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A NEW APPROACH TO ANALYZING THE MUSICAL SCALES OF TRADITIONAL VOCAL POLYPHONY

There is a wide diversity of forms of oral tradition polyphonic vocal music. Each tradition has a sound identity that can be recognized by ear, because of the specific features of its interval organization and the combinations that result from its blending beats – as well as by the sound qualities of the voices themselves.

The research that we present here is based on the constant interaction between listening and spectro-temporal acoustic analysis, one questioning the other and vice versa[1].

1. Some Remarkable Sound Characteristics of Traditional Polyphonic Music

Singing in the open air promotes vocal emission which is rich in harmonics. The sensation of a full sound is reflected in acoustic analyses by great spectral richness, up to 8000 Hz and more, thereby making it possible to seek high-level harmonic coincidences[2] (Fig. 1).

The second important point for our approach is frequency stability. As a „living" musical instrument, the voice has an intrinsic short-term instability[3] visible in analyses, which we perceptively ignore because it is remembered as a characteristic of the vocal source. Without vibrato, the voices of traditional singers are most often perceived as being „straight", and thus stable.

Long-term frequency stability allows us to compare the harmonic spectra over an entire piece. The stability that we observed in the singing of the Aka Pygmies is all the more remarkable because the group of singers includes all of the members of the encampment, with no distinctions (Fig. 2).

In other cases, the singers do not remain at the same pitch: they most often go progressively sharp, as we can see in the Vietnamese song (Fig. 3). This effect is not a drawback in our approach because the relative stability between the parts is maintained thanks to the common harmonics which constitute the musical frame of reference of a polyphonic piece.

2. The Notion of Common Harmonics in Melody

The notion of common harmonics is part of a long history, i.e. the use of proportions. Prior to the use of measurements which are expressed with respect to an absolute reference – the meter for lengths, the 440 Hertz tuning fork for frequencies – the common practice of engineers, architects, and stringed-instrument makers was based on the comparison and measurement of the **ratios** between the various quantities involved. The long history of Western music theory is based on comparisons of the length of strings producing the intervals of the musical scale: the ratio of 2 to 1 for the octave, the ratio of 3 to 2 for the fifth as seen from the numerous illustrations of musical treatises.

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[1] It goes without saying that the technical qualities of the recording support should be taken into account before any acoustic measurements.

[2] Particularly with the Audiosculpt software (@Ircam) which offers numerous interactions between the visual representations coupled with tools for filtering and synthesis of the harmonic spectrum.

[3] Very short-term instability. Mentioned in the abstract, on the order of 25 cents (Kastelengo, 2015: 265, sound 6.5).

When violinists tune the *E* string to the *A* string, to tune the fifth interval between these two strings, they carry out a similar comparison operation by eliminating the beats due to the common harmonics: they unconsciously practice very precise arithmetic. The sound phenomena that occur during the combination of the two periodic sounds are clearly audible for musicians and visible on an acoustic analysis (Fig. 4a, 4b).

Let us consider for example the ascending fifth *A3–E4*. The two sounds have in common the *E5* which is harmonic 3 of *A3* and which is also the octave of *E4*. On a sonographic analysis in which the scale of frequencies is linear, the common harmonic of the two successive sounds is visible, and thus identifiable right away, with no calculation. Let us add that the precision is all the greater when the number of harmonics is large because the frequency difference increases with the rank of the harmonics[4]. In musical practice, however, the more the voices are rich in harmonics, the more the adjustment of the intervals is a perceptible effect taken into account by the singers, an effect that influences the overall perceived quality.

For the researcher, the method of visual evaluation of intervals by seeking common harmonics – which we have long practiced – sometimes involves surprises, as seen in Figure 5 (audio. 1).

