Music as a Carbon Language: Clarifying Methods, Results, Fresh Data, and Perspectives

Gabriel Pareyon

CENIDIM-INBA, Mexico City

CUCSH-UDG, Guadalajara

cenidim.gpareyon@inba.edu.mx

Orcid: 0000-0002-3471-0102

Abstract: From a cross-domain perspective, this article recapitulates fundamental concepts and procedures exposed in the antecedent homonymous paper (MusMat, first issue, 2016: 25–43). Firstly, the methodology used and here improved becomes explicit. An advanced section clarifies aspects that remained obscure in the first article. This theoretical approach falls entirely into the domain of study of the nuclear precession frequencies or Larmor frequencies in the NMR (nuclear magnetic resonance) context, here incorporated to biomusicology. The structure obtained is a free-scale geometric set and its generalization interprets the frequencies as a system of harmonically organized patterns. Intermediate findings provide arguments to strengthen the conjecture that the transversality of harmonic phenomena is related to a tendency towards structural self-similarity, without necessarily implying spurious relationships between causation and correlation.

Keywords: Larmor frequencies, harmony theory, self-similarity, scale-free distribution, biomusicology.

I Introduction

After seven years of the publication of the article "Music as Carbon Language: A Mathematical Analogy and its Interpretation in Biomusicology" [16], a number of reviews and criticisms were received. Some of them refer insufficient transparency on methodology as well as on key concepts. However, new revisions (on my own) confirm the validity for the article's main arguments and conclusions. The nature of such validity is matter in the discussion of the present article. In addition, it has become necessary to review some conceptual refinements, to correct imprecisions and provide solid evidences. While the article in question (henceforth MCL-2016) presents certain heaviness —due to the referred issues—, it is expected that the present one may run fluently with much greater understanding.

At first, it would seem that pointing out the failures in MCL-2016 should take precedence. However, this task is transferred to an advanced section. The priority here is to make explicit the

Table 1: *The first elements produced in the universe displayed by their atomic number. When the nuclear spin (I) is equal to 0, it has no any Larmor frequency as there is no any specific angular momentum. This is why ^4He, for example, cannot have any number in the rightmost column. The superscript to the left of the symbol of each chemical element represents the mass number (A), that is, the number of neutrons plus the number of protons of each isotope.*

Element	Isotope (nuclide) **A**	Nuclear spin **I**	Natural Abundance %	Specific Larmor frequency (MHz/Teslas) **γ**
Hydrogen				
Protium	^{1}H	1/2	99.9885	42.5761
Deuterium	^{2}H	1	0.0115	6.5357
Tritium	^{3}H	1/2	0.000(1)	45.4134
Helium	^{3}He	1/2	1.34E-04	32.4340
	^{4}He	0	99.99	—
Lithium	^{6}Li	1	7.59	6.2654
	^{7}Li	3/2	92.41	16.5467
Beryllium	^{9}Be	3/2	100	5.9827

method of translating nuclear precession frequencies into harmonic (musical) structures, as well as the method to define these structures as objective relationships that may contribute to clarify the bonds among music, mathematics and the natural sciences.

A Larmor (nuclear) frequency is the rate at which an atom nucleus precesses. The nuclei precess since they have non-zero angular momenta that force the nuclei to resist the change of their state of motion. Hence, the nuclei do not completely align with the external magnetic field, and precess instead [9, pp. 8–9]. Otherwise, if nuclei have zero angular momenta then there is no Larmor frequency to be measured.

Larmor frequencies are not intrinsic values for each element in the periodic table, but rather depend on the external magnetic field around which atomic nuclei precess. However, the gyromagnetic relationship between the nucleus and the external magnetic field is indeed intrinsic to each isotope. Such a relationship, typically denoted by the letter γ (see: Table 1), would be the Specific Larmor frequency, or Larmor frequency per unit magnetic field.[1]

The nuclear spin, designated I, has an integral or half-integral value. The nuclei of isotopes ^{4}He, ^{12}Ca, ^{16}O, ^{18}O, ^{20}Ne, ^{28}Si and ^{32}S have $I = 0$. These nuclei contain filled shells of protons and neutrons with the vector sum of the component angular momenta equal to zero, analogous to closed shells of electrons in atoms and molecules [3]. In fact, all even-even nuclei have spins of zero and this is why —with few exceptions like ^{2}H, ^{6}Li, ^{10}B, ^{14}N and ^{50}V —, stable isotopes even-numbered do not appear with any specific Larmor frequency (see: Appendix). By consequence, a succession of odd-enumerated isotopes plus quoted exceptions is the guide for the general harmonic structure studied along this article.

The highest Larmor frequency is registered for hydrogen (see: Table 1). The frequency of

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[1] The magnitude of the external magnetic field with respect to which the Larmor frequencies are calculated in this work is 7.04925 (MHz vs. Bruker Field Strengths in Tesla units). Source: [13].

protium (^{1}H) is 42.5761 MHz and of tritium (^{3}H) is 45.4134 MHz. The latter, however, has no specific meaning for biomusicology because of its rare natural abundance in the universe, and its extreme rarity on Earth (abundance is a feature relevant to the selection in the Appendix, although data on some abundant isotopes still unavailable with gaps in the available statistics). Besides, tritium is a radioactive, non-stable form of hydrogen, in contrast to the stable isotopes of protium and deuterium. The three isotopes of hydrogen are included in the Appendix because of their potential usefulness for harmonic calculations, albeit ^{1}H has a capital role in the development of this study, in reason of its central implications in cosmology, astronomy, chemistry and biology, and consequently in biosocial and cultural processes.

Given that the Larmor frequencies are the numerical identifiers of the periodic dynamics that make up matter, it seems relevant to study them as a whole plot of proportion and correspondence, if any. This identification is formally described by the Larmor equation:

$$\omega_0 = \gamma \mathbf{B}_0,$$

where ω_0 does mean the frequency of precession, γ is the gyromagnetic constant specific for the atom, and $\mathbf{B}_0$ is the magnetic field. This initial focus is primarily on biomusicological correspondences; nevertheless, for illustrative purposes, we may start by translating the first four elements in the periodic table with their most stable and abundant isotopes, as follows:

$$^1\text{H} = E^{+1/3},\ ^3\text{He}\ (C^{8va}),\ ^6\text{Li}\ (= G^{+1/4}),\ ^7\text{Li}\ (= C_{8vab}),\ ^9\text{Be}\ (= G):$$
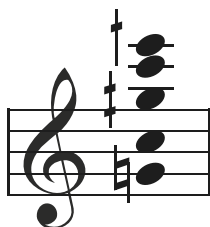

Figure 1: *Primary chord with the first four elements in the periodic table of the elements (with two lithium isotopes) displayed as Specific Larmor frequencies. Their musical correspondences are pitch-modulated to the audible human register from G_4 to $E_6^{+1/3}$.*

Beforehand we accepted the common place A = 440 Hz in order to generalize all calculations, and use the Appendix at the end of this study for every single isotope here translated into musical pitch classes. The technical source for Larmor frequencies in this article as well as in MCL-2016, is the Bruker's Nuclear Magnetic Resonance Tables [13], using the NMR Frequencies vs. Bruker Field Strengths as quotients for the numbers in the Appendix.

The relevant issue is to preserve an invariant scale, in search for a scale-free generalization; thus, the emphasis is not over any particular translation of an isotope into music, but on the constant proportionality common to both models. Based on this warning, in Figure 1, first hydrogen —the isotope called protium— translates itself into pitch class E, plus one-third tone. The reason for interpreting protium in this fashion is because of the corresponding Larmor frequency of ^{1}H, which is 42.576... $\times 10^6$ Hz analogous to a musical pitch E (slightly high by a third-tone) in the musical frequency of 41.2 Hz (E natural) plus a third of tone, within the modulation of MHz/T into Hz.

Musical representation in this study does neither strive to associate an exhaustive tuning identical as an analogy to the Larmor frequencies, but just to approximate a musical tuning whose

limits are halves, thirds or quarter tones (this however does not cancel further research to extend higher precision into smaller musical intervals, in order to consider a greater variety of isotopes). For schematic purposes, we may resume the interpretation of the sequence ^{1}H, ^{3}He, ^{6}Li, ^{7}Li, ^{9}Be, as the musical pitch classes shown in Figure 1, and also to admit the three hydrogen isotopes primary to the cosmological development:

$$^1\text{H } (E^{+1/3}), \ ^2\text{H } (G\sharp), \ ^3\text{H } (F^{+1/3}), \ ^3\text{He } (C_{8va}), \ ^6\text{Li } (= G^{+1/4}), \ ^7\text{Li } (C_{8vab}), \ ^9\text{Be } (G) :$$
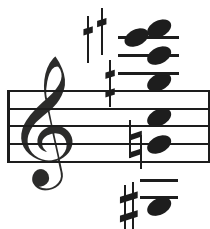

Figure 2: *From top to bottom, the sequence ^{3}H, ^{1}H, ^{3}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{2}H. The conventional sign* † *stands here for 1/3-tone up, and* ‡ *for 1/4-tone up.*

Figure 3 shows the same chord (than in Figure 2), however musically "normalized". Roughly speaking, this concept of *normalization* consists of a musical conventional inversion of each note from a chord or row, with the aim of obtaining musical pitches ordered from low to high, i.e. from the "generator" to the successive harmonic series, a formalization first put forward by theorist and composer Jean-Philippe Rameau (1683–1764) [19]. Since the absolute generator here is ^{1}H, then we invert the complete scale extracted from the Larmor frequencies in order to begin with ^{1}H at the bottom of the scale.

