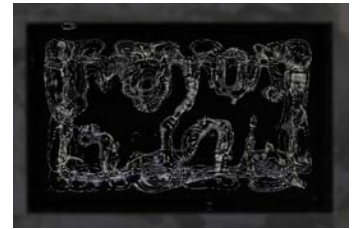
116 Hz



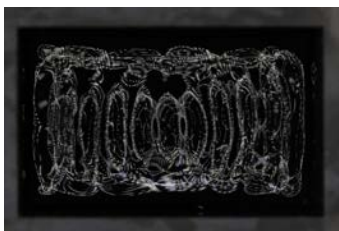
117 Hz



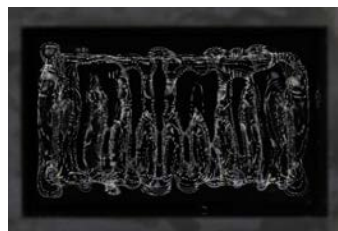
118 Hz



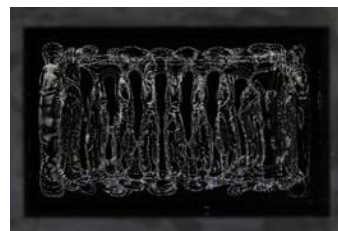
119 Hz



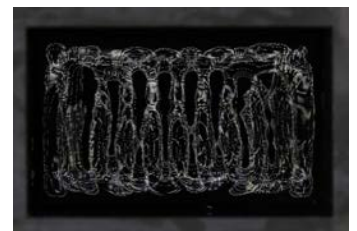
120 Hz



121 Hz



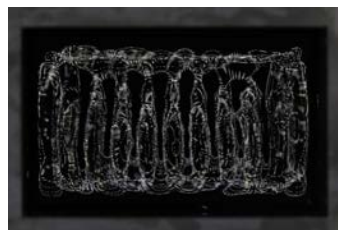
122 Hz



123 Hz



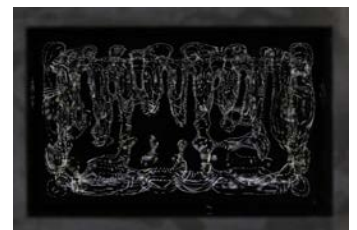
124 Hz



125 Hz



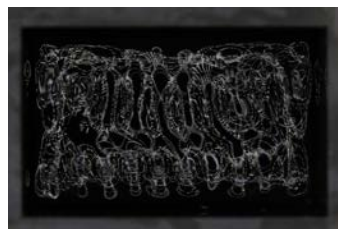
126 Hz



127 Hz



128 Hz



129 Hz



130 Hz



131 Hz



132 Hz



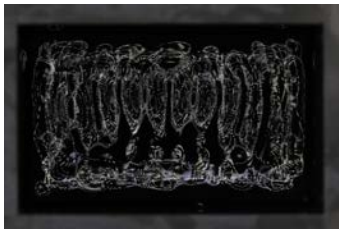
133 Hz



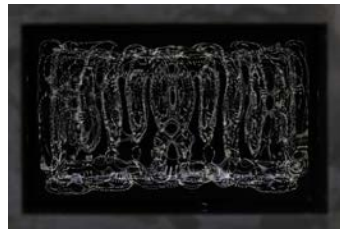
134 Hz



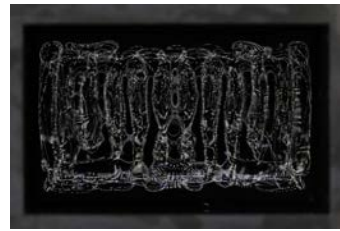
135 Hz



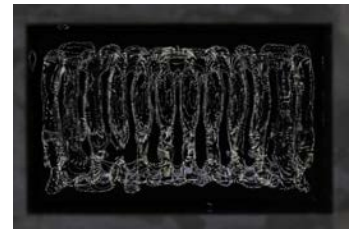
136 Hz



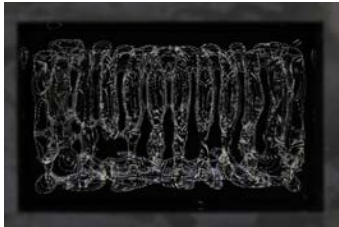
137 Hz



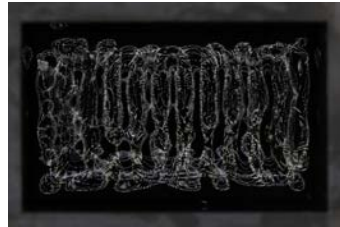
138 Hz



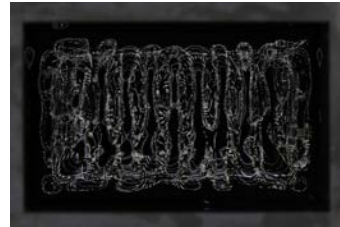
139 Hz



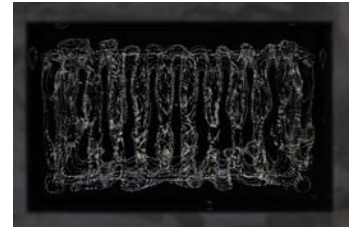
140 Hz



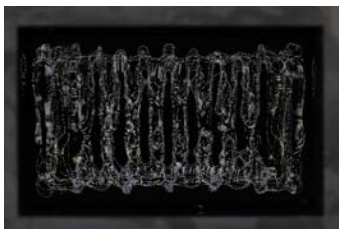
141 Hz



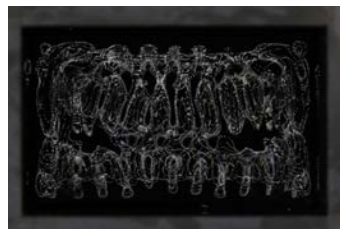
142 Hz



143 Hz



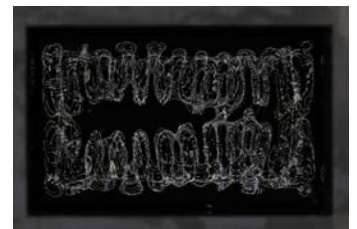
144 Hz



145 Hz



146 Hz



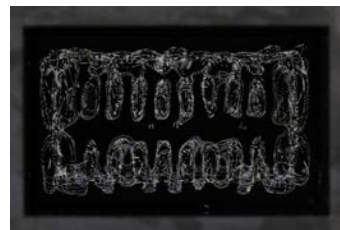
147 Hz



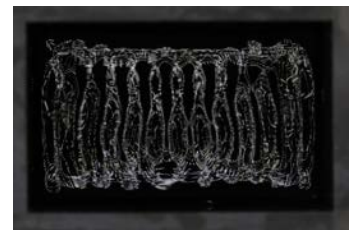
148 Hz



149 Hz



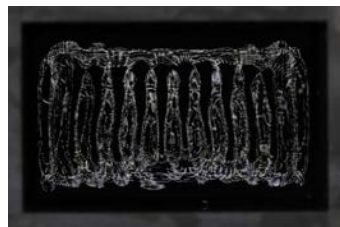
150 Hz



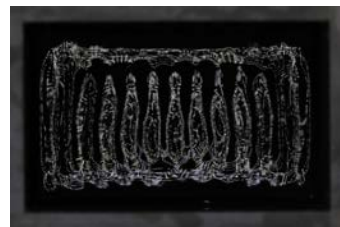
151 Hz



152 Hz



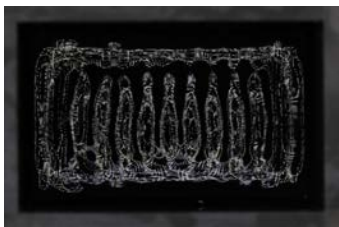