This is a sonogram of a separated part of a polyphony recorded in re-recording by Simha Arom[5]. Three separated melodic segments appear against the backdrop of the rhythm (clapping). By numbering the harmonics starting from the lowest one (H1), we observe in the middle of the emission a horizontal coincidence between harmonics 7 and 8 of two successive sounds of the melody. Although the voice moves a little bit, it is statistically clear that it is indeed the vocal realization of the interval 8/7[6]**.** This interval is not found in Western culture. Let us add that the path of the horizontal line going through the two harmonics 8 and 7 allows us to estimate the inevitable instability of the voice – very low for this singer – while confirming that it is indeed the harmonic ratio 8/7, which occurs again in each segment of the song.

3. Common Harmonics in two-part Polyphony

As soon as two parts start singing simultaneously, their frequencies come together, producing various acoustic phenomena: beats, roughness, and differential sounds. Most often the parts are mixed in the recording and it becomes difficult to access the musical scale that they come from. We present here two examples of duets for which the spectrographic image offers new interpretation possibilities based on the observation of common harmonics.

3.1. Traditional Song from Vietnam (Fig. 6, audio ex. 2).

The analysis of the duet of young boys is a good example of the diversity of musical situations in polyphony. In each of the four parts of the song we hear successively:

a- The alternating entrance of each voice V1 and V2 in solo.

b- The union of stable voice V1 and voice V2 which is close in frequency, evolving rapidly.

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4 For the common harmonics see: Kastelengo, 2015: 55, 401.

5 This example is part of the research carried out with Susanne Fürniss on the study of the interval system of the Aka Pygmies based on sound archives constituted by Simha Arom from 1971 to 1986. The results are now in publication and will appear in a publication of the AAWM association.

6 In the numerical expression of the intervals, it is customary to put the larger number in the numerator to obtain a result greater than 0.

c- The simultaneous stabilization of V1 and V2 on a fifth interval for four seconds.

d- The unison of the two parts on the preceding low sound for 14 seconds, interrupted by the rapid evolutions of voice 2.

The spectral analysis also reveals a remarkable sound achievement. The two singers obtain, through the controlled use of the two formant zones of the vowel [a], the reinforcing of harmonics 3 and 6 of the low sound, such that we hear the permanence of a fifth interval, even when the two voices are in unison[7].

3.2. **Example of a Traditional Duet of Singers from the Island of Flores (Lamaholot)**

(Fig. 7, audio ex. 3)

In this style of duets, the voices alternate between moments where they continue, making between them very small intervals, difficult to identify by ear, and moments of stability on an interval of the harmonic series or in a unison.

The control of the beats and the variable „roughness“ on the held notes is appreciated by the tradition bearers and is part of the mastery of the best singers, but the „score“ of each voice is practically impossible to extract because the intervals between the two parts are very small and of very short duration.

It is the visual identification of the spectro-temporal analysis of a harmonic common to 13 occurrences of the same frequency which gave us the key for accessing the main underlying intervals and also the framework interval of ratio 7/5. This common harmonic, only 4 kHz from it (fig. 7) goes through harmonic 6 of the sounds indicated by numbers 1–7–11; it also goes through the harmonic common to the two sounds of the minor third chord 6/5: sounds number 2–5–8 and through harmonic 7 with a melodic uncoupling of one of the two parts in unison, visible at numbers 3, 4, 6, 9, 10, 12, 13.

4. Polyphonies in 3 or More Parts: Example of Polyphony of the Aka Pygmies

When listening to the sound example corresponding to Figure 5 (audio ex. 1), all musicians hear a major tone, „a slightly large one“, but acceptable with regard to the usual variability of vocal production, or because of the minor flaws due to the recording as can be observed with records.

But here, the technical quality of the recordings is not in question[8]. Our analyses attest to the reproducibility of the stability of the singers. Given that the musical structure is periodic, we can superimpose several realizations of the same segment by transparency. As we can see in Figure 8, the two singers have impressive reproducibility: all of the intervals, 9/8, 8/7, and 7/6 are perfectly controlled from one period to another.

Most often these are listening „misunderstandings“ of musicians who have in memory the sounds of the tempered scale which are responsible for erroneous interpretations when the measurements of intervals in cents move too far away from the division of the octave into twelve equal parts.