The chord in Figure 2 somehow suggests that the first process of primal nucleosynthesis in the origin of the universe, started to self-organize in a harmonic way, i.e. under a principle of self-proportion along time-space; otherwise, any system of harmonic ratio and proportion for the self-generation of these intervals would not be observable.

Figure 3 arbitrarily inverts this arrangement, just to make visible this harmonic organization to the musical convention in terms of a "normal chord". This arbitrariness, however, is guided by the mirror and inversion of the molecular world we hear, regarding the atomic world we cannot hear: in the audible vibrations quite commonly we register low pitches as fundamental generators of harmonic sounds composed by "ascending" layers or waves gradually diminishing in amplitude and tonal hierarchy. In contrast, in the atomic domain the fundamental generators are the lightest elements (H, He, Li) that gradually transform into progressively complex and heavier isotopes. So, the goal with this mechanism for "normalizing" hyper-frequencies into audible frequencies has an aesthetic purpose —by the etymological sense of aesthetics as sensory perception.

Along with the Appendix, Figure 4 clarifies this translation procedure. The scale in Figure 4-A displays 25 tones, each of them with musical frequencies (Hz) matching with specific isotopes (MHz). Some of them fall into a same class of pitches because their individual differences are smaller than the established quarter tone limit. Because of this *almost overlapping* scale, Figure 4-B simplifies and shrinks the scale into 16 tones. This 16-tone scale synthesizes the harmonic properties —in the musical sense— of the whole collection, although without necessarily eliminating the differences of its individual components, something explained later, in the context of Figure 13.
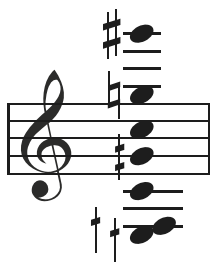
Figure 3: *The same sequence ^3H, ^1H, ^3He, ^6Li, ^7Li, ^9Be, ^2H, musically "normalized" from bottom to top. Metaphorically, this heptachord represents the Mother chord for the universe's baryonic mass.*

II   EXPLICIT METHODOLOGY

Protium (^1H), deuterium (^2H) and helium (^1He) have a liminal record at the beginning of the baryonic self-organization and a crucial role in the formation of stars, galaxies and planetary systems. In this way, the harmonic span between these isotopes characterized by their specific Larmor frequencies is determinant for the whole structure of any primary harmonicity. Figure 1 to 3 suffice by now to depict this relationship. Henceforth, the focus would be on the abundance, distribution and proportion among isotopes particularly meaningful in biology and even more precisely, with clear significance to biomusicology.

Whether a conventional musical narrative, as the one displayed in Figure 5, can be accepted alluding classical music for weaving a story telling of frequencies along cosmic history, then the wholeness of this yet blurry picture will become technically luminous and theoretically useful. This is crucial if we may imagine the history of the universe as musically apprehensible in a kind of post-Aristotelian philosophy of science, nonetheless graspable through a set of specific intervals. Such intervals preserve a free-scale structure for the isotopes organized by their degrees of proportion: a self-organizing harmony that leads to the trophic equilibrium in biological and musical patterns.

Let's give an imaginary chance, for a while, that the time span in the musical notes in Figure 5 result from a realistic evolution of galaxies and stars, and these musical pitches may come from the spontaneous long-term organization of elements along their nucleosynthesis. Then, the main challenge for making this imagination valuable to musicology and the natural sciences would be to prove every single relation nested within this construction. The corresponding procedure would be a basic tonal analysis, although not so much over traditional tonal relationships, but by physical analogies.

By now, the leading concept is straightforward related to the fact that the *Mother chord* for the baryonic mass (Figure 3) entails the musical crucial components of an octave (^eHe, ^7Li), a fifth (^7Li, ^9Be) and a third (^1H, ^9Be). Whether stars like our Sun are made of 74% hydrogen, 25% helium, and 1% other elements, and living organisms are mainly composed by four elements: oxygen, carbon, hydrogen and nitrogen [11], it seems evident that life results from a dissipative equilibrium closely related to the continuity of the same principle of proportionality. According to this principle, the tiny percentage of "other elements" should reflect precise signs for such continuity, even in minuscule proportions. Reciprocally, the arrangement of these proportions would be of vital importance in such a way that these arrangements would have to be registered by biomusicology and acoustic ethology. Somehow, a broad notion of this equilibrium can be appreciated when comparing Figures 5 and 6, and in fact this corresponds to the intention of synthesis for the *Prelude* in Figure 5.
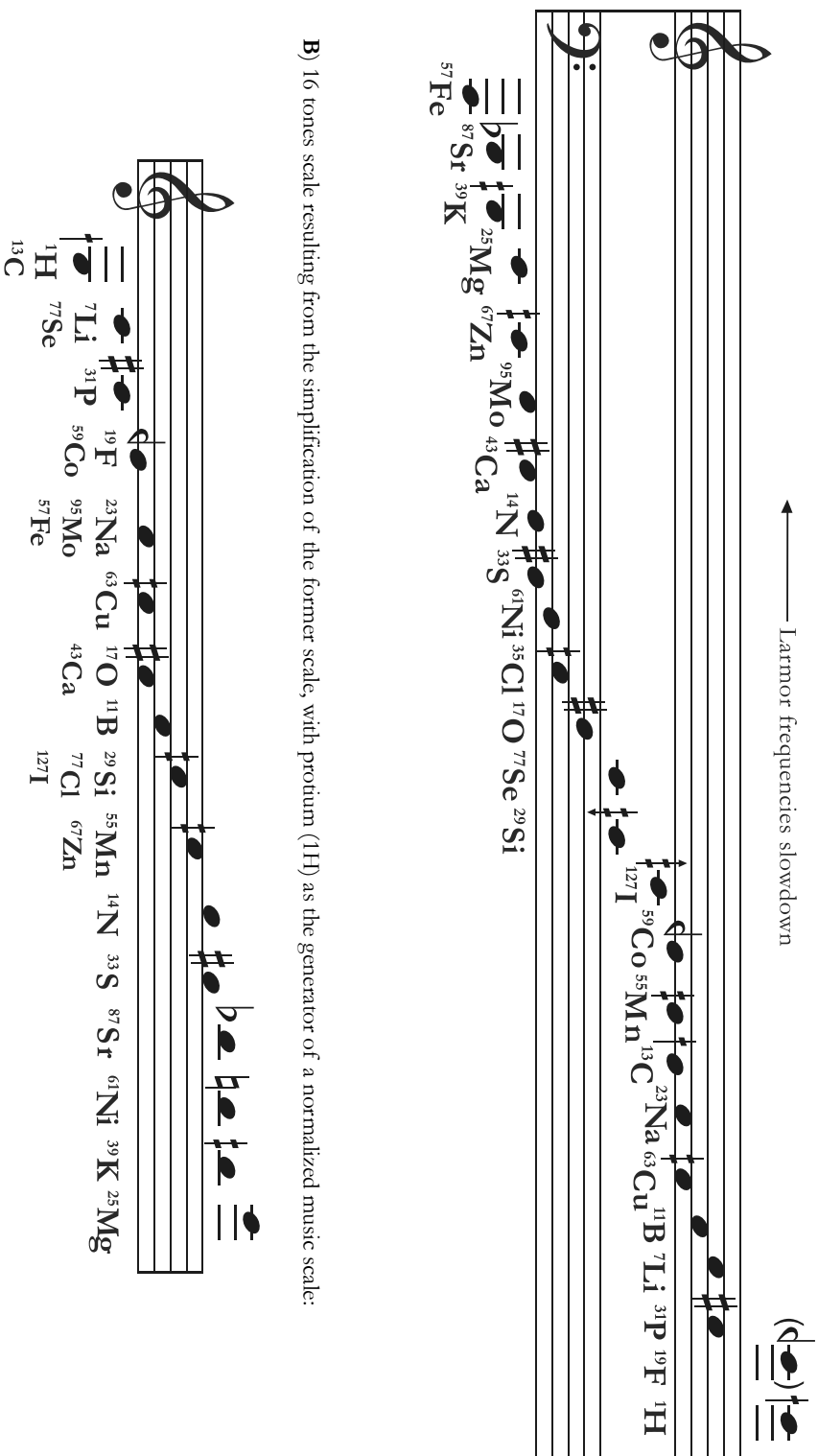
A) 25 tones scale including 99.99% of the nutritional essential and trace elements represented by their most stable and abundant isotopes:

Larmor frequencies slowdown

B) 16 tones scale resulting from the simplification of the former scale, with protium (1H) as the generator of a normalized music scale:

Figure 4: *Two musical scales obtained by conversion of atomic Larmor frequencies modulated from KHz to audible pitches. The upper scale (A) can be read from right to left as the natural Larmor frequencies slowdown from the highest value, 1H, to the lowest one, ^{57}Fe. The lower scale (B) is musically normalized: it can be read from left to right, presuming that 1H is the generator tone; besides, information redundancy is simplified here for similar pitches as pitch class sets. For example, ^{1}H and ^{13}C have the same value, E+1/3, 19F and ^{69}Co correspond to E−1/4; ^{23}Na, ^{95}Mo and ^{57}Fe correspond to F, and so on. This method of tonal organization makes it easier to understand the composition of the following example, Figure 5.*
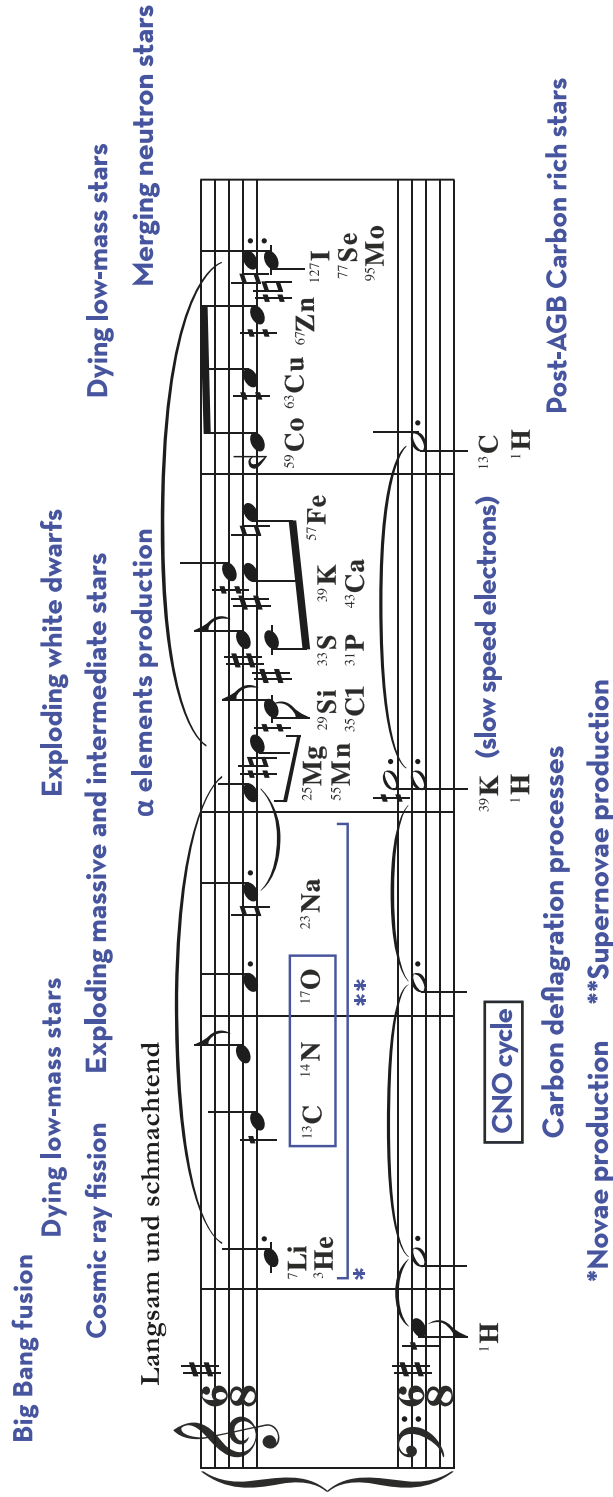
Figure 5: *The Prelude for life on Earth seen as a musical development, using pitches from Figure 4. The narrative strategy occurs from the cosmological creation of first hydrogen. Next elements appear from left to right according to their astronomical emergence, so the text in blue provides useful information to follow the whole development in vertical and horizontal coordinates. Only the most relevant isotopes for life self-organizing are displayed. Since the passage vaguely resembles R. Wagner's **Tristan** initial sequence, the header **Langsam und schmachtend** (slowly and languidly) comes from that source, and stands as a reference for a realistic performance on a keyboard (provided that it can produce thirds and quarter tones). The written E minor key signature stresses the relationship of hydrogen ($E^{+1/3}$) with oxygen (F#) along this development. Other technicalities are explained in the main text.*
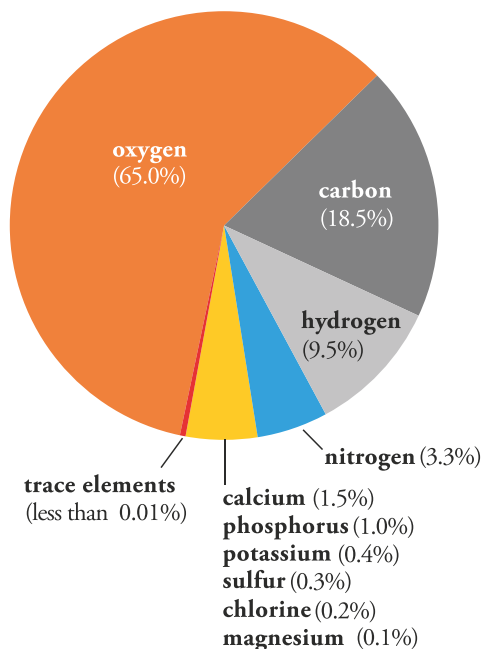
Figure 6: *The chemical elements that compose the human body (source: [11]). This graph may help to see why F♯ (oxygen) is the key signature in Figure 5.*

Figure 7 is useful to visualize how the even numbered elements are more abundant than the odd ones. This is due to the additive chemical function of helium (with atomic number 2), as the source of the stellar nucleosynthesis processes for the production of the elements.

An interesting fact is that by substituting the symbols of the elements in Figure 7 with the musical pitch classes in Figure 8, and rounding the frequencies for the same pitches under the tonal system (TET), there is a majority of E, F, followed by B, C, in turn followed by a second hierarchy (occurrence = 2) and a last one (occurrence = 1). The bubbles-like pattern (Figure 8, rightmost column) clusters the pitches E, F (7 + 5) and B, C (2 + 4) in order to emphasize the conjecture that high numbers denote a hierarchical arrangement. So it seems that the distribution of the abundance of the elements created in the stars already outlines a gross harmonic hierarchy, which is much better perceptible in a finer harmonization when looking at the Larmor frequencies of these elements.

Finally, it is necessary to mention that the natural abundance of the isotopes and their molar mass are closely related physical phenomena [15, p. 130], so that a relation between the atomic (molar) mass and the Larmor frequencies must be also considered.

The abundance of oxygen, translated into F♯ in Figure 6, points out the prevalence of the E minor key signature as a necessary trait of the *Prelude* in Figure 5, where hydrogen and carbon are present in manifold ways. Similar to the argument of a story, in this passage realism is guided by a certain order, proportion and correlation. As a message decoded from this narrative, we may highlight a balance or negotiation between natural abundance read as thermodynamic stability, and a harmonic guidance which drifts in the phenomenon of life.
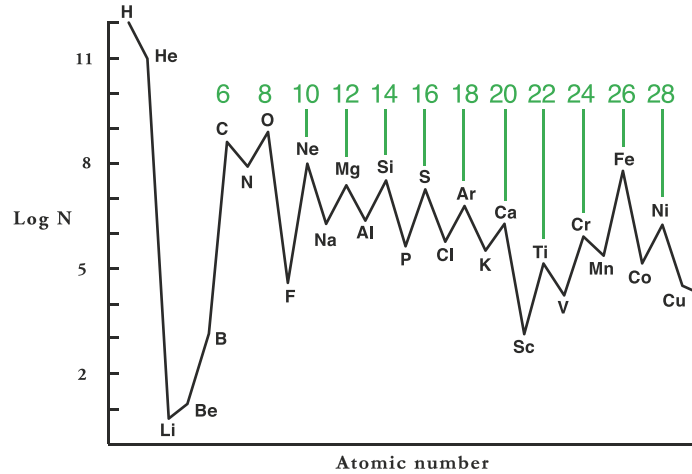
Figure 7: *The first 29 chemical elements ranking by their natural abundance in the universe (source: [11]). The vertical axis measures abundance, and the horizontal one corresponds to successive atomic numbers in the periodic table. Green numbers point out how the even numbered elements are more abundant than the odd ones. This is due to ^{2}He additive series from which the elements built up themselves.*
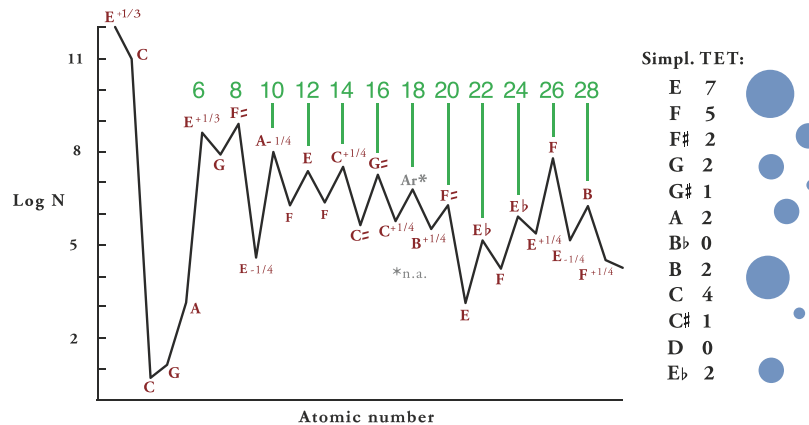

Figure 8: *The same graph as above (Figure 7), with the same elements labeled by their Larmor frequencies converted into musical pitch classes. The frequency for ^{36}Ar (argon) is unavailable since its angular momentum is zero. The column to the right lists the frequencies of the graphed set simplified to the chromatic scale of the twelve-equal temperament (TET). The rightmost vertical **bubble graph** captures this harmonic pattern, useful to cross natural abundance with a hierarchical resonance.*

III   THE PHENOMENON OF LIFE AND THE TONALITY OF E MINOR

The following short sections describe the astronomical technicalities in Figure 5, so that a reader acquainted with musicology can decipher the passage in its physical wide connotations. Contrasting descriptions must find here an effort for synthesis, provided that a specialized literature on these topics is publicly available.

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reader acquainted with musicology can decipher the passage in its physical wide connotations. Contrasting descriptions must find here an effort for synthesis, provided that a specialized literature on these topics is publicly available.