153 Hz



154 Hz



155 Hz



156 Hz



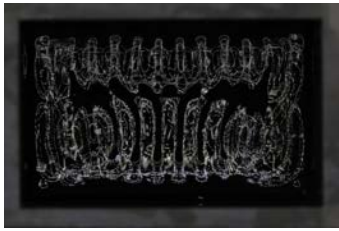
157 Hz



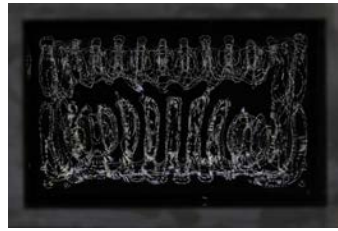
158 Hz



159 Hz



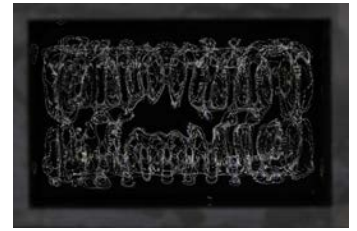
160 Hz



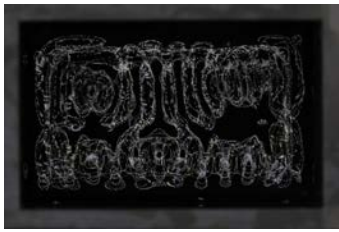
161 Hz



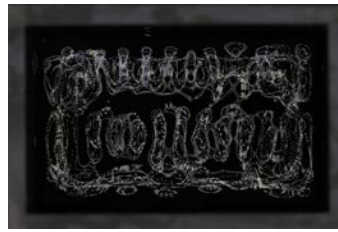
162 Hz



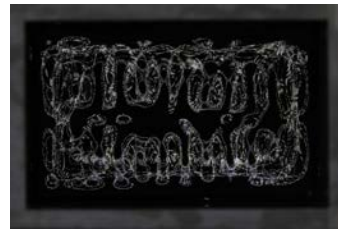
163 Hz



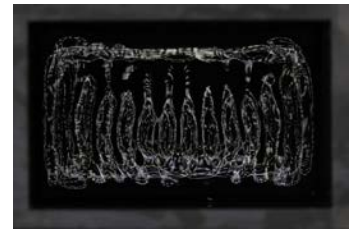
164 Hz



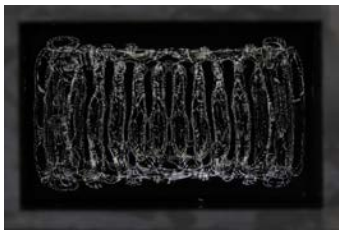
165 Hz



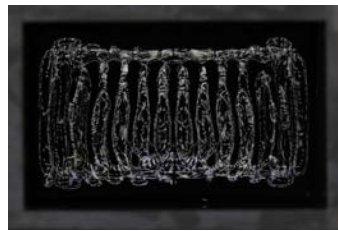
166 Hz



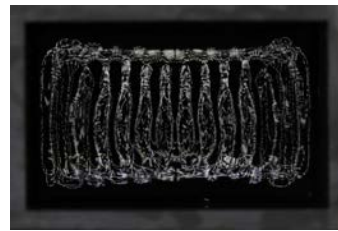
167 Hz



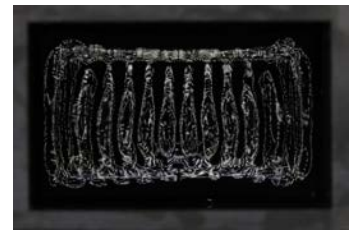
168 Hz



169 Hz



170 Hz



171 Hz



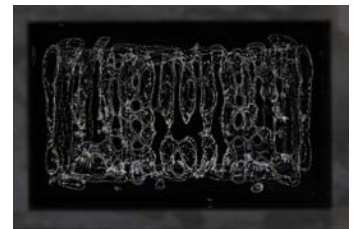
172 Hz



173 Hz



174 Hz



175 Hz



176 Hz



177 Hz



178 Hz



179 Hz



180 Hz



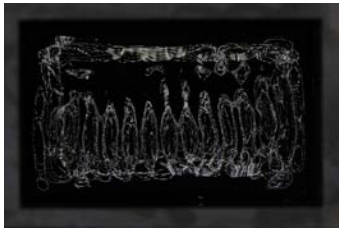
181 Hz



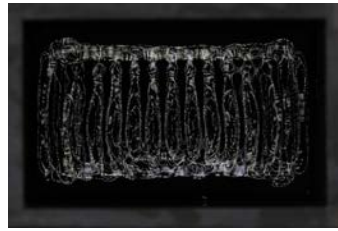
182 Hz



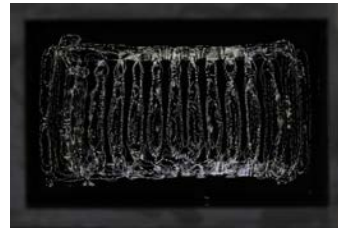
183 Hz



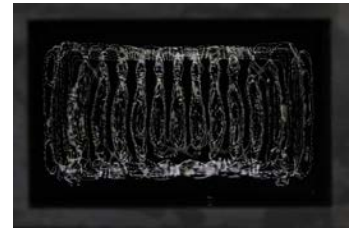
184 Hz



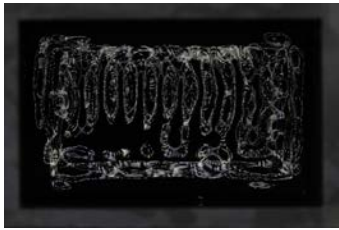
185 Hz



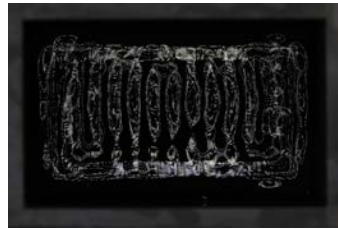
186 Hz



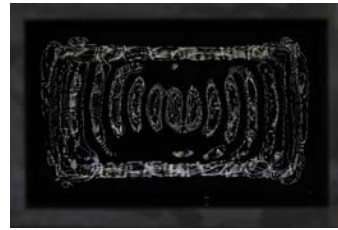
187 Hz



188 Hz



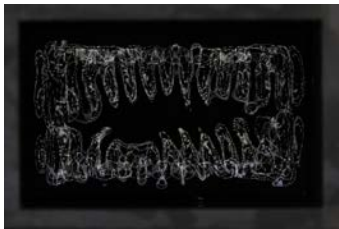
189 Hz



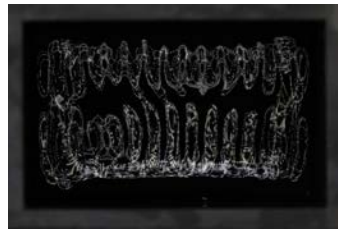
190 Hz



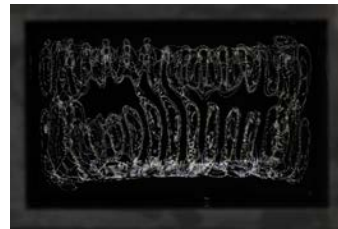
191 Hz



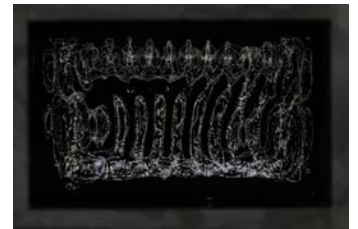
192 Hz