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[7] The adjustment of the vocal formants on the harmonics of the sung sound is used in many vocal traditions. (Kastelengo, 2015: 465–470).

[8] Recording on Nagra. This acoustical study benefits not just from the technical quality of the support, but also from the re-recording method which offers the possibility of accessing the separate parts of the polyphony. We would like to thank Simha Arom for giving us access to his archives.

5. Overview and Conclusion

To understand all interval systems, we must take another look at the harmonic series (figure 9). Most traditional polyphonic music stabilizes vertically over the first intervals of the harmonic series: the octave H1–H2; the fifth H2–H3 and the fourth H3–H4, „framework" intervals of which the common harmonics are easily audible and measurable[9].

The presence of harmonic 7, ignored in Western musicology although it is an integral part of Pygmy music and the duets from Flores, orients on the choice of the other parts of the harmonic series, such as that found between harmonics 6 and 12, where we see that the fourth H6–H8[10] [has as an intermediary H7. Continuing the process, we note that the fifth H8–H12 is composed of four intervals of decreasing value: the major tone 9/8, the minor tone 10/9[11], and two others which are still smaller, 11/10 and 12/11. These intervals are found in several types of music and in particular in Georgian music. Figure 10 shows the analysis of the coda of a liturgical chant recorded in 2019[12] which offers two remarkable points: the presence of the so-called „neutral" third and small intervals which are difficult to interpret because of their smallness and the uncertainties of measurement.

The sequence is harmonically contained within a stable 3/2 fifth interval from A to B

In A, the middle part shares the fifth in two intervals, a major tone 9/8 and a fourth 8/6.

In B, the middle part goes lower and the fifth interval is shared in two equal intervals which sounds like a strange third. The values of these two intervals are 301.5/246 = 1.225 and 246/200.1 = 1.229. It is easy to interpret. Between the major third 5/4 (here 10/8) and the minor third 6/5 (here 12/10) there is an intermediary interval, the 11/9 third (neutral third).

In C, the top part goes down; the other two voices come together to form with the first a single neutral third.

In D, the three parts are in unison, musically sharing the starting fifth, which is underlying in harmony in a minor third (6/5) and a major third (5/4)

This musical excerpt borrows the intervals of the harmonic tranche 8/12 and we can expect that the small melodic intervals are also within the same system, which the reader can verify.

Such melodic refinements are very far from the numerical speculations that encumber several books on acoustics. They are directly observable on the spectral analyses by the seeking of common harmonics and they are found to be interpreting the calculations in the system that covers them. Above all, they reflect the exceptional skill of the instrumentalists and singers who are part of a millennial tradition and who make adjustments by ear.

Many thanks to Frank Kane for the English translation.

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[9] Some, like those of the „Bunun" of Taiwan, chose the octave, the fifth and the minor third: see Wu Rung Shun, 1996.

[10] The numerical expression of the fourth is the quotient of the two harmonic numbers that surround it. We see indeed that the ratio of 8 to 6 is the same as 4 to 3.

[11] These two intervals together form the „pure" major third of several tuning systems of the *Renaissance* music. See Duffin (2006).

[12] Recording of the singing of Tornike Shkiereli at the home of Simha Arom in 2019; re-recording technique.

Audio Examples

1. S. Arom personal archive; kokoyandongo – 1979.11; track 18; singer: Ndole
2. Chant de travail alterné, xi; Viet-Nam [Nùng An] LangTrên, province de CaoBang. «Les Voix du Monde» III n°16, CNRS-Musée de l'Homme, Paris 1996.
3. Dana Rapport personal archive; Flores Island; „Tanjung-Bunga" district; 2007.