IV   FROM COSMIC RAY FISSION TO THE DEATH OF LOW-MASS STARS

Just few minutes after the Big Bang explosion, high-energy particles moving and generating space at nearly the speed of light, produced the cosmic ray fission for the first clustering of fundamental particles that composed H, He, and a tiny proportion of Li. At the beginning of stellar evolution, the gas clouds contracted; nuclear reactions begun in the center of the stellar masses and 4 H nuclei merged into 1 He nucleus. This proportion fundamental to the hydrostatic equilibrium, conformed He, with number atomic 2, into the guide and basic column for the development of the even numbered elements as the most abundant in the universe (Figure 7 and 8).

Massive stars can fuse hydrogen to helium, and then helium to carbon; then undergo other nuclear reactions where helium and carbon make oxygen. Helium and oxygen can make neon and carbon, and carbon can make magnesium, oxygen, silicon and so on. . . the nucleosynthesis in stars produces other elements, all of them after the helium atom. This is why helium cannot be absent in Figure 5, at the beginning of the passage. Helium directly does not make part of living organisms, however this passage, picturing in few measurements *the cosmic history of life*, could not ignore this first steps where helium has a capital role for the subsequent creation of the rest of the elements in this picture.

Following the beginning of the score, a powerful tone is heard in an immense field of resonances, undoubtedly with the fundamental tone: hydrogen, from which its main harmonic tones gradually become apparent. As soon as the first atoms are created, a tone doubled in their frequencies is perceived: helium seems omnipresent. Lithium mimics it from afar.

V   THE CARBON-NITROGEN-OXYGEN (CNO) CYCLE

The CNO isotopes cycle is a catalytic cycle where four protons fuse, each of which is consumed at one step of the cycle, but re-generated in a later step. The end product is one alpha particle —a stable He nucleus—, two positrons, and two electron neutrinos. A *particle dance* of symmetries and anti-symmetries develops in odd-even transformations.

As a feature characteristic to this cycle, nuclei of ^{13}C, ^{14}N and ^{17}O act as reactants and catalysts in the evolution of massive stars. Thus, ^{13}C is produced by the explosive CNO cycle in He flashes and in intermediate mass stars and novae. ^{14}N is produced in the CNO cycle in low and intermediate mass stars, and ^{17}O is produced in hydrogen's rich areas in the evolution of high-mass stars and the explosive nucleosynthesis of supernovae.

The ^{12}C nuclei used in the initial reaction is regenerated in the final one and hence acts as a catalyst for the whole CNO cycle. Stars of lower mass convert H to He via an alternative process known as the *proton-proton* chain. We can observe here the formation of galaxies, stars and first generation supernovae. Music transitions from a relative monotony, to a matrix sequence: the musical motif H, He/Li (CNO, Na, Mg), or, in other words, $E^{+1/3}$, C/c ($e^{+1/3}$ GF♯, F). Whether this is not the melodic flourishment of life sprouting in planets, we are few notes away for the self-organizing complexity in that direction.

VI ALPHA ELEMENTS PRODUCTION

The *Alpha process* elements or *α* elements are so-called since their most abundant isotopes are integer multiples of four, the mass of the He nucleus or "alpha" particle. The stable alpha elements are: C, O, Ne, Mg, Si, and S. Mg and Si are produced in carbon-rich zones in the explosive nucleosynthesis of supernovae. Other elements such as S, Ca and Fe are produced by the combustion of O in massive and intermediate stars and the deflagration of carbon in supernovae. All these elements follow one another in our musical passage, except by neon (Ne). Although Ne is abundant in the universe (see Figure 7, with Ne ranking 5th), and ^{21}Ne of terrestrial rocks has demonstrated its cosmogenic —cosmic ray— production, it is not part of the living organisms' essential nutrients. Musically pitched $A_{-1/4}$, ^{21}Ne is rather a dissonance in respect to the organic H-C harmonization, and therefore it is absent in Figure 9 and 10.

In an alternative process, exploding white dwarfs contribute to enrich the Li, Fe, Cu and Zn abundance. In the evolution of low/high mass stars, after C, O, Mg, Si and S, comes the production of elements Na, K, Ca, Mn, Fe, Co, P and Se musically translated into F, B$^{+1/4}$, F♯, E$^{+1/4}$, F, E$_{-1/4}$, C♯ and C. In the bass staff, K (potassium, the seventh most abundant element in the Earth's crust) formed in supernovae Type II, symbolizes the tipping point for this development after the combustion of He, C, Ne and O.

The asymptotic giant branch (AGB) is a period of stellar evolution undertaken by all low- to intermediate-mass stars late in their lives. Whether atoms of H, He and Li are produced since the beginning of the history of the universe, the elements numbered from 6 (C) to 28 (Ni) in the periodic table are produced in low- and high-mass stars; but after element 29 (Cu), natural elements are produced within post-AGB nucleosynthesis. Therefore, the last notes of the *Prelude* in Figure 5, ^{127}I, ^{77}Se and ^{95}Mo (C$^{+1/4}$, C, F), result from the collision between neutron stars. All of them are essential trace elements in the human body and other organisms living on Earth.

VII RELATIONAL DISTRIBUTION BY CYCLES AND PERIODS

When comparing Figure 6 (elements that compose the human body) with Figure 7 (elements ordered by their abundance in the universe), it is clear that the natural abundance of primary elements (H, C, N, O and Mg, but also Fe) is a key for organizing the components of life on Earth. However, natural abundance is insufficient to produce by itself the combinatory arrangements for the evolution of life, from matter in archean, to complex organisms. An equally paramount component for life evolution is a balance among isotopes increasing in their capacity for dynamically recombining themselves under particular conditions.[2]

In order to characterize the process of harmonic self-organization for the living organisms, we need to describe a *generator category* (Figure 9), a secondary category (Figure 10), and a last category for generalizing the complete system (abstractly summarized in Figure 11). Thus, Figure 9 displays the harmonic distribution of CHNOPS, as well as the musical translation of these elements as a chord composed by pitches E$^{+1/3}$, e$^{+1/3}$, G, C♯, F♯ and G♯, obtained from the respective Larmor frequencies correspondences. As Table 2. illustrates, this *chemical chord* has an essential role for the pre-biotic functions and biological structures.

Although we see a regular spiral in Figure 9 and 10, actually this regularity is logarithmically forced by the ordered subharmonics of protium (^{1}H): the light blue dots over the same back-vertical thin line (a binary logarithmic scale). The word *coil* is used here to intend the "slightly apart

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[2]In a broad sense, this concept of dynamical-proportional recombination was the key for the Miller–Urey experiment (1952) that simulated the conditions to test the hypothesis of the chemical origin of life on Earth. From then on, there is continuity in the experimental methods under the same hypothesis [7].

springings (with respect to the chroma)" described by [20, p. 324]. For this case we only use the analogy of a same object studied as an abstract structure mapping the same intervals. In contrast with [20], here we do not scale dimensions, but examine the same object through its parallax and preserving features substantial to the embedded whole set (Figure 9 to Figure 13).
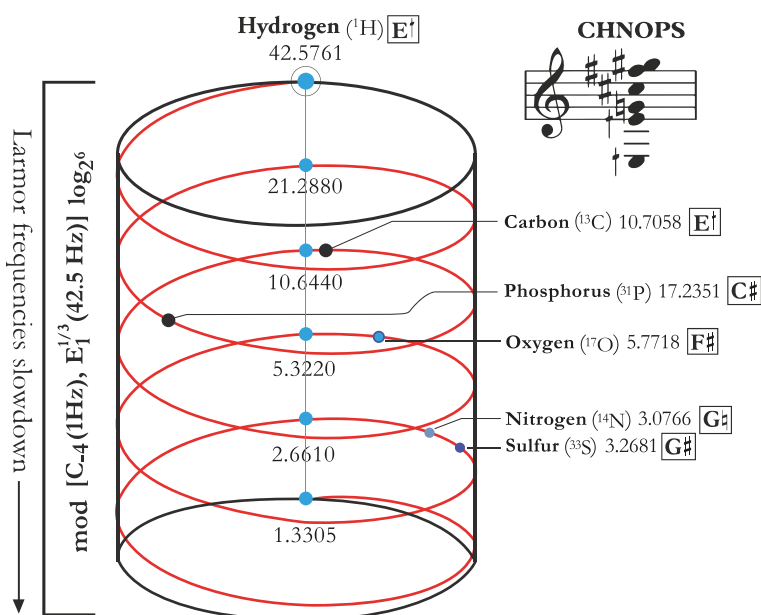

Figure 9: *An abstract coil-map for the Larmor distribution of the CHNOPS set of elements that constitute around 98.8% of the elements in the mass of plants and animals (see Table 2). The associated musical pitches in the pentagram analogously correspond to each of the same six elements. Height represents the Larmor frequencies increasing logarithmically ($\log_2$). Light blue numbered dots correspond to hydrogen on the vertical central line representing protium (^1H) subharmonics.*

The acronym CHNOPS, which stands for carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur, symbolizes the six most important chemical elements whose covalent combinations make up most of the biological molecules on Earth (see: Table 2).

Figure 9 and 10 map the Larmor frequencies at original rates in megahertz. The lateral edge to the left indicates that the complete height of the figure is modulated to the musical interval C_{-4} to $E^{+1/3}_1$ where the sub-indices refer to infrasonic grounds that can be converted into musical audible frequencies raised to the power of 2 to obtain a value n for each harmonic. This is a scale-free shape (distribution data preserving structure) whose degree distribution follows the power law originated from the $^1H/^2He$ nucleosynthesis as the elements production rate.