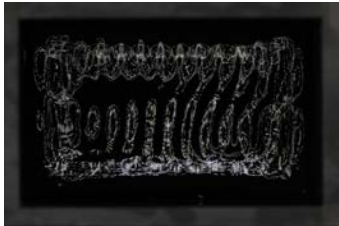
193 Hz



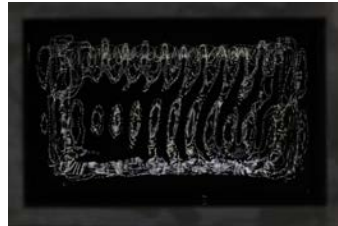
194 Hz



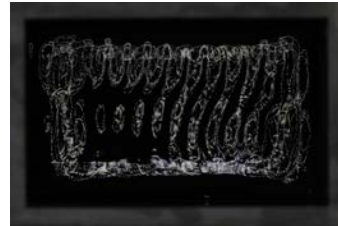
195 Hz



196 Hz



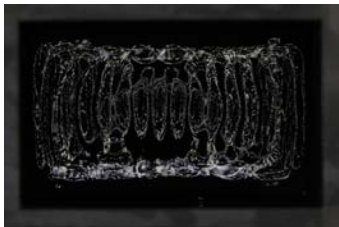
197 Hz



198 Hz



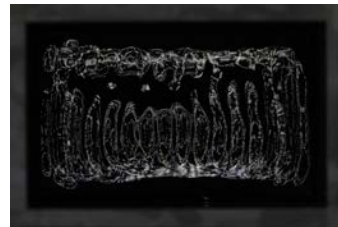
199 Hz



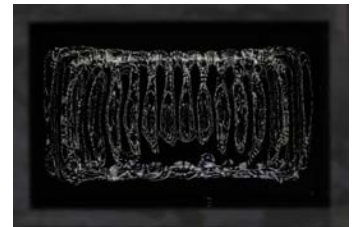
200 Hz



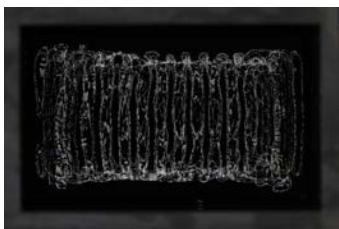
201 Hz



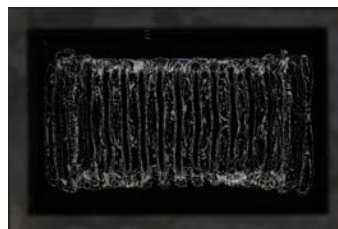
202 Hz



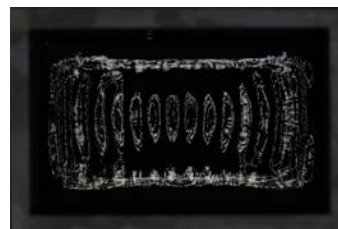
203 Hz



204 Hz



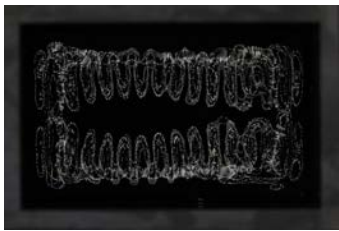
205 Hz



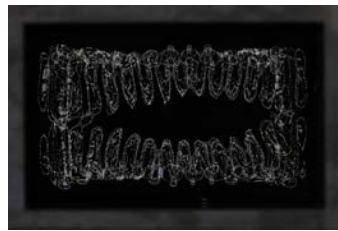
206 Hz



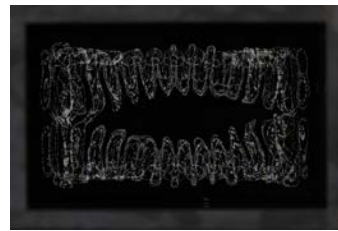
207 Hz



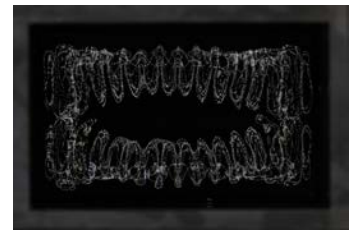
208 Hz



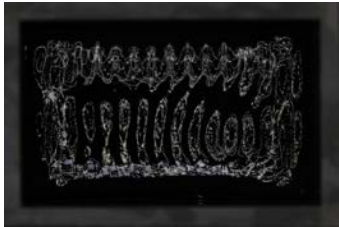
209 Hz



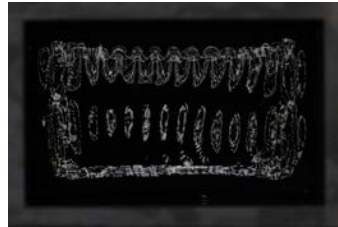
210 Hz



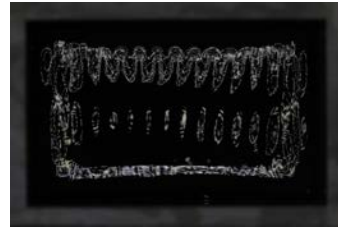
211 Hz



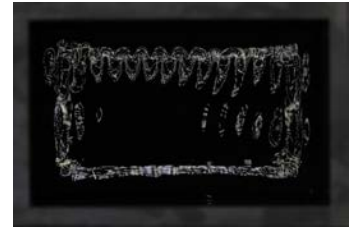
212 Hz



213 Hz



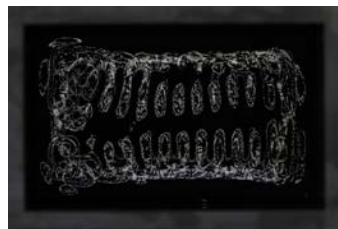
214 Hz



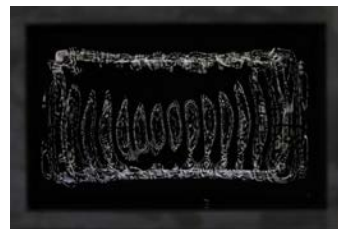
215 Hz



216 Hz



217 Hz



218 Hz



219 Hz



220 Hz



221 Hz



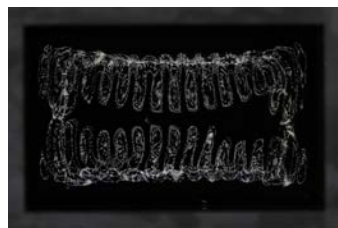
222 Hz



223 Hz



224 Hz



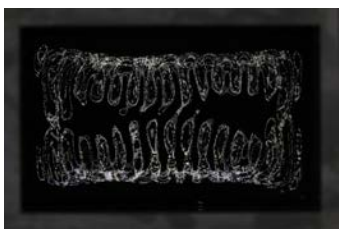
225 Hz



226 Hz



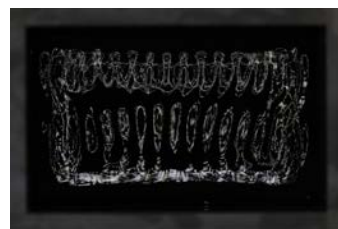
227 Hz



228 Hz



229 Hz



230 Hz



231 Hz



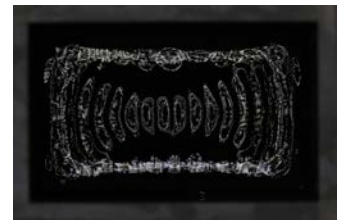
232 Hz



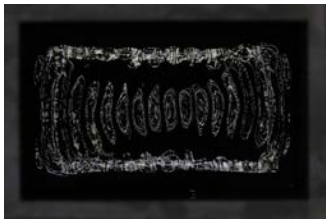