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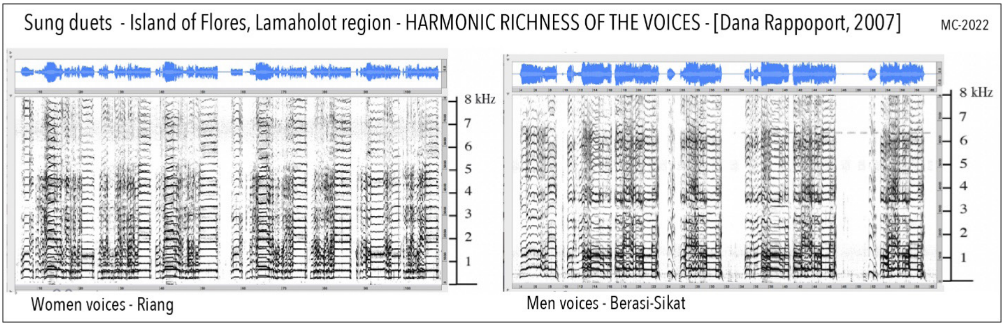
Duffin, R. W. (2006). Just Intonation in Renaissance Theory and Practice. *Society for Music Theory,* 12 (3), 1–16. http://journals.openedition.org/ethnomusicologie/2604

Leipp, É. (1971). *Acoustique et musique.* Paris: Masson

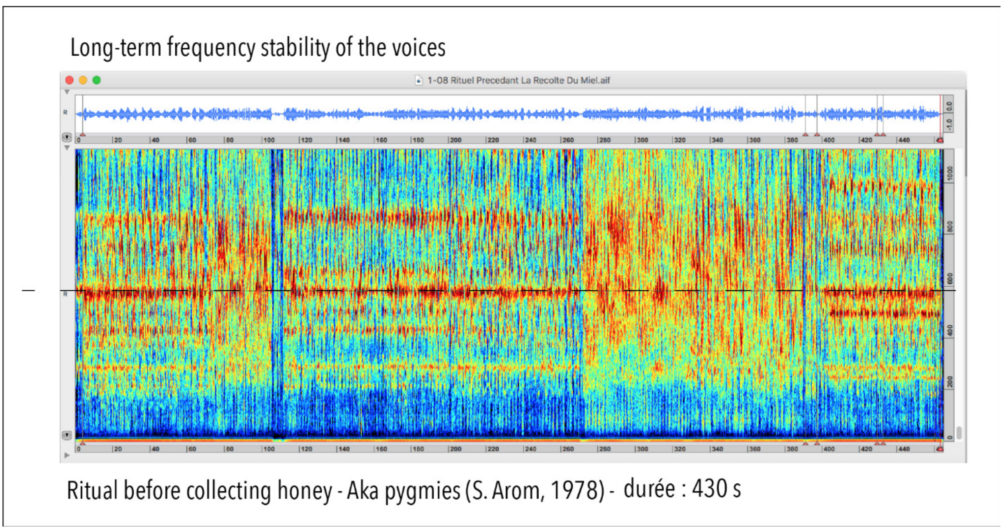
Rappoport, D. (2011). 5. To Sing the Rice in Tanjung Bunga (Eastern Flores), Indonesia 103 Dana Rappoport. In B. Abels (Ed.), *Austronesian Soundscapes: Performing Arts in Oceania and Southeast Asia* (pp. 103–132). Amsterdam: Amsterdam University Press. https://doi.org/10.1515/9789048508112-008

Wu Rung Shun. (1996). *Tradition et transformation: le pasi but but, un chant polyphonique des bunun de Taïwan.* Nanterre: Thèse, Paris Nanterre University