When observing Figure 10, hydrogen appears at the top as the generating tone, and iron appears at the bottom, at the end of the system. By connecting the beginning of the system with its end, the interval $E^{+1/3}$ to F couples an endless spiral which reflects the so-called *scale-free structure* (in the mathematical sense). This nicely matches the scale (in the musical sense) in Figure 4-A where ^1H is the highest pitch and ^{57}Fe is the lowest one. However, in this spiral (Figure 10) the aspects of distribution and hierarchy stand out in a way that cannot be captured in the musical row of Figure 4-A. Thus, Figure 10 is a finer device permitting to grasp at once the whole system's harmony.

It is also interesting to compare the universal *Mother chord* in Figure 3, with the CHNOPS chord in Figure 9. It is hard to achieve greater epistemic transparency for the comparison of

Table 2: *CHNOPS masses composing biological structures.*

| Element	Mass in plants	Mass in animals	Biological participation
C	11%	19%	Carbohydrates, lipids, nucleic acids, and proteins
H	10%	10%	Carbohydrates, lipids, nucleic acids, and proteins
N	1%	4%	Nucleic acids, proteins and lipids
O	76%	63%	Carbohydrates, lipids, nucleic acids, and proteins
P	<1%	<1%	Found in lipids and nucleic acids
S	<1%	<1%	Proteins and amino acids cysteine and methionine
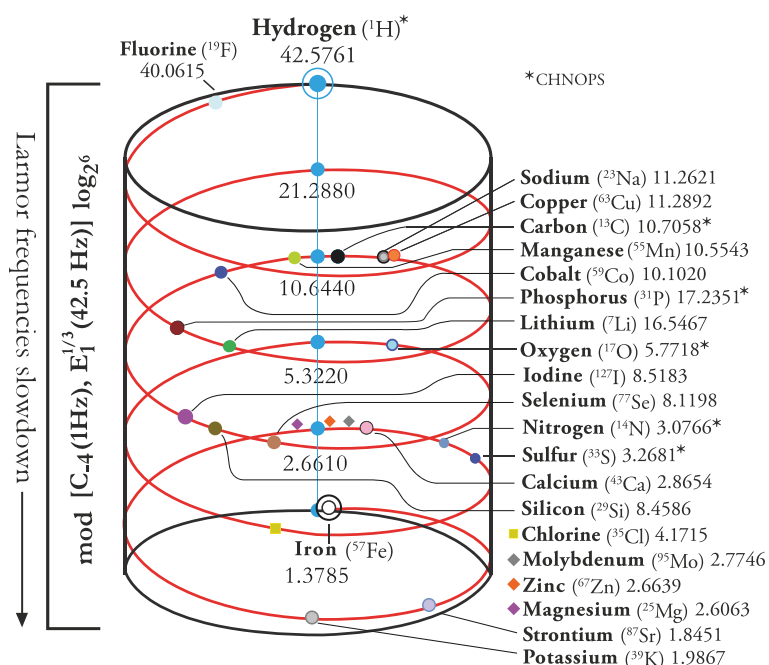
Figure 10: *The same coil-map for CHNOPS, now including 99.99% of the elements that constitute the whole mass of plants and animals. Not being an essential nutrient, fluorine (^{19}F) appears at the top of the coil, just before protium, as an exceptionally high Larmor frequency. This image is useful to better understand the section Fluorine peculiar features, below. Notice that number 1.3785 (the Larmor frequency of ^{57}Fe, back-bottom of this figure) slightly differs from 1.3305 (^{1}H fifth subharmonic in Figure 9). This tiny interval connects this spiral with its own modulation, from the top to the bottom, and from the bottom to the top.*

both structures, than in this kind of musical approach: in the first chord (Figure 3) there are wide intervals of octaves and fifths, while in the CHNOPS chord the octave-generating ratio is complemented by closer intervals of fourths, thirds and seconds. As if the material transit of the origin of atoms were led towards a higher ordering and sophistication of proportions, as in fact occurs along the evolution of matter in progressively complex forms until the emergence of the biological phenomena.
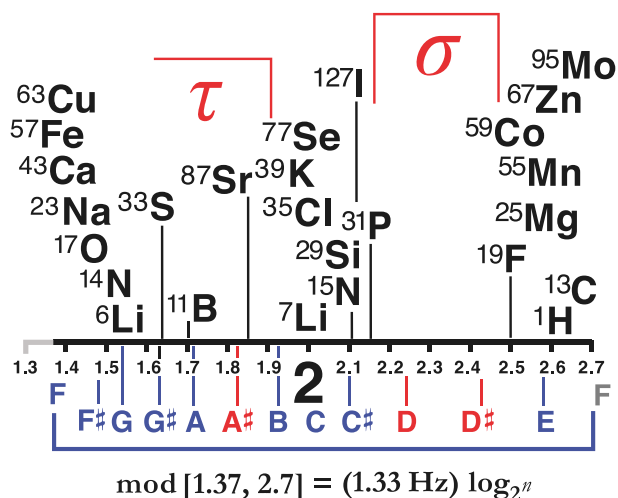
$$\text{mod}\,[1.37, 2.7] = (1.33\ \text{Hz})\,\log_2{}^n$$

Figure 11: *Harmonious distribution of the organic isotopes. The horizontal smallest value corresponds to the Larmor frequency of ^{57}Fe (1.3785 MHz); the highest value represents the Larmor frequency of ^1H constrained by the binary logarithm for the interval $[1.37, 2.7]$. The vertical upper arrangement of the chemical symbols represents a relative increasing heaviness of the elements. Special focus is on the three clusters of stable organic isotopes, harmonically distributed as a set of consonances. Mapping these data in the circle (see: Figure 13) reveals two clusters (not three), given that the rightmost and the leftmost ones compose indeed the same system. Greek letters σ and τ label two "gaps" or syncopations in this scheme, associated to relations disharmonious to the system.*

VIII   LINEAR DISTRIBUTION AND SYNCOPATION

While Figure 10 is helpful to see the included isotopes ordered by their harmonic distribution in a spiral model, and further Figure 13 shows the analogous data mapped in the circle, Figure 11 converts the original spiral (in Figures 9 and 10) into a cut thread: a straight line segment mapping the Larmor frequencies of the isotopes in the interval $[1.37, 2.7]$ Hz, in order to obtain a structural summary. The key to this compaction is still the binary logarithm, this time in the immediate number space around 2, where ^{7}Li is significantly located in perfect harmony with respect to ^{6}Li. In fact, it is inevitable to observe how this harmony resembles a simple C chord when also looking at ^{1}H, ^{13}C (i.e. composing the chord C-E-G); although since the beginning of the article, Figure 1 stresses the role of ^{1}H ($= E^{+1/3}$), i.e. not lithium, nor helium, as the source of this harmonic pattern (in accordance with previous section *The phenomenon of life and the tonality of E minor*).

Red segments σ and τ in Figures 10 and 11 denote two dissonant subsets that correspond to isotopes harmful to living organisms. The image can go on exhaustively, a purpose tackled in [16, Figure 1] which still deserve further in-detail explanation elsewhere. By now, Figure 12 captures the most basic notion of harmony and dissonance as interplay of proportions common in music and in organic and biomolecular chemistry.

Thus far is notorious fact from [16, p. 38] that arsenic (^{75}As), by its relation with hydrogen (^{1}H) produces the tritone 64 : 65. In twelve-equal temperament the tritone divides the octave exactly in its half as 12 : 2 semitones. Therefore it breaks off the classical harmonic proportion of 5 : 7 : 12, and collapses the musical consonance as it destroys the *diazeuctic* feature for such proportion.

The ancient term *diazeuctic* is both, technically correct and metaphorically meaningful. The Greek word zeugma ($\zeta\epsilon\tilde{\upsilon}\gamma\mu\alpha$) literally does mean "a yoking together". In fact, [2, p. 14] defines "*Diazeusis*, or *Diauzetikos* [as] 'separation', or 'tone of division' because it separates the Tetrachords".
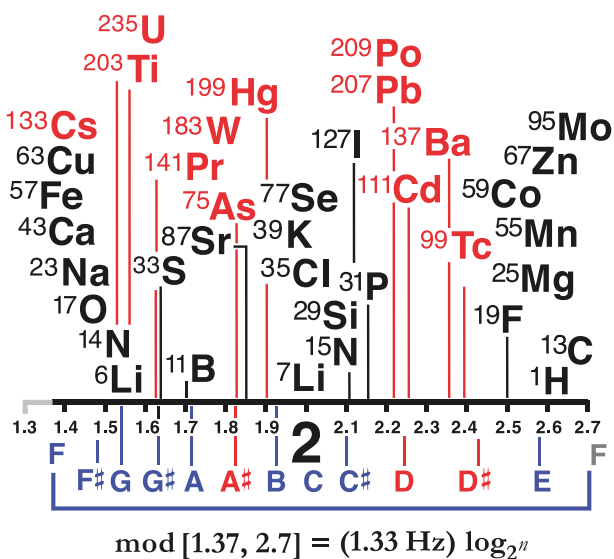
Figure 12: *The same data as the one shown in Figure 10, here adding in red the two dissonant or "toxic" syncopations (σ, τ) against the harmonic plot of the organic isotopes. The musical modulation for the whole set, in blue, matches the isotopes' values with the chromatic set (TET). Musical pitch classes A#, D and D#, in red, denote dissonances against the E/F harmonic root. Regarding the ^{133}Cs, ^{203}Tl, ^{235}U and ^{87}Sr "dislocated" positions see: Harmonic mimicry. . . (section below).*

Indeed, it separates but also unites the two main components of a harmonic collection. Then the diazeuctic —or *diazeugmatic*— feature of a tonal scale corresponds to the functionalized pair of the two ratios $(5:7):(7:12)$ as pivotal sources for the asymmetric arrangements of melody and harmony. This proportion of asymmetry is related to the aesthetic phenomenon of pleasantness in music in Western and Non-Western traditions.[3]

Besides, Figure 12 pictures for the σ segment right-limit, the interval hydrogen (^{1}H) to technetium (^{99}Tc) analogous to the dissonant interval of a seventh. Somehow, the context of As, Hg or W (subset τ) falls into the dissonant aura of the tritone, while the context of Pb, Cd or Tc (subset σ) falls into the dissonant aura of the seventh. Summarizing, one may pose the hypothesis that there exists a correlation between the aesthetic elaboration through the senses, and the evolutionary environment in which species —and culture — develop their aesthetic and cognitive capacities.