233 Hz



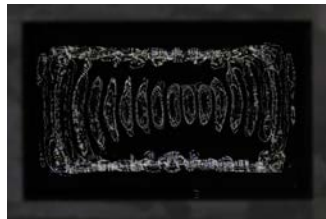
234 Hz



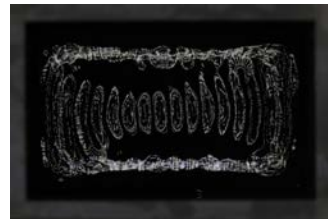
235 Hz



236 Hz



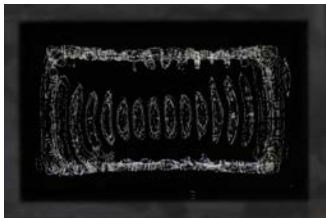
237 Hz



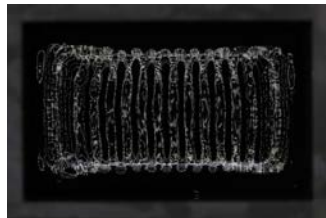
238 Hz



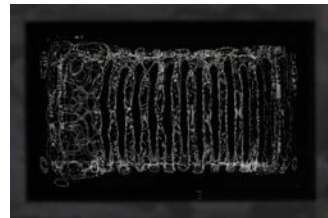
239 Hz



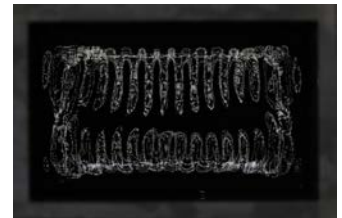
240 Hz



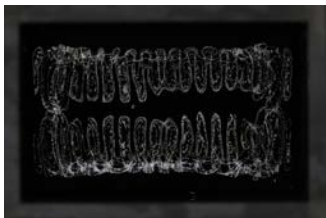
241 Hz



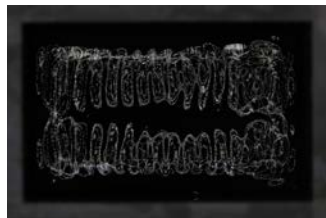
242 Hz



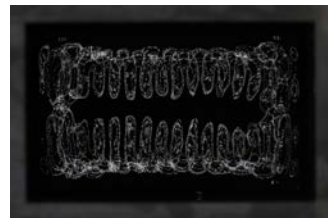
243 Hz



244 Hz



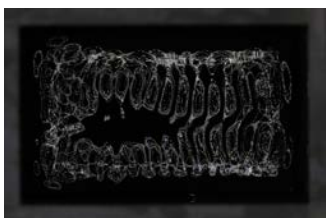
245 Hz



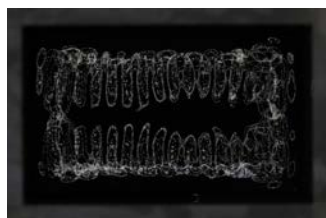
246 Hz



247 Hz



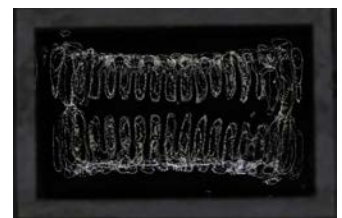
248 Hz



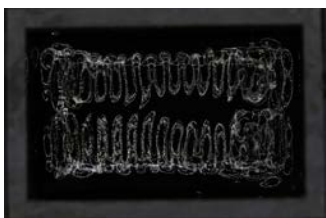
249 Hz



250 Hz



251 Hz



252 Hz



253 Hz



254 Hz



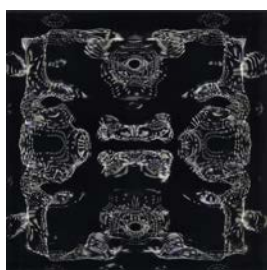
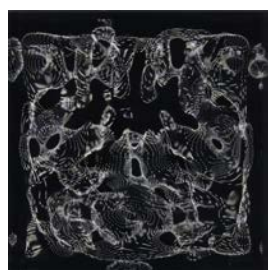
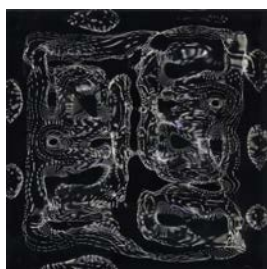
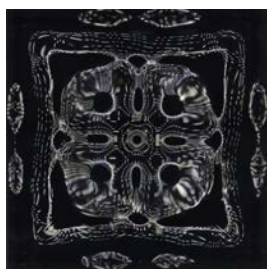
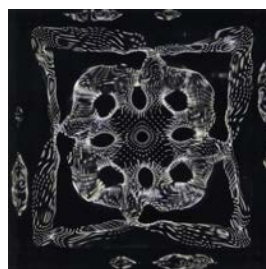
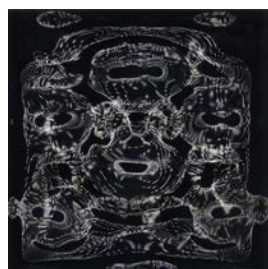
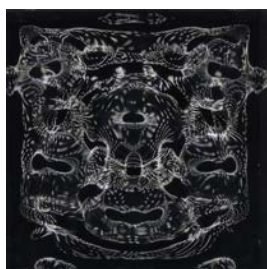
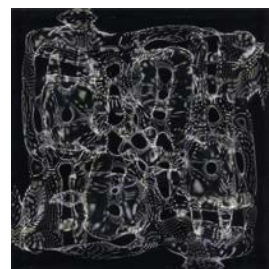
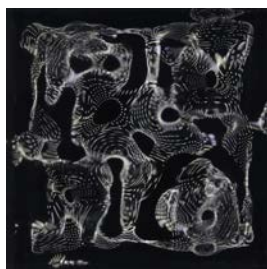
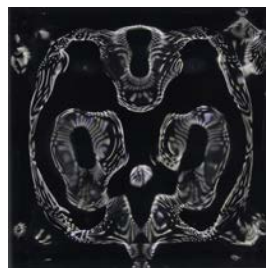
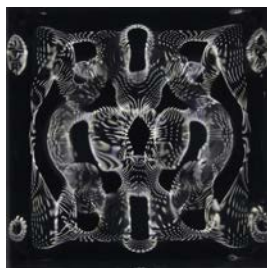
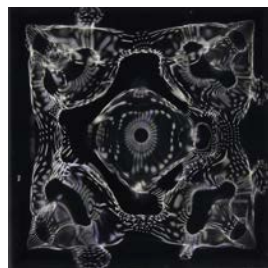
255 Hz



260 Hz

Resonant wave phenomena in a 25.2 mm square cuvette for frequencies 16 – 256 Hz.