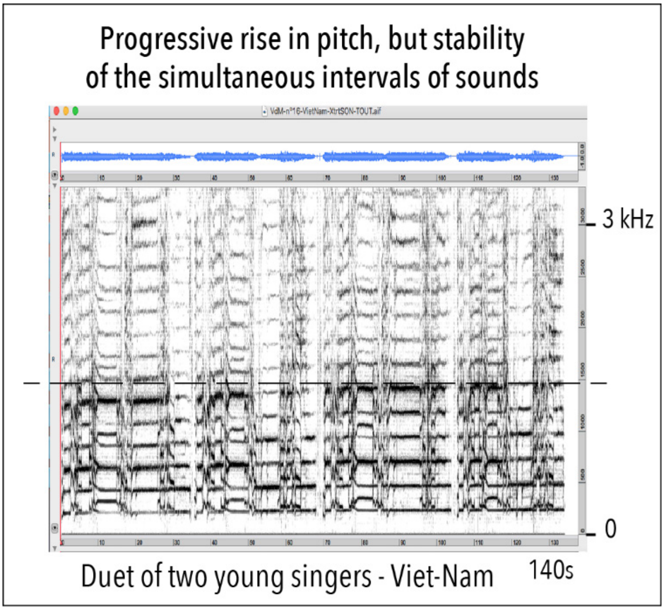
სურათი 1. ქალისა და მამაკაცის სასიმღერო ხმის ორი ნიმუშის ანალიზი.
Figure 1. the analysis of two examples of men's and women's singing voices.



სურათი 2. 7'40" ზომის ფრაგმენტის სპექტროგრაფიული ანალიზი, რომელზეც სიმღერის ერთ-ერთი ხარისხის ნიშანი 0-ის მაჩვენებლის პარალელურია შესრულების დაწყებიდან დასრულებამდე.
Figure 2. The spectrographic analysis of a 7'40" piece on which a reference mark of one of the degrees of the song stays parallel with the reference 0 from the beginning to the end of the performance.

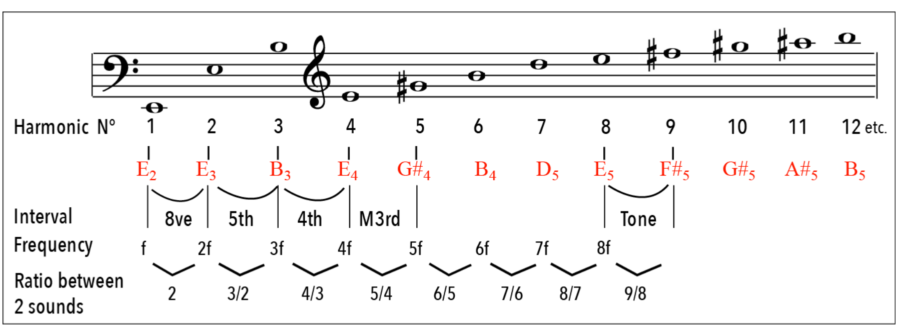


სურათი 3. ეს ეფექტი არ არის ჩვენი მიდგომის ხარვეზი, რადგან ნაწილებს შორის შედარებითი სტაბილურობა შენარჩუნებულია საერთო ობერტონების წყალობით, რომლებიც ქმნიან მრავალხმიანი ნაწარმოების ჩარჩოს.
Figure 3. This effect is not a drawback in our approach because the relative stability between the parts is maintained thanks to the common harmonics which constitute the musical frame of reference of a polyphonic piece.