IX HARMONIC MIMICRY, AMBIGUITY AND HARMFUL ISOTOPES

Some heavy elements mimic other ones with basic biological functions. This condition is used by various living organisms, but it can also be a boundary condition. In particular, four stable isotopes stand out with this feature: ^{87}Sr, ^{133}Cs, ^{205}Tl and ^{235}Ur. Table 3 displays remarkable information as a biomusicological approach to this biochemical behavior.

Absorption of uranium by inhaling air or ingesting contaminated water and food usually occurs in very small amounts, and most ingested uranium is excreted during digestion [18, p. 564]. Under a biomusicological interpretation, ^{235}Ur lies under ^{6}Li as a subharmonic ratio 23 (i.e. the uranium's Larmor frequency 0.7840×8). This "harmonic mimesis" seems to be related to

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[3]For an approach to the aesthetic role of this subtle asymmetry in Mexican culture, see the concept of *Teponazcuauhtla* in [17]. For an approach to a comparable concept in Wabi-sabi Japanese aesthetics, see [23].

Table 3: *Four heavy isotopes that mimic essential nutritional elements, followed by the harmonic ratios that approximate their Larmor frequencies.*

Isotope	Element	Larmor freq.	Assoc. musical pitch	Mimicked isotope (*Mi*)	Larmor freq.	Harmonic ratios to *Mi*
^{87}Sr	Strontium	1.8451	A#$^{+1/8}$	^{43}Ca (Calcium, F#)	2.8654	9/7
^{133}Cs	Cesium	5.5842	F$^{+1/4}$	^{39}K (Potassium, B$^{+1/4}$)	1.9867	3/2
^{205}Tl	Thallium	24.5596	G	^{14}N (Nitrogen, G)	3.0766	2^3
^{235}Ur	Uranium	0.7840	G$^{+1/4}$	^{6}Li (Lithium, G$^{+1/4}$)	6.2654	2^3

the fact that ^{235}Ur appears in Fig. 11 beyond the G♯ limit, like a non-dissonant pitch within the whole set. Similarly, this also happens with highly poisonous ^{205}Tl, which, according with Table 2, mimics ^{14}N as its harmonic $\times 2^3$. In its turn, ^{133}Cs has a very close relation with ^{39}K according to the official standards [21, p. 87]:

> Absorbed cesium behaves in a manner similar to that of potassium. Both potassium and cesium are alkali metals that are distributed throughout the body as cations, becoming incorporated into intracellular fluids. Cesium has been shown to compete with potassium for transport through potassium channels and can also substitute for potassium in activation of the sodium pump and subsequent transport into the cell.

Strontium (^{87}Sr) corresponding pitch is $A\sharp^{+1/8}$, which makes an interval quite close to the tritone in respect to fundamental ^{1}H ($E^{+1/3}$). Actually, ^{87}Sr is near to ^{75}As in the toxic region τ. Albeit it also happens that ^{87}Sr first subharmonic (0.92255 Hz) spans a wide major sixth ($E^{+1/3}/C^{+2/3}$). Then strontium would be both, highly dissonant (toxic) and relatively harmonic (non-toxic), depending on its resonance context. This is why Figure 13 shows Sr in the τ border, and it is also symmetrically connected with D(σ) in the aug5$^{\text{th}}$ – dim4$^{\text{th}}$ strip limit. This hypothetical association begins to provide a more complete picture of how complex a survey into these resonances would be.

Strontium and calcium (^{43}Ca $= F\sharp$) are chemically similar —both are contiguous in the periodic table's Group 2A column, the alkaline earth metals— and Sr toxicity is mainly due to its mimesis in relation to Ca within the human body [12, 6]. Note that F♯ Major root chord is F♯ (A♯ - C♯). If written F♯ (A♯ - C$^{+2/3}$), its chemical translation is ^{43}Ca (^{87}Sr - ^{87}Sr first subharmonic). In addition to Sr, the dim5$^{\text{th}}$ – aug4th strip (in Figure 13) also points out a relationship with the other two *limit isotopes*: fluorine (^{19}F $= E_{-1/4}$) and boron (^{11}B $= A$), both with a complex or at least ambiguous relationship with harmony based on the hydrogen/carbon root ($E^{+1/3}$, $e^{+1/3}$).

Other *toxic elements* may also play this double role, depending on proportional arrangements and quantities. An example is tin: while ^{119}Sn, with musical pitch $B^{+1/4}$ is located near to the left of selenium (^{77}Se) in Figure 12, ^{117}Sn pitched $B_{-1/4}$ would be located near to the left of mercury (^{199}Hg). Besides, ^{115}Sn musical pitch is A, still in the critical harmonic limit. From this viewpoint, Sn is an ambiguous element in the limit of toxicity or beyond, highly toxic. Another case: ^{129}Xe (F♯) appears as harmless, while ^{131}Xe ($A^{+1/4}$) is mapped as highly poisonous.

In short, caution is in order not to overinterpret these schematic representations, and to take into account that even beneficial isotopes as essential nutrients can be highly harmful out of context and proportion: ^{6}Li, ^{7}Li, ^{14}N, ^{23}Na, ^{31}P, or ^{35}Cl are just some examples among other well-known isotopes that can illustrate this fact. An additional remark is to stress the point that the information here provided is of an experimental character, waiting for music theory to consolidate a pending dialogue with biology and biomedicine in order to reach robust and correct

interpretations of the whole data set for these relations. In any case, such a dialogue is necessary in the near future, to avoid fanciful and unfounded conceptions built around this perspective, and to review the kind of "resonance" this does mean for science.

X   TYPO IN MCL-2016

The beginning of this article starts with a promise to clarify and solve failures in MCL-2016, which are substantially due to a single typo: in MCL-2016 the label ^{57}Fe (iron) was mistaken by ^{19}F (fluorine), wrongly crossing their Larmor frequency numbers. The results after corrections provide much more coherent data in respect to the original hypothesis. MCL-2016 states that "iron has an interesting congruence with the diazeuctic feature of the diatonic/chromatic proportion $(12/8 : 3/2)$" and then the following statement appears:

> the iron ratio (15/8) is *responsible of magnetizing the tonal octave*, as it produces a harmonic loop successively leading to a self-similar return to the H-C generator interval $(1/1 : 2/1)$, then producing the *spiral of tonal harmony*.

The former section describes the diazeuctic feature and its role for building up melody and harmony in tonal music, rather from a modal inheritance [4, pp. 145, 159]. Then, potassium (^{39}K), not iron, performs the diazeuctic function, as it appears in Figure 13, making the axis I-V in symmetry with ^{1}H, but also related in asymmetry with the degrees IV and VI of the tonal scale. Besides, the iron ratio (here corrected as a sixth-tone, 49/48, alternatively measured as the irrational value of $\sqrt[36]{2}$) *is responsible of magnetizing the octave* (not the tonal TET octave) by connecting the harmonic spiral as shown in Figure 13, closing the harmonic coil-map in Figure 10 from the scale's bottom to its top.[4] In respect to the "self-similar return to the H-C generator interval", this feature also related to the concept of scale-free structure in Figure 10 elaborates in the *Discussion* section.

XI   FLUORINE PECULIAR FEATURES

As an assumption derived from the previous section, it would seem that fluorine should be eliminated from calculations useful to biomusicology, since it does not make part of the basic chemistry in living organisms. However, and considering its numerical values, the harmonic meaning of fluorine turns out to be interesting within this context.

First of all, let's mention some of the most outstanding features of this element. Fluorine is the smallest atom only after H^{32} and He^{37} (not to confuse these superscripts indicating atomic radius in picometers, with the superscripts to the left used to indicate the isotopes' numbers). The size of atoms gradually increases as we read the periodic table of the elements from top right to bottom left, but the sequence C^{75}, N^{71}, O^{64}, F^{60}, Ne^{62} has an evident pitfall at F^{60}. This peculiarity is in connection to the fluorine's high first ionization energy and electronegativity levels, and its direct combination with inert gases, and low dissociation energy of F2 molecule as compared to Cl2 and Br2 molecules in halogens homologous series. Whether this is quite evident for chemists, for musicologists this can be interpreted under Figure 10, where fluorine represents a diminished proportion regarding the hydrogen axis.

An issue put forward in MCL-2016, is fluorine (F, not Fe, as it is corrected here) by its extraordinarily high Larmor frequency 40.0615×10^6 Hz, almost-reaching the Larmor frequency

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[4]It is interesting to notice, also, that the ratio for the Larmor frequencies of ^{1}H divided by ^{57}Fe (i.e. 42.5761/1.3785) equals 30.8858, near to ^{3}He (32.4340), producing the sequence E$^{+1/3}$, F, C.

of ^{1}H (42.5761×10^6 Hz). This and other peculiarities of fluorine are exposed by [10], taking into account that ^{19}F "is considered to be the only stable isotope of the fluorine element in the Sun", which plays a major role in the stars nucleosynthesis for the production of elements. Again, these special traits, including its stability in the Sun and its exceptionally high Larmor frequency, seem to be related to the smallness of ^{19}F and its minimum mass excess (see *Conclusion* in [10]). For musical interests, we see, also, that ^{19}F lies in the limit of consonance beyond ^{59}Co, at the σ limit in Figure 11 to 13.