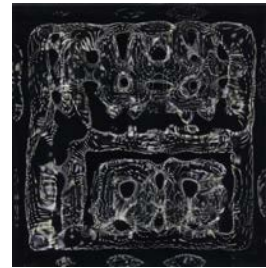
66 Hz



67 Hz



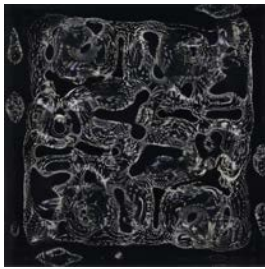
68 Hz



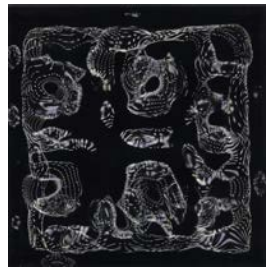
69 Hz



70 Hz



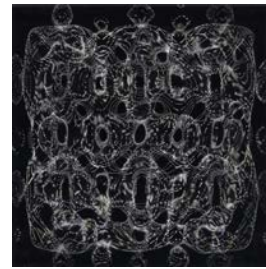
71 Hz



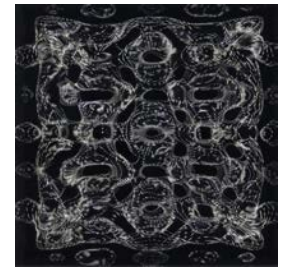
72 Hz



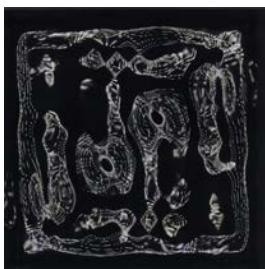
73 Hz



74 Hz



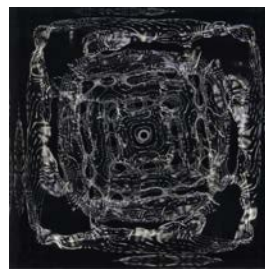
75 Hz



76 Hz



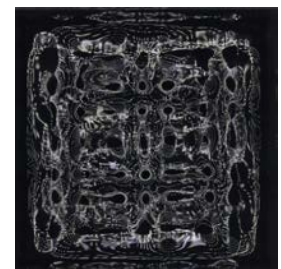
77 Hz



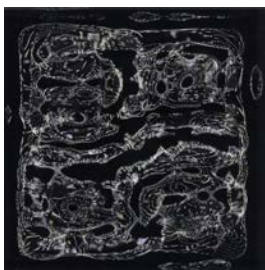
78 Hz



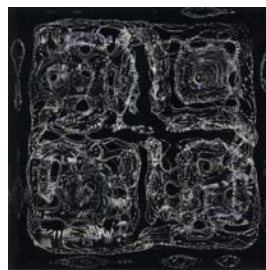
79 Hz



80 Hz



81 Hz



82 Hz



83 Hz



84 Hz



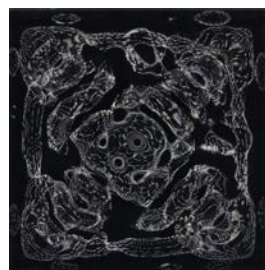
85 Hz



86 Hz



87 Hz



88 Hz



89 Hz



90 Hz



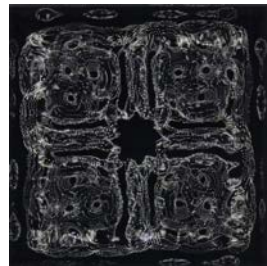
91 Hz



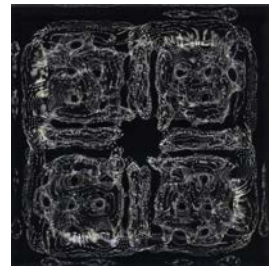
92 Hz



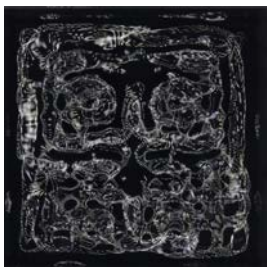
93 Hz



94 Hz



95 Hz



96 Hz



97 Hz



98 Hz



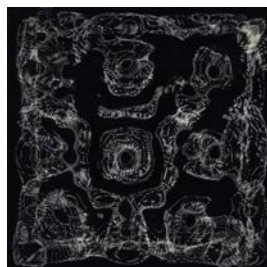
99 Hz



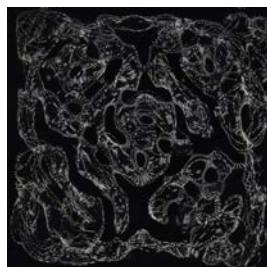
100 Hz



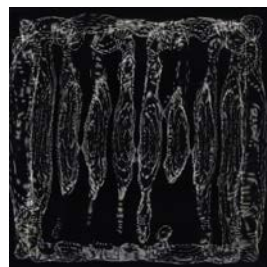
101 Hz



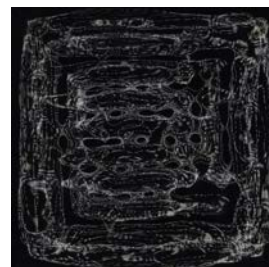
102 Hz



103 Hz



104 Hz



105 Hz



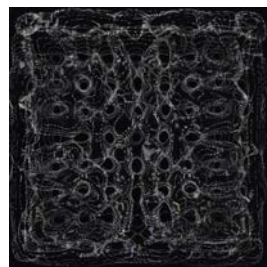
106 Hz



107 Hz



108 Hz



109 Hz



110 Hz



111 Hz



112 Hz



113 Hz



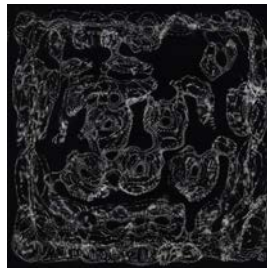
114 Hz



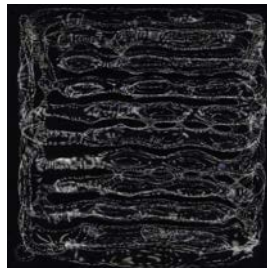
115 Hz



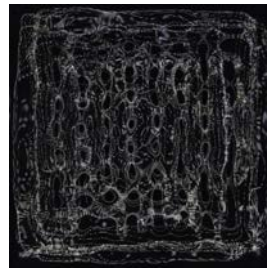
116 Hz



117 Hz



118 Hz



119 Hz



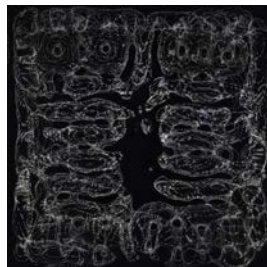
120 Hz



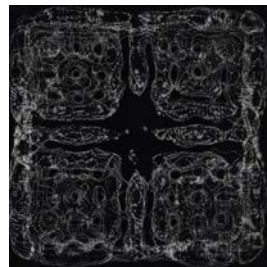
121 Hz



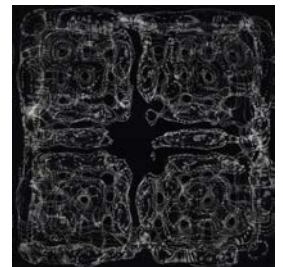
122 Hz



123 Hz



124 Hz



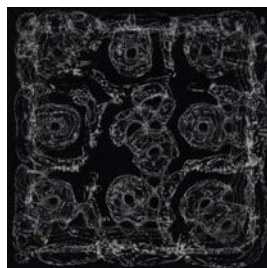
125 Hz



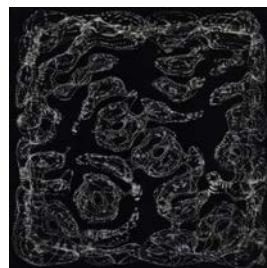
126 Hz



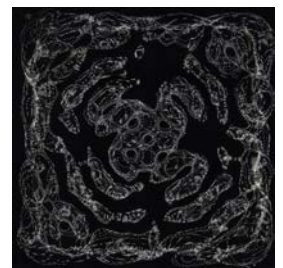
127 Hz



128 Hz



129 Hz



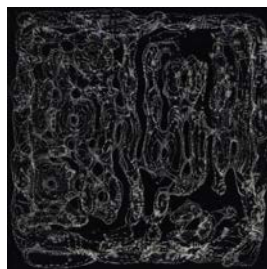
130 Hz



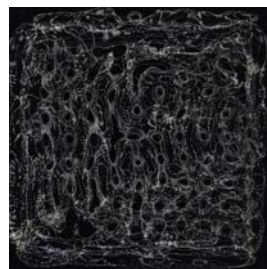
131 Hz



132 Hz



133 Hz



134 Hz



135 Hz



136 Hz



137 Hz



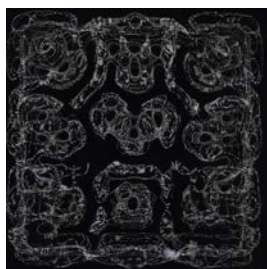
138 Hz



139 Hz



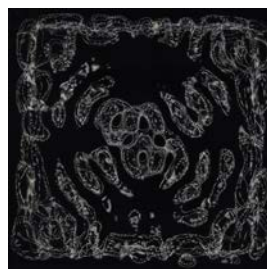
140 Hz



141 Hz



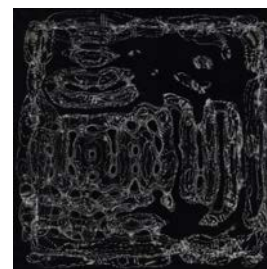
142 Hz



143 Hz



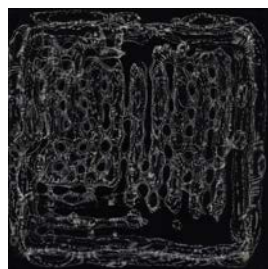
144 Hz



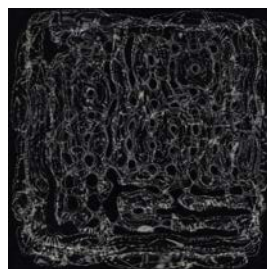
145 Hz



146 Hz



147 Hz



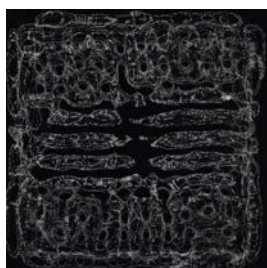
148 Hz



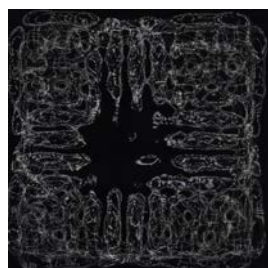
149 Hz



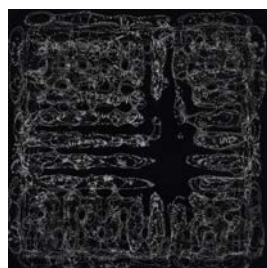
150 Hz



151 Hz



152 Hz



153 Hz



154 Hz



155 Hz



156 Hz



157 Hz