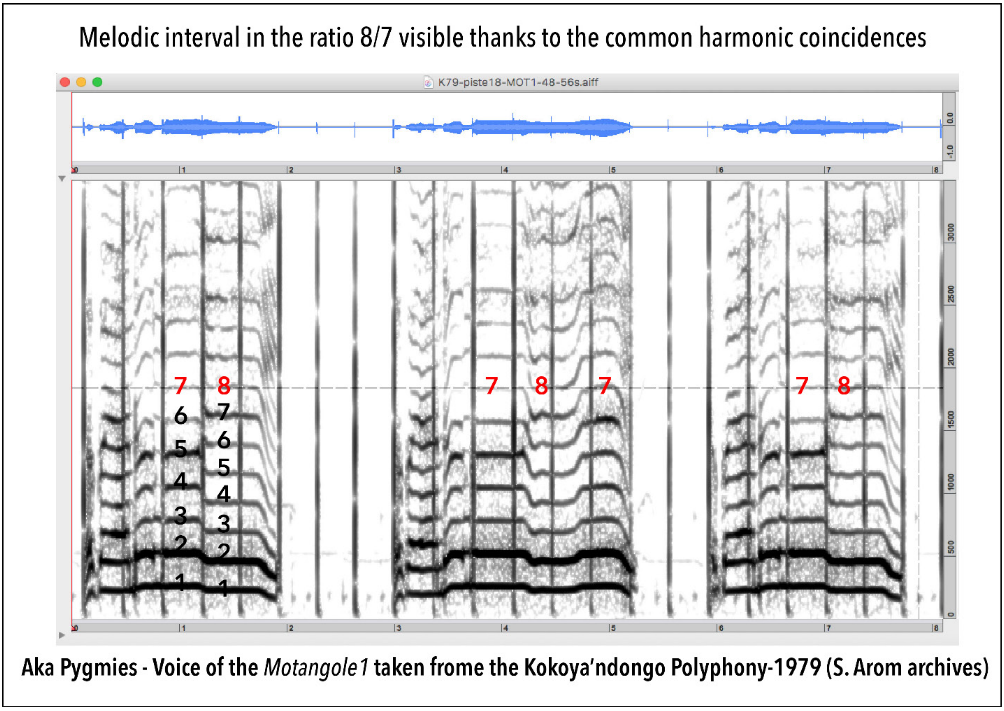


სურათი 4ა, ბ. ხმოვანი მოვლენები, რომლებიც თავს იჩენენ ორი პერიოდული ბგერის შერწყმისას.
Figure 4 a, b. The sound phenomena which occur during the combination of the two periodic sounds are clearly audible for musicians and visible on an acoustic analysis

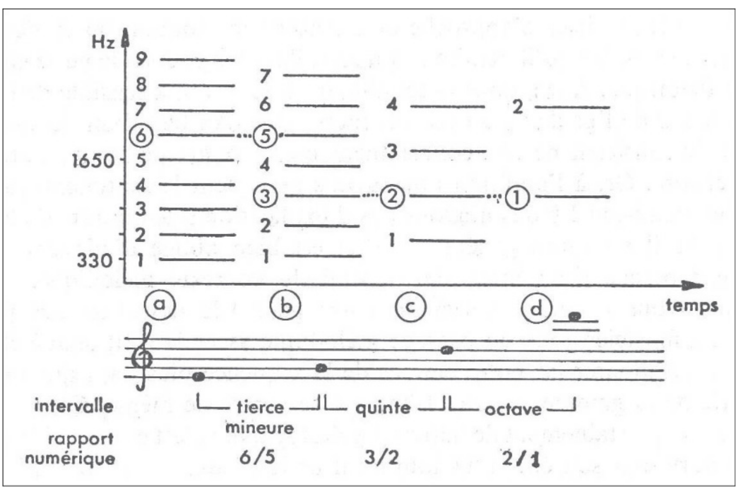
სურ. 4a
Fig 4a



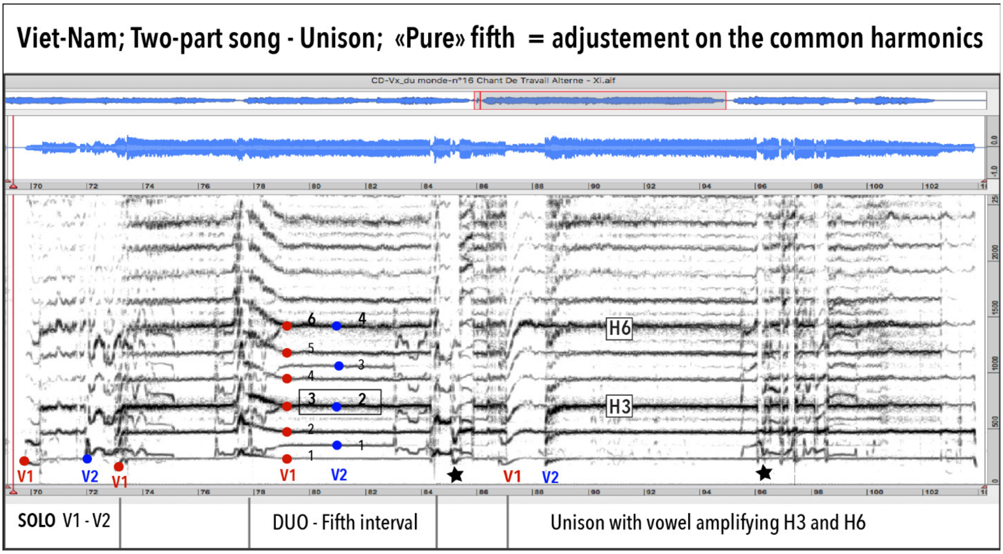
სურ.4b
Fig. 4b



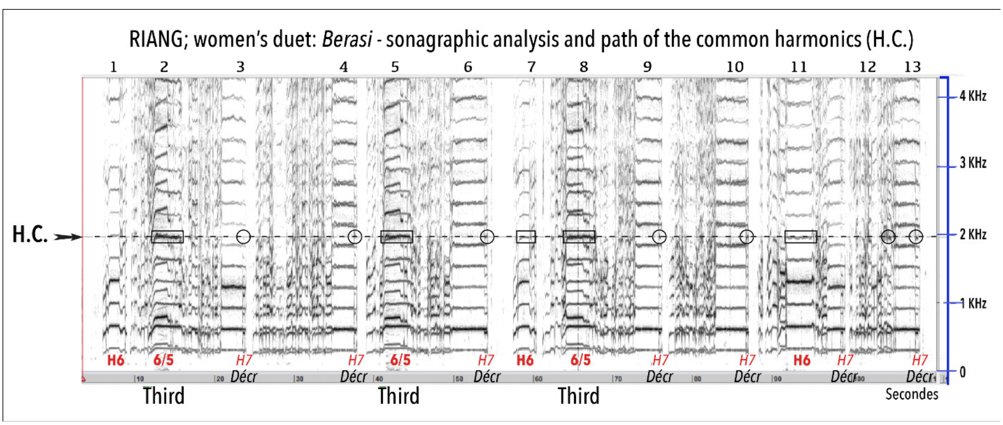
სურათი 5. ინტერვალების ვიზუალური შეფასების მეთოდი საერთო ობერტონების ძიებით ზოგჯერ სიურპრიზებს გულისხმობს.
Figure 5. The method of visual evaluation of intervals by seeking common harmonics sometimes involves surprises.



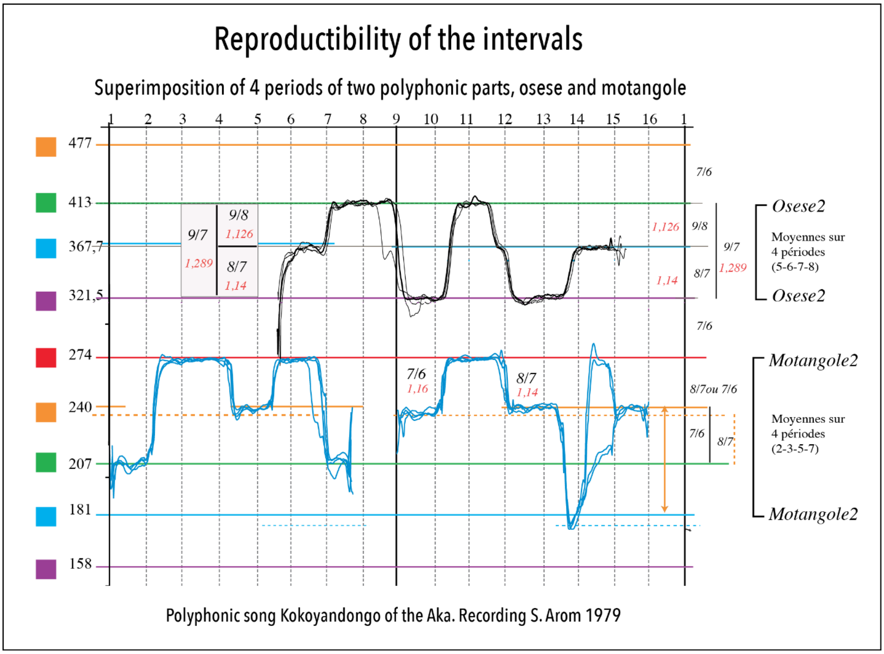
სურათი 6. ახალგაზრდა მამაკაცების დუეტის ანალიზი, ვიეტნამი.
Figure 6. The analysis of the duet of young boys from Viet-Nam.