XII   Li AND K ISOTOPES ADJUSTMENTS

Another correction for MCL-2016 is to take into account both isotopes of lithium, ^{6}Li and ^{7}Li, and to distinguish them by their own harmonic features and functions. The first specialists to realize an exceptional distinction for both isotopes acting in the human body —mainly in brain physiology and biochemistry— were [8]. More recent research found that these isotopes play significant roles in different proportions of quantity and temporality through several functions of distinct organs and not exclusively in the brain's biochemistry [1].[5]

Within the methodological context in the last sections, and for the sake of biomusicology, it results that ^{6}Li ($G^{+1/4}$) with Larmor frequency 6.2654×10^6 Hz, musically interpreted as 9/7 (septimal major third), differs from ^{7}Li (C) with Larmor frequency 16.5467×10^6 Hz, musically interpreted as 8/5 (minor sixth, actually with selenium, ^{77}Se, as its first [sub]harmonic). In addition, a minor adjustment is Potassium's Larmor frequency represented as musical pitch, from $B^{+1/3}$ in MCL-2016, to more precise $B^{+1/4}$.

XIII   DISCUSSION

The hermeneutic opportunity to interpret a general harmony over the spin frequencies in NMR is far away from a fanciful neo-Pythagorean misunderstanding of data correlation and causality. The evidence presented so far does not cast a trivial similarity for an isolated physical source and a musical metaphor, but, instead, a systematic correspondence expressed in distinct domains of human knowledge and culture.

For this case, causality and correlation deploy reciprocal structuring related to a multifractal matter-energy construction as currently studied by the analysis of astronomical and cosmological data (see, for example, [22]); particularly if we keep in mind the origin of the elements in stellar nucleosynthesis and its bonds with planetary development and the emergence of life on Earth. It is no surprise, then, to detect a relevant pattern common to organic chemistry, biology, linguistics or biomusicology as a power laws development leading to a number of correlations in energy-matter self-organization under the Boltzmann constant. What is striking is the scant attention over this pattern from the philosophy of science and anthropology of language and music. This study proposes a breakthrough so that greater attention and discussion finally so be possible.

If MCL-2016 attempted to describe these phenomena by the use of dynamical systems, specifically with the employment of the Arnold tongues as an ideal modeling, the fact is that nor that article, not the present one would suffice to clarify important issues on this employment, but by successive articles covering in detail the whole state of the art. By now, to defend such an argument for depicting a "cascade" that entails a self-similar harmony which also includes chaotic regions opposed to the same harmony, is rather of speculative inspiration. Nonetheless, recent

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[5][1, p. 585](*Conclusion*): "The results show that apparently all the fluids and organs measured so far, i.e. serum, red blood cells, muscle, liver, brain and kidney, have a characteristic Li isotopic signature."

research in the field of astronomy seems to enhance this view, and to provide specific tools and partial conclusions for conceiving such a *hierarchical cascade* where matter/energy dynamics "allow matter to condense locally, resulting in a cascade of turbulence from large to small scales" [22, p. 12].

> This concept of hierarchical *subfragmentation* originates from Hoyle (1953) who studied the hierarchical collapse from galactic scale down to prestellar cores assuming isothermal collapse of a spherical cloud. In this model, we expect a fractal process of fragmentation in which two fragments are formed each time the scale of the parent is reduced by a factor of two.

If Hoyle's theorization on self-organization and self-similarity of massive clusters of stars still to be insufficient to depict an implicate order wholeness, it is also true that any astronomic cloud composed of massive clusters of stars follows the dynamical paths of a number of multi-harmonic trends and contrary forces, too, according to the thermodynamic principles. That is probably the reason for [22] to conclude that "We do not see evidence for any hierarchical structural signature of the cloud [. . .] implying that the structure of the cloud does not follow a simple fractal law along the scales but instead might be submitted to a multi-fractal process".

We may summarize this discussion in the precise upshot of validating the phenomena of consonance/dissonance, not by the traditional polarization of *subjective* and *objective*, but rather by the nuances of a physical stability or instability of one or more associated systems. A clear example of this, illustrated by Figure 13, is the detection of a whole structure for harmony, by definition composed by its own hierarchies, and a complementary structure for disharmony (in this scheme decomposed by sub-hierarchies σ, τ, dissonant or "toxic" for their biomusicological implications). Further research may delve into the concept of harmony and harmonic cycles in the stellar nucleosynthesis and massive self-organization from [5] to [22] contexts.

An enormously tempting approach to the general hypothesis proposed here is the study of the intervals conceived, not uniquely as pitch classes, but as musical lengths (like Figure 5 suggests). Therefore, the analogy between pitch class and rhythmic pattern, as well as between chord and counterpoint, presents a new challenge. Notwithstanding the method is anticipated to be relatively simple —pure analogy for the time-span composition—, this advance is left for further investigation.

It would of course be interesting to recapitulate certain medieval appreciations made by the alchemists who believed it was possible to turn lead into gold, and by their contemporaries, the musical theorists who called for banning the *diabolus in musica* (the tritone), as part of a human history of physical and symbolic epistemics. Although today the arguments and facts on these issues are completely different, there is a history of toxicity and nutrition in both senses, aural and chemical, that perhaps would be worth recovering for their intuitive configuration.

Lastly, it should be noted that Figure 13 solves the problem so as not to omit some of the 25 tones in Figure 4-A, but to evaluate the particular utility of each one of them, considering differences less than a third and a quarter tone. In any case, the greatest interest would be on the values and relationships between the frequencies, and not necessarily on subsuming them into the tonal scheme within the quarter tone limit.

If the title "Music as Carbon Language" may continue to be acceptable, it is because carbon plays a central role in harmonizing hydrogen within subsequent proportionalities composing the foundations of self-organizing molecules and triggering the evolution of organisms and their adaptability to an environment chemically featured by homologous relations. Nevertheless, and in order to accomplish the promise of non-dispersion for this study, a more specific research for the
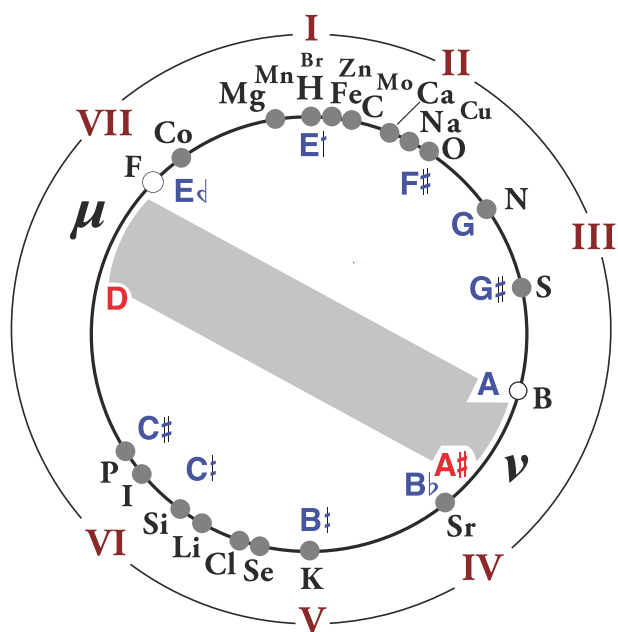
Figure 13: *The coil-shape in Figure 10, here seen from above. The harmonic cycle for the organic isotopes set and its musical analogy are in blue. Pitches D and A#, in red, denote musical dissonances in the harmonious context ^1H, ^{39}K: major seventh, diminished fifth (tritone) and augmented fourth. Note that minor second is rather irrelevant or non-existent as a dissonance. Fluorine (F), boron (B) and strontium (Sr) appear almost upon the limit of harmony or non-toxicity in biomedical terms.*

polyclinic structures of carbon and more extended structures in organic chemistry still pending for a further development in the domain of a new comparative musicology.

XIV   CONCLUSIONS

The periodic table of the elements facilitates the understanding of at least two new *musicological texts*: one that explains the harmonious organization of music with respect to biochemistry, and the other one eloquent about the astronomical harmony emanated from stellar nucleosynthesis cycles.

The specific Larmor frequencies of the atomic nuclear precessions have not a random distribution, at all. On the contrary, the most authentic concept of harmony relies on the kind of distribution of energy from the nuclear spin, altogether with other forces making up the emergence of molecules and compounds performing physical and biochemical complexity.

For the interests of biomusicology, we may establish that the principle of proportionality in music is homologous to the trophic balance principle for the living organisms. Both principles are conformed onto a same dissipative equilibrium. A possible contribution to the natural sciences from this perspective is the translatability of one into the other. Since translation processes are always forms of expansion and digression of the input signifiers, for the same reason they throw out new emerging output information. For this, it is necessary to develop a more precise theory of translatability from different lines of interdisciplinary studies.

Since the last years of the 20th century a growing tendency to create music is observable by using data intuitively taken from abstract structures that portrait genetic codes, nitrogenous bases,

proteins, molecules, crystals and atoms. It has also been tried to interpret the spectral chromatic code of the chemical elements as ranges of colors translatable into musical scales (although it would be much more appropriate, in the latter case, to produce musical timbres, not pitch class-scales, due to the type of analogy in question). Interestingly, from now on, it seems feasible to translate musical traditions —melodies, harmonies, rhythms, timbres— into genetic codes, bases, proteins, molecules, crystals and atoms. This is also a new challenge for the interdisciplinary reinforcement of musicology in the field of musical self-similarity.