158 Hz



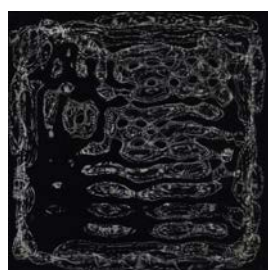
159 Hz



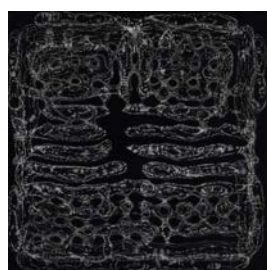
160 Hz



161 Hz



162 Hz



163 Hz



164 Hz



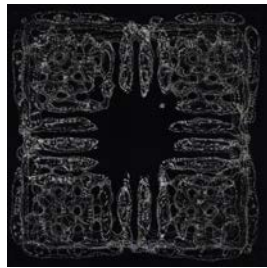
165 Hz



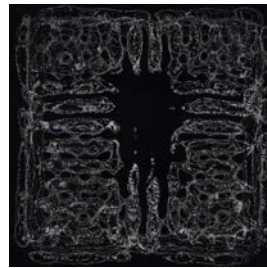
166 Hz



167 Hz



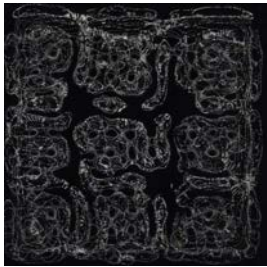
168 Hz



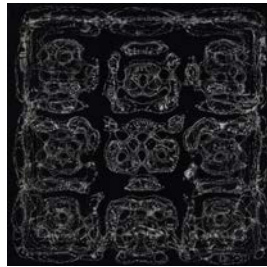
169 Hz



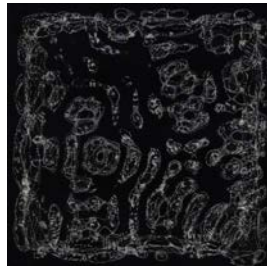
170 Hz



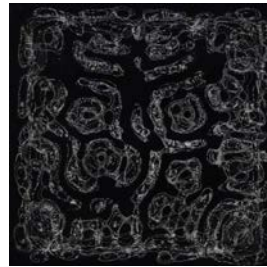
171 Hz



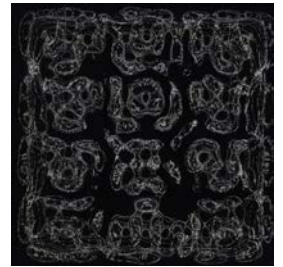
172 Hz



173 Hz



174 Hz



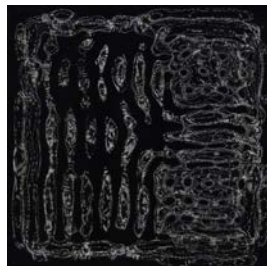
175 Hz



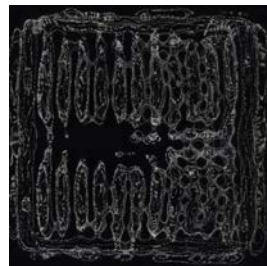
176 Hz



177 Hz



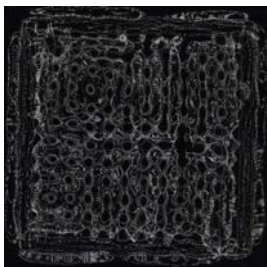
178 Hz



179 Hz



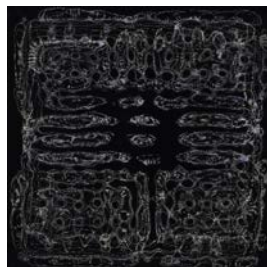
180 Hz



181 Hz



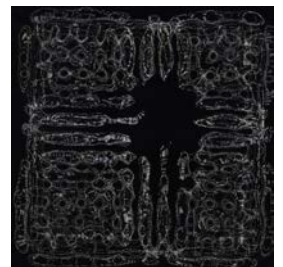
182 Hz



183 Hz



184 Hz



185 Hz



186 Hz



187 Hz



188 Hz



189 Hz



190 Hz



191 Hz



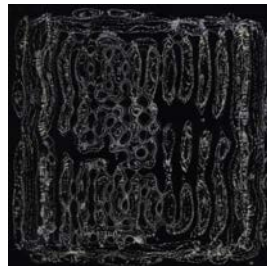
192 Hz



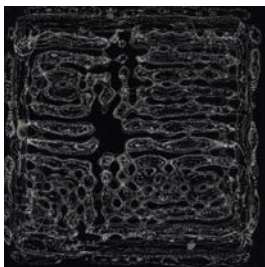
193 Hz



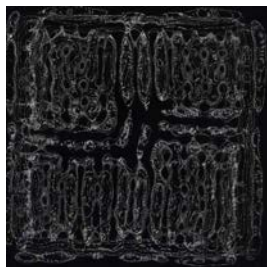
194 Hz



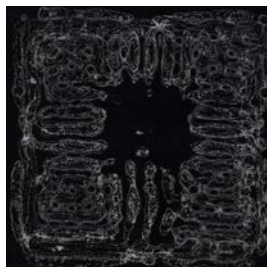
195 Hz



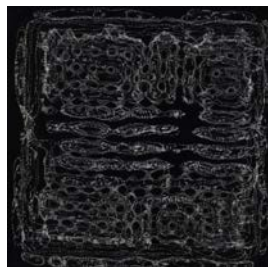
196 Hz



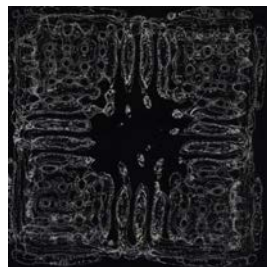
197 Hz



198 Hz



199 Hz



200 Hz



201 Hz



202 Hz



203 Hz



204 Hz



205 Hz



206 Hz



207 Hz



208 Hz



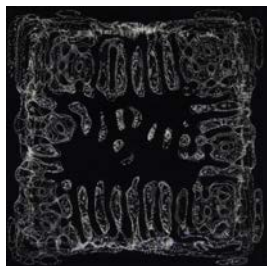
209 Hz



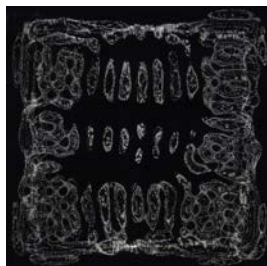
210 Hz



211 Hz



212 Hz



213 Hz



214 Hz



215 Hz



216 Hz



217 Hz



218 Hz



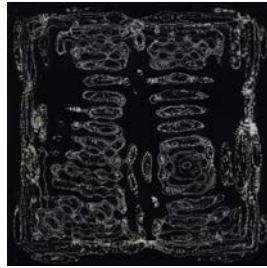
219 Hz



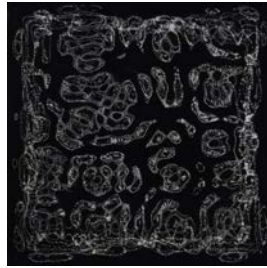
220 Hz



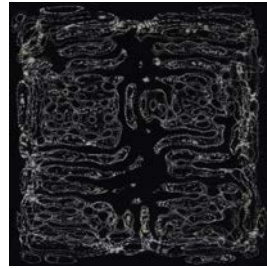
221 Hz



222 Hz



223 Hz



224 Hz



225 Hz



226 Hz



227 Hz



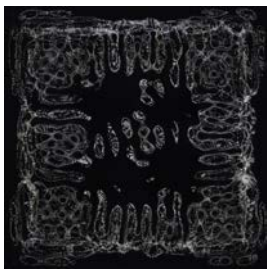
228 Hz



229 Hz



230 Hz



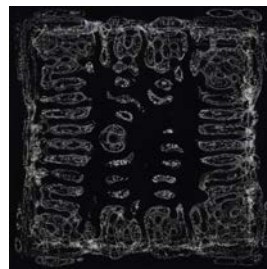
231 Hz



232 Hz



233 Hz



234 Hz



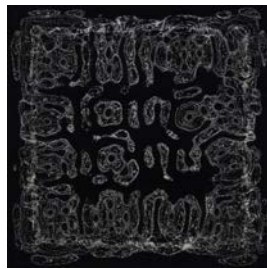
235 Hz



236 Hz



237 Hz



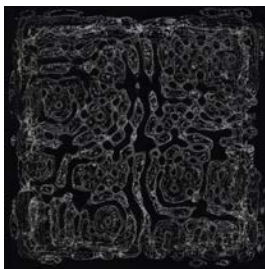
238 Hz



239 Hz



240 Hz



241 Hz



242 Hz



243



244 Hz



245 Hz



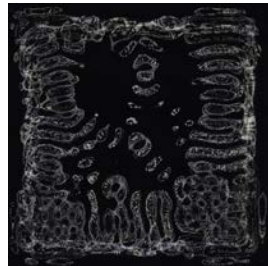
246 Hz



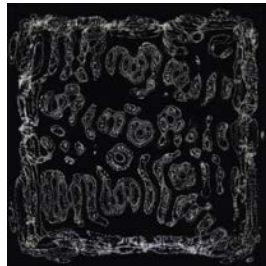
247 Hz



248 Hz



249 Hz



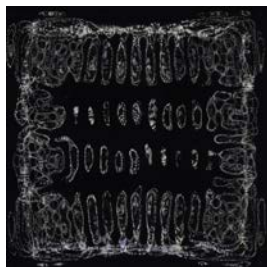
250 Hz



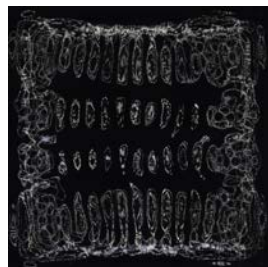
251 Hz



252 Hz



253 Hz



254 Hz



255 Hz



256 Hz

APPENDIX 4

Resonant wave phenomena in a 24.25 mm circular cuvette for frequencies 16 – 256 Hz.



16 Hz



17 Hz



18 Hz



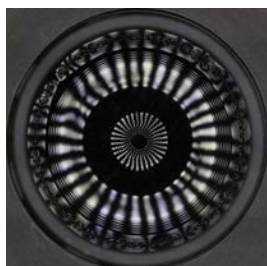
19 Hz



20 Hz



21 Hz



22 Hz



23 Hz



24 Hz



25 Hz



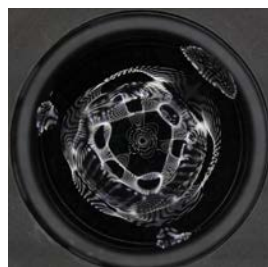
26 Hz



27 Hz



28 Hz



29 Hz



30 Hz



31 Hz



32 Hz



33 Hz



34 Hz



35 Hz



36 Hz



37 Hz



38 Hz



39 Hz



40 Hz



41 Hz



42 Hz



43 Hz



44 Hz



45 Hz



46 Hz



47 Hz



48 Hz



49 Hz



50 Hz



51 Hz



52 Hz



53 Hz



54 Hz



55 Hz



56 Hz



57 Hz



58 Hz



59 Hz



60 Hz



61 Hz



62 Hz



63 Hz



64 Hz



65 Hz



66 Hz



67 Hz



68 Hz



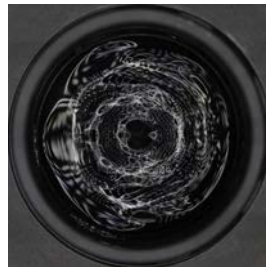
69 Hz



70 Hz



71 Hz



72 Hz



73 Hz



74 Hz



75 Hz



76 Hz



77 Hz



78 Hz



79 Hz



80 Hz



81 Hz



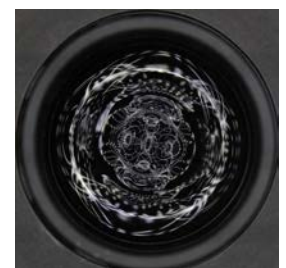
82 Hz



83 Hz



84 Hz



85 Hz



86 Hz



87 Hz



88 Hz



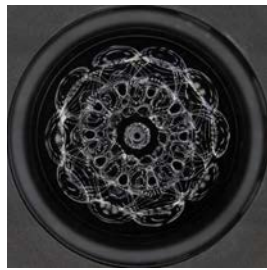
89 Hz



90 Hz



91 Hz



92 Hz



93 Hz



94 Hz



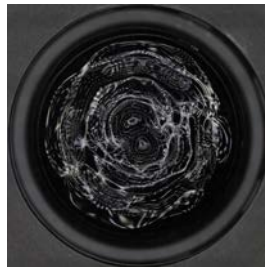
95 Hz



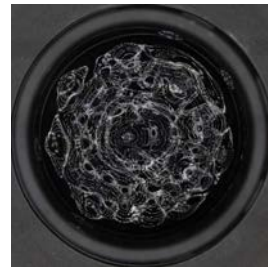
96 Hz



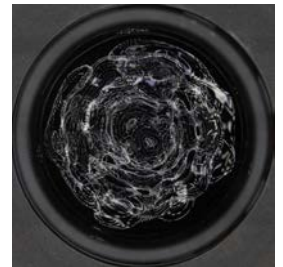
97 Hz



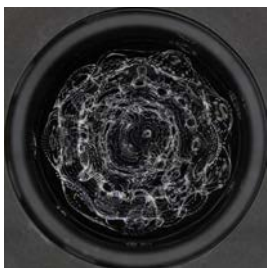
98 Hz



99 Hz



100 Hz



101 Hz



102 Hz



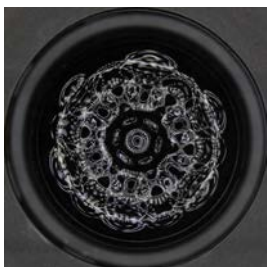
103 Hz



104 Hz



105 Hz



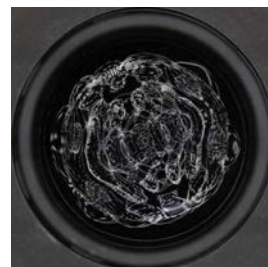
106 Hz



107 Hz



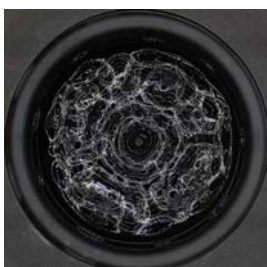
108 Hz



109 Hz



110 Hz



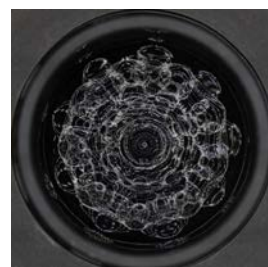
111 Hz



112 Hz



113 Hz



114 Hz



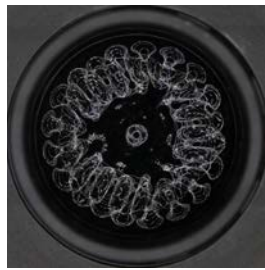
115 Hz



116 Hz



117 Hz



118 Hz



119 Hz



120 Hz



121 Hz



122 Hz



123 Hz



124 Hz



125 Hz



126 Hz



127 Hz



128 Hz



129 Hz



130 Hz



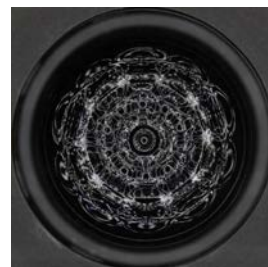
131 Hz



132 Hz



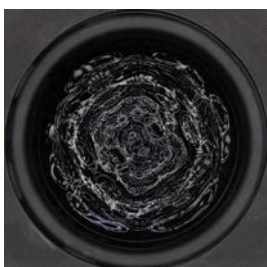
133 Hz



134 Hz



135 Hz



136 Hz



137 Hz



138 Hz



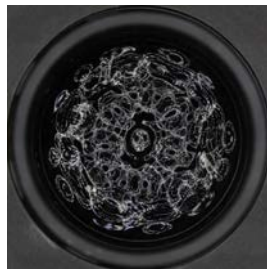
139 Hz



140 Hz



141 Hz



142 Hz



143 Hz



144 Hz



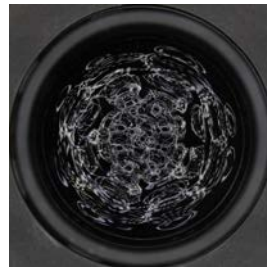
145 Hz



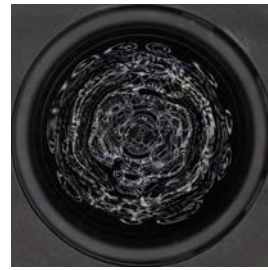
146 Hz



147 Hz



148 Hz



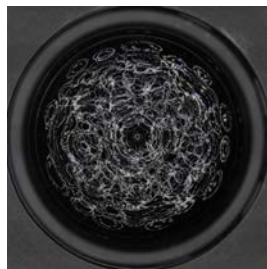
149 Hz



150 Hz



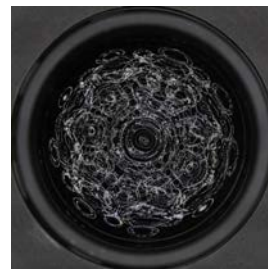
151 Hz



152 Hz



153 Hz



154 Hz



155 Hz



156 Hz



157 Hz



158 Hz



159 Hz



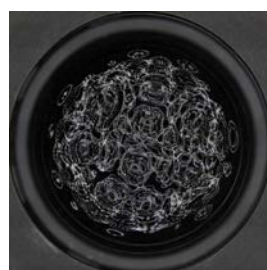
160 Hz



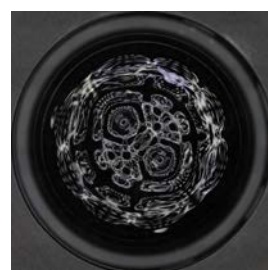
161 Hz



162 Hz



163 Hz



164 Hz



165 Hz



166 Hz



167 Hz



168 Hz



169 Hz



170 Hz



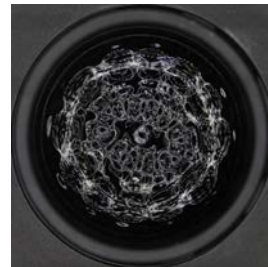
171 Hz



172 Hz



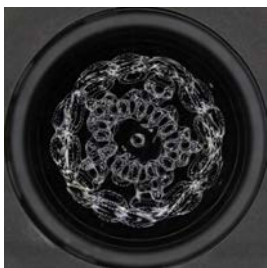
173 Hz



174 Hz



175 Hz



176 Hz



177 Hz



178 Hz



179 Hz



180 Hz



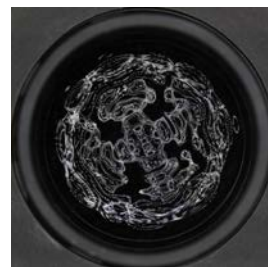
181 Hz



182 Hz



183 Hz



184 Hz



185 Hz



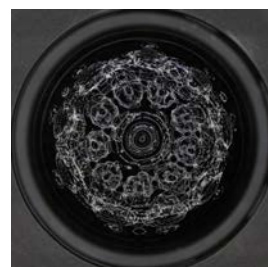
186 Hz



187 Hz



188 Hz



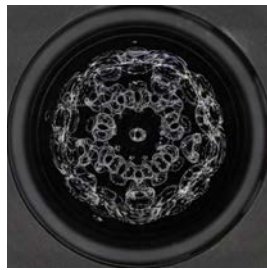
189 Hz



190 Hz



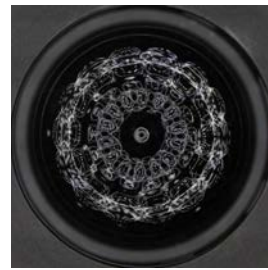
191 Hz



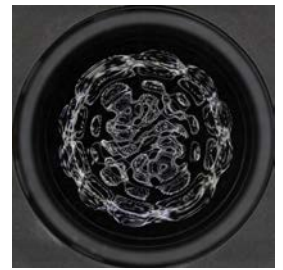
192 Hz



193 Hz



194 Hz



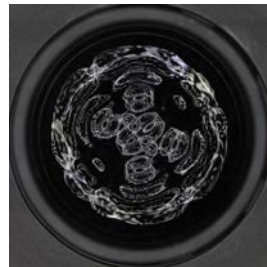
195 Hz



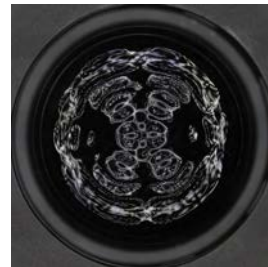
196 Hz



197 Hz



198 Hz



199 Hz



200 Hz



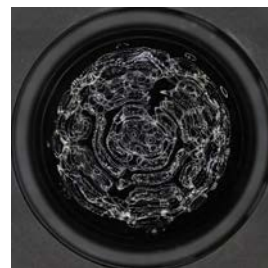
201 Hz



202 Hz



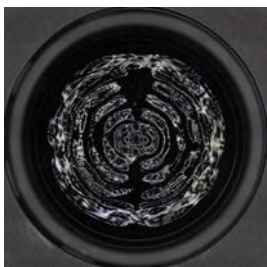
203 Hz



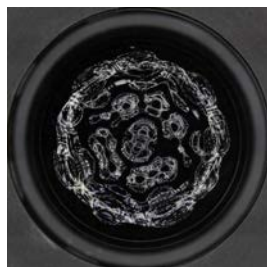
204 Hz



205 Hz



206 Hz



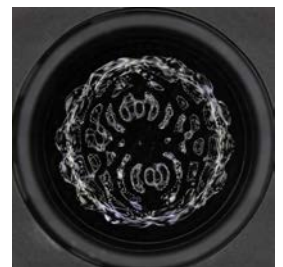
207 Hz



208 Hz



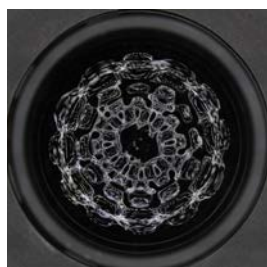
209 Hz



210 Hz



211 Hz



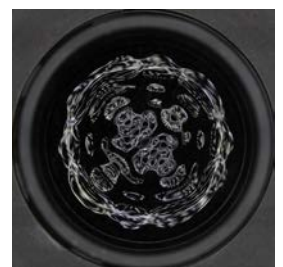
212 Hz



213 Hz



214 Hz



215 Hz



216 Hz



217 Hz



218 Hz



219 Hz



220 Hz



221 Hz



222 Hz



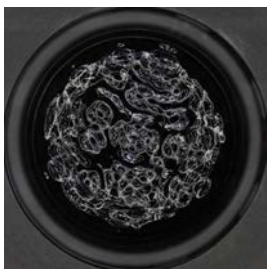
223 Hz



224 Hz



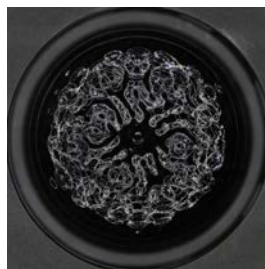
225 Hz



226 Hz



227 Hz



228 Hz



229 Hz



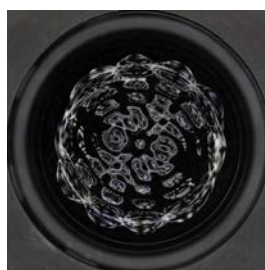
230 Hz



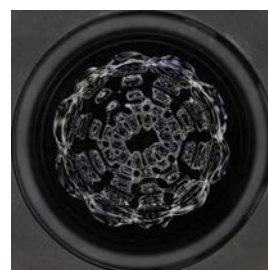
231 Hz



232 Hz



233 Hz



234 Hz



235 Hz



236 Hz



237 Hz



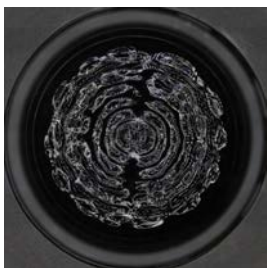
238 Hz



239 Hz



240 Hz



241 Hz



242 Hz



243



244 Hz



245 Hz



246 Hz



247 Hz



248 Hz



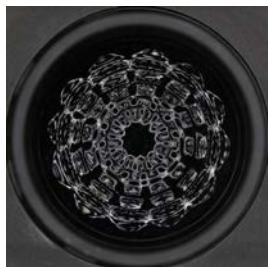
249 Hz



250 Hz



251 Hz



252 Hz



253 Hz



254 Hz



255 Hz



256 Hz