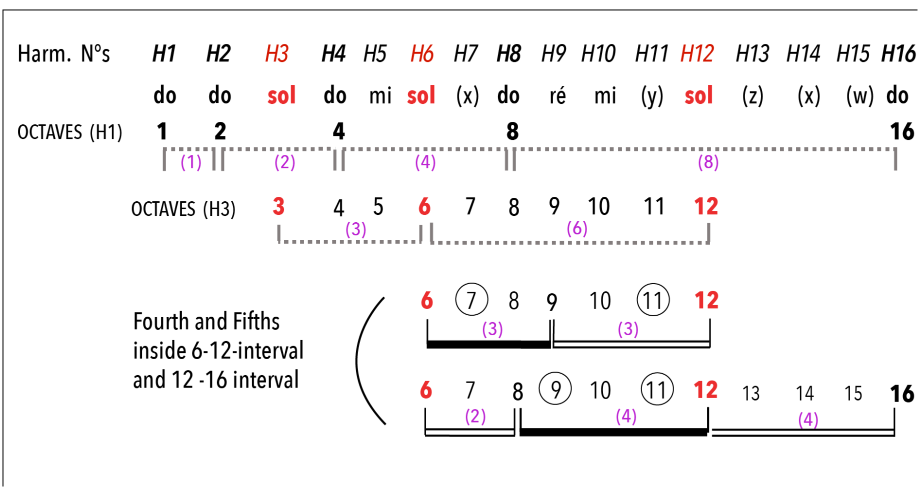
სურათი 7. საერთო ობერტონის მხოლოდ 4კHზ გაივლის 1-7-11 ციფრებით მითითებული 6 ბგერის ობერტონში; ასევე, გაივლის მცირე ტერციის 6/5 ბგერებისთვის საერთო ობერტონში: 2-5-8 ციფრებით მითითებულ ბგერებში და მე7-ობერტონში ორი ხმიდან ერთ-ერთის მელოდიური განცალკევებით, რომელიც ჩანს 3,4,6,9,10,12,13 ციფრებზე.
Figure 7. The common harmonic, only 4 kHz from it goes through harmonic 6 of the sounds indicated by numbers 1-7-11; it also goes through the harmonic common to the two sounds of the minor third chord 6/5: sounds number 2-5-8 and through harmonic 7 with a melodic uncoupling of one of the two parts in unison, visible at numbers 3, 4, 6, 9, 10, 12, 13.



სურათი 8. ორი მომღერალი შთამბეჭდავ იმპროვიზაციას აკეთებს: ყველა ინტერვალი 9/8, 8/7 და 7/6 შესანიშნავად კონტროლდება ერთი პერიოდიდან მეორეში.
Figure 8. The two singers have impressive reproducibility: all of the intervals, 9/8, 8/7 and 7/6 are perfectly controlled from one period to another.



სურათი 9. ყველაზე ტრადიციული მრავალხმიანი მუსიკა სტაბილიზდება ვერტიკალურად ობერტონული მწკრივის პირველ ინტერვალებზე.
Figure 9. Most traditional polyphonic music stabilizes vertically over the first intervals of the harmonic series.



სურათი 10. გვიჩვენებს 2019 წელს ჩაწერილი ლიტურგიკული გალობის დაბოლოების ანალიზს. თორნიკე სხიერელის ნამღერის ჩანაწერი სიმჰა არომის სახლში 2019 წელს; ხელახალი ჩაწერის ტექნიკა.

Figure 10. The analysis of the *coda* of a liturgical chant recorded in 2019. Recording of the singing of Tornike Shkiereli at the home of Simha Arom in 2019; re-recording technique.