In the educational field, from basic education to the study of complex patterns in scientific specialization, listening to the periodic table of the elements for each of its isotopes is a promising didactic and technical perspective. At the same time, a thorough judgment should strengthen a bias to rigorously separate metaphor from analogy.

XV ACKNOWLEDGEMENTS

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XVI   APPENDIX

A. Table of the specific Larmor frequencies employed (digits restricted to first four decimals), listed by the consecutive order of the elements in the periodic table.

Isotope	Element	Larmor freq. (MHz)	Assoc. musical pitch class	Isotope	Element	Larmor freq. (MHz)	Assoc. musical pitch class
^{1}H	Hydrogen (protium)	42.5761	E$^{+1/3}$	^{33}S	Sulfur	3.2681	G#
^{2}H	Hydrogen (deuterium)	6.5357	G#	^{35}Cl	Chlorine	4.1715	C$^{+1/4}$
^{3}H	Hydrogen (tritium)	45.4134	F$^{+1/3}$	^{39}K	Potassium	1.9867	B$^{+1/4}$
^{3}He	Helium	32.4340	C	^{43}Ca	Calcium	2.8654	F#
^{6}Li	Lithium	6.2654	G$^{+1/4}$	^{55}Mn	Manganese	10.5543	E$^{+1/4}$
^{7}Li	Lithium	16.5467	C				
^{9}Be	Beryllium	5.9827	G	^{57}Fe	Iron***	1.3785	F
^{11}B	Boron	13.6601	A	^{59}Co	Cobalt	10.1020	E$^{-1/4}$
^{13}C	Carbon	10.7058	E$^{+1/3}$	^{61}Ni	Nickel	3.8046	B
^{14}N	Nitrogen	3.0766	G	^{63}Cu	Copper	11.2892	F$^{+1/4}$
^{15}N	Nitrogen	4.3157	C#				
^{17}O	Oxygen*	5.7718	F#	^{67}Zn	Zinc	2.6639	E$^{+1/4}$
^{19}F	Fluorine**	40.0615	E$^{-1/4}$	^{77}Se	Selenium	8.1198	C
^{23}Na	Sodium	11.2621	F	^{79}Br	Bromine	10.6670	E$^{+1/3}$
^{25}Mg	Magnesium	2.6063	E	^{87}Sr	Strontium	1.8451	Bb
^{29}Si	Silicon	8.4586	C$^{+1/4}$	^{95}Mo	Molybdenum	2.7746	F
^{31}P	Phosphorus	17.2351	C#	^{127}I	Iodine	8.5183	C$^{+1/4}$

Note 1: the specification of pitch classes is restricted to the limits of 1/2, 1/3 and 1/4-tone. The table omits smaller differences for schematic efficiency in relation with the classical twelve-tone equal temperament.

Note 2: gray rows indicate isotopes that are unrelated to the basic chemistry in living organisms. They are included because of their structural role in basic harmonicity for the whole sequence of isotopes, from its beginning.

* According to [24, pp. 320–321], in contrast to the natural abundance of ^{16}O and ^{18}O, ^{17}O is the only oxygen nuclei with a magnetic moment that can be detected by NMR. See the *Introduction* for further explanation about the isotopes even-numbered without detectable Larmor frequency.

** The exceptional high Larmor frequency for fluorine is related to the exceptional smallness of its atomic radius, as described in this article.

*** Human blood and tissues bear isotopes ^{54}Fe, ^{56}Fe and ^{57}Fe (see: [14]), however, ^{57}Fe is the only iron nucleus detected by NMR. See the *Introduction* for further explanation about the isotopes even-numbered without detectable Larmor frequency.

B. The same than table A, here with the primary tonal functions colored.

Isotope	Element	Larmor freq. (MHz)	Assoc. musical pitch class	Isotope	Element	Larmor freq. (MHz)	Assoc. musical pitch class
^{1}H	Hydrogen (protium)	42.5761	E$^{+1/3}$	^{33}S	Sulfur	3.2681	G#
^{2}H	Hydrogen (deuterium)	6.5357	G#	^{35}Cl	Chlorine	4.1715	C$^{+1/4}$
^{3}H	Hydrogen (tritium)	45.4134	F$^{+1/3}$	^{39}K	Potassium	1.9867	B$^{+1/4}$
^{3}He	Helium	32.4340	C	^{43}Ca	Calcium	2.8654	F#
^{6}Li	Lithium	6.2654	G$^{+1/4}$	^{55}Mn	Manganese	10.5543	E$^{+1/4}$
^{7}Li	Lithium	16.5467	C				
^{9}Be	Beryllium	5.9827	G	^{57}Fe	Iron	1.3785	F
^{11}B	Boron	13.6601	A	^{59}Co	Cobalt	10.1020	E$_{-1/4}$
^{13}C	Carbon	10.7058	E$^{+1/3}$	^{61}Ni	Nickel	3.8046	B
^{14}N	Nitrogen	3.0766	G	^{63}Cu	Copper	11.2892	F$^{+1/4}$
^{15}N	Nitrogen	4.3157	C#				
^{17}O	Oxygen	5.7718	F#	^{67}Zn	Zinc	2.6639	E$^{+1/4}$
^{19}F	Fluorine	40.0615	E$_{-1/4}$	^{77}Se	Selenium	8.1198	C
^{23}Na	Sodium	11.2621	F	^{79}Br	Bromine	10.6670	E$^{+1/3}$
^{25}Mg	Magnesium	2.6063	E	^{87}Sr	Strontium	1.8451	B$\flat$
^{29}Si	Silicon	8.4586	C$^{+1/4}$	^{95}Mo	Molybdenum	2.7746	F
^{31}P	Phosphorus	17.2351	C#	^{127}I	Iodine	8.5183	C$^{+1/4}$

Pink gamut : related to the tone generator and its doublings ("octaves").

Orange : related to the third functions.

Green : related to the fifth.

Cyan : related to the sixth.

Blue : related to the (small) tone size; also associated to the E minor key signature.

Brown : Boron is the only element associated to the fourth.

Yellow : 1/6-tone.

White: tritone (see section *Harmonic mimicry, ambiguity and harmful isotopes*).

C. Plot for the isotopes in tables A/B, comparing TET with the specific Larmor frequencies modulated within the arbitrary musical pitch range from 0 to 1800 Hz.
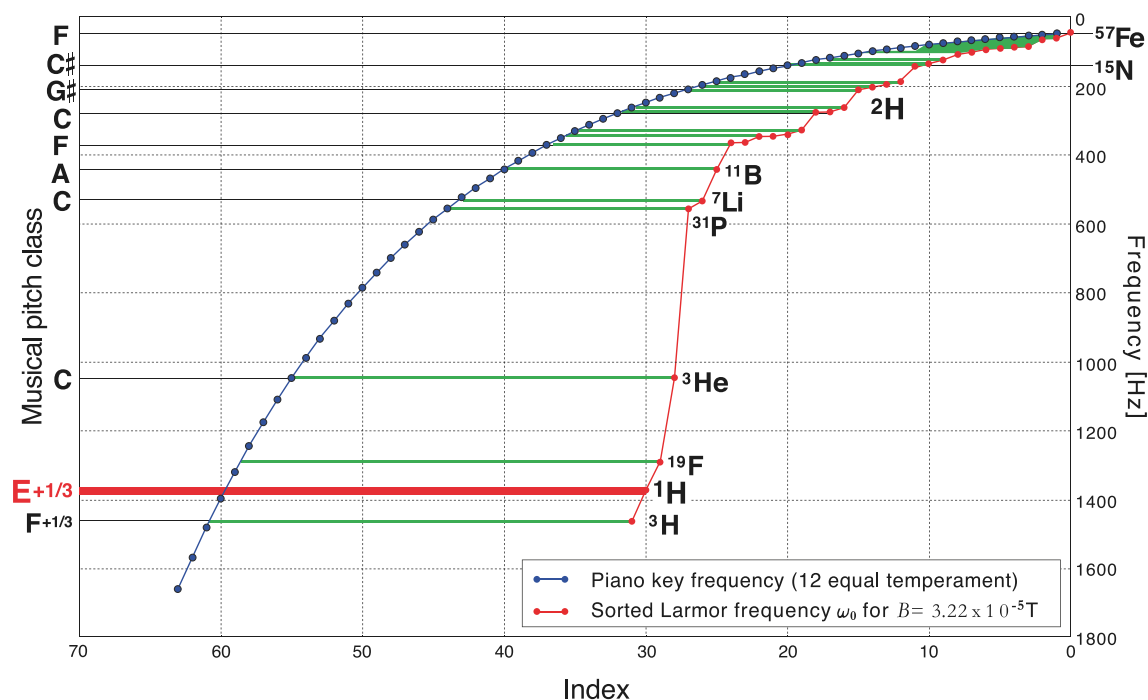
This graph synthesizes the harmonic structure of tables A/B, encompassing the hierarchical plot key to the organic and prebiotic compounds. The blue dots describe the logarithmic succession of semitones of the equal temperament along five octaves. By contrast, the red dots indicate the 32 tones (isotopes mapped onto their specific Larmor frequencies) listed in the A/B tables. The leftmost column displays the musical pitch class correspondences that make visible a harmonic pattern by layers. For the values implying the formula $\omega_0 = \gamma \mathbf{B}_0$, see the article's *Introduction*.

The graph is upside down with the aim of depicting this harmonic structure according to the traditional musicological criteria; a concept that throughout this article is named as *normalization* in reference to the human ambient sonority, of a molecular-source nature (with low fundamental tones), in contrast with the hyper-sonority of the fundamental particles in which higher frequencies give rise to consecutively lower frequencies (i.e. lighter elements as the source of heavier ones; see also: *Introduction